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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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Keith M. Sakuma[1], Franklin B. Schwing[2],
Mark H. Pickett[2], Dale Roberts[1], and Stephen Ralston[1]

[1]National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center
Santa Cruz/Tiburon Laboratory
110 Shaffer Road
Santa Cruz, California 95060

[2]National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center
Pacific Fisheries Environmental Laboratory
1352 Lighthouse Avenue
Pacific Grove, California 93950

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U.S. DEPARTMENT OF COMMERCE
Norman Y. Mineta, Secretary
National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary for Oceans and Atmosphere
National Marine Fisheries Service
Penelope Dalton, Assistant Administrator for Fisheries

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ABSTRACT

Hydrographic conditions during three periods of approximately ten days each from mid-May through mid-June 1998 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 summarized in a series of horizontal maps and vertical sections. A total of 218 standard conductivity-temperature-depth (CTD) casts were obtained during the NOAA R/V *David Starr Jordan* cruise DSJ9807 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 the cruise; (2) surface meteorological time series from the region's four National Data Buoy Center (NDBC) meteorological buoys; (3) horizontal maps of sea surface temperatures (SST) from AVHRR satellite images; (4) 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; (5) temperature, salinity and σ_θ along four cross-shelf vertical transects; and (6) dynamic height topography (0/500 m and 200/500 m) in the survey region.

INTRODUCTION

The current regime off central California is hydrodynamically complex, composed of both geostrophic and wind-driven forces. The California Current provides the backdrop for large-scale, seasonal circulation patterns (Hickey 1979), while coastal upwelling 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 add further complexity to the circulation regime.

Since 1983, the National Marine Fisheries (NMFS) Southwest Fisheries Science Center's (SWFSC) Santa Cruz/Tiburon Laboratory has worked on developing a recruitment index for rockfish within the hydrographic region off central California. Annual juvenile rockfish surveys aboard the National Oceanic and Atmospheric Administration (NOAA) research vessel (R/V) *David Starr Jordan* (DSJ) 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*; and bocaccio, *S. paucispinis*). Moreover, extreme interannual fluctuations in abundance have occurred, with combined back-transformed mean $\log_e$ catches ranging from 0.1-78.6 juvenile rockfish/tow (Adams 1995[1]).

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 NMFS SWFSC Santa Cruz/Tiburon Laboratory's annual juvenile rockfish surveys. The staff of the NMFS SWFSC Pacific Fisheries Environmental Laboratory (PFEL) subsequently began analyzing the CTD data to assist 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 1997. 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), 1991 (DSJ9102 and DSJ9105), 1992 (DSJ9203 and DSJ9206), 1993 (DSJ9304 and DSJ9307), 1994 (DSJ9403 and DSJ9406), 1995 (DSJ9506), and 1996 (DSJ9606) have been published (Schwing et al. 1990; Johnson et al. 1992; Sakuma et al. 1994a; Sakuma et al. 1994b; Sakuma et al. 1995a; Sakuma et al. 1995b, Sakuma et al. 1996, Sakuma et al. 1997). A companion volume (Schwing and Ralston 1990[2])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).

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[1]Adams, P. B. (editor). 1995. Progress in rockfish recruitment studies. SWFSC Admin. Rep. T-95-01, 51 p., unpublished report.

[2]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.

MATERIALS AND METHODS

Meteorological Data

Surface data were obtained from four NOAA National Data Buoy Center (NDBC) moored buoys located within the rockfish survey region. These four buoys are 46013 (Bodega Bay; 38°12'N, 123°18'W), 46026 (Farallones; 37°48'N, 122°42'W), 46012 (Half Moon Bay; 37°24'N, 122°42'W) and 46042 (Monterey Bay; 36°48'N, 122°24'W) (Appendix 2). Daily averages of sea surface temperature (SST) and the east and north wind components were calculated from hourly mean buoy measurements. The angle of the alongshore wind component, relative to north, was determined by a principal component analysis (PCA) of the daily-averaged wind data from each buoy. This angle can be thought of as the predominant direction toward which the wind blows.

Annual climatologies and variance were determined for SST and the alongshore wind component at each buoy with a biharmonic analysis of all daily mean data over the buoy's entire operating period. These operating periods were 1981 to 1996 for buoy 46013, 1982 to 1996 for buoy 46026, 1980 to 1996 for buoy 46012, and 1987 to 1996 for buoy 46042. The annual cycles were estimated by a least squares regression of the data to an annual and semiannual harmonic signal of the form

$$SST(t) = A_0 + A_1\cos(2\pi t) + B_1\sin(2\pi t) + A_2\cos(4\pi t) + B_2\sin(4\pi t)$$

where t is the Julian Day/365 and the A_i and B_i are coefficients determined by regression at each buoy. The fits were not improved significantly by including higher harmonics. Standard errors were calculated for each Julian day, then fit with the same biharmonic model.

SST Data from AVHRR Satellite Imagery

Beginning in February 1998, products generated by the NOAA CoastWatch Group in La Jolla, California were changed from previous years. SSTs were derived from advanced very high resolution radiometer (AVHRR) data from channel 4 and 5 of the NOAA-11 polar orbiting satellite and were designated as non-linear multichannel SST. A cloud masking routine was run on each image file, and then the images were partitioned into different geographic regions along the West Coast. This yielded a high resolution image file which could then be read and analyzed by the PC-based Windows Image Manager (WIM) software developed by Mati Kahru of Scripps Institution of Oceanography in La Jolla, California. The image files were compressed and downloaded to the Ship's PC by using a cellular telephone, a cellular telephone modem interface, and a commercial modem communications software. Once an image was received, the WIM software was used to decompress, display and manipulate the satellite image in order to discern SST gradients and areas of upwelling and mesoscale eddy activity. All images which were clear or relatively clear of clouds/fog were saved on a PC computer and stored at the NMFS SWFSC Santa Cruz/Tiburon Laboratory and at the NMFS SWFSC PFEL as part of the Oceanographic database system.

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 juvenile rockfishes are identifiable 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. Five or six stations along a transect were sampled each night and seven transects were completed for each sweep. 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 three nights of additional discretionary sampling), adverse weather conditions can extend the duration 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 used in this report.

Collection of CTD Data at Sea

CTD data from the 1998 juvenile rockfish survey presented in this report was collected with a Sea-Bird Electronics, Inc., SEACAT-SBE-19 profiler[3]. This particular unit was rated to a depth of 600 m and contained 256K of memory. The CTD was also equipped with a WETStar model WS3-030 miniature fluorometer. 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), conductivity (0.001 S/m from 0 to 7 S/m), and fluorometer voltage at a baud rate of 9,600. The temperature and conductivity sensors of the profiler have been recalibrated annually by Sea-Bird Electronics, Inc., prior to its use aboard ship.

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 two minutes to allow the conductivity, temperature, and fluorometer sensors to equilibrate. The rate of descent was 45 m/minute to a depth 10 m off the bottom if water depths were less than 500 m. Otherwise 520 m of cable was let out to ensure collection of data at 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 index number, (5) the trawl station number (when appropriate), (6) latitude, (7) longitude, (8) bucket temperature (temperature [°C] of a bucket sample of surface water using a mercury thermometer), (9) bucket salinity (salinity of a bucket sample of surface water using a hand-held portable salinometer), and (10) bottom depth in meters. In addition, a water sample from 10 m was collected once a day (using a Niskin bottle attached to the hydrographic winch cable) for later use in calibrating the WETStar fluorometer dsta. Position fixes were obtained using the Global Positioning System (GPS). Collection information recorded on the data sheets were eventually entered into data files on a personal computer.

Data collected from a short series of casts (usually no more than 5-7) were periodically uploaded to a laptop computer. During this step, each cast was stored as a separate file. After uploading, the profiler was reinitialized and the files on the laptop computer were backed up onto a desktop computer on board the vessel.

An additional source of hydrographic data was the vessel's Sea-Bird Electronics, Inc., thermosalinometer (TS) unit, which provided a continuous data stream of surface temperature and salinity. These data were logged by the vessel's scientific computer system and transferred to a personal computer for further processing, analysis, and comparison with, and verification of, CTD observations. Position fixes for the TS unit were based on GPS.

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[3]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.

Data Processing

The first step in data processing was to convert the uploaded CTD files to ASCII files. This was accomplished using programs supplied by Sea-Bird Electronics, Inc., in SEASOFT menu-driven release Version 4.227[4]. All files were batch-processed through the SEASOFT modules DATCNV, FILTER, ALIGNCTD, LOOPEDIT, BINAVG, and DERIVE (refer to footnote 4 and past Technical Memorandums, e.g., Sakuma et al. 1995b, for more information) and output as ASCII files macros. All data were averaged into two-meter depth bins. Each CTD ASCII file was subsequently manually edited to remove large outliers (i.e., data spikes) in salinity and/or density, which sometimes occurred near the surface and at the thermocline. Comparisons were made between CTD temperature and salinity from the two-meter depth bin, TS temperature and salinity, bucket temperature, and bucket salinity at each CTD station using a simple regression to check for data outliers and any blatant calibration problems (Appendix 5).

Processed hydrographic data were summarized, by sweep, in a series of horizontal maps and vertical sections. Although additional CTD casts were completed during DSJ9807, only casts from the grid of standard CTD stations and those casts which provided a relatively continuous sampling track within a specific sweep were included in the data summary for the horizontal maps (Appendix 6). This was done in an attempt to generate a relatively synoptic representation of each individual sweep and to spatially standardize hydrographic comparisons among sweeps. Vertical sections from the three sweeps of DSJ9807 were also spatially standardized (Appendix 7). However, the Farallones transect line was less synoptic than the Pt. Reyes, Pescadero, and Davenport transect lines, because casts were combined over a 2- to 3-day time period instead of the more usual 24-hour period. In addition, the Farallones transect line does not follow a straight course, which may lead to some distortion of the vertical section contours nearshore. All contouring of CTD data for horizontal maps and vertical sections was done using SURFER FOR WINDOWS graphics software[5], 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 (Cressie 1991).

The TS raw data were edited to provide a nearly continuous sampling track for each sweep of DSJ9807. However, there appeared to be a consistent offset between salinity recorded by the TS and salinity recorded by the CTD at 2-m depth for the entire cruise (Appendix 5). Because the CTD was calibrated annually by the manufacturer, and because problems occurred with the TS unit in the past during DSJ9203, DSJ9304, and DSJ9406, TS salinity values were considered less reliable and, when necessary, were adjusted using a regression comparison with the CTD. That is,

$$TS' = \alpha + \beta(TS)$$

where TS' is the adjusted thermosalinometer value (either temperature or salinity), TS is the unadjusted value, and α and β are the intercept and slope parameters of the regression of 2-m CTD data (temperature or salinity) on the corresponding TS value. TS data were subsequently contoured using SURFER FOR WINDOWS[5].

There was a problem in obtaining a satisfactory calibration for the WETStar fluorometer using the Niskin bottle samples from DSJ9807, which we are currently trying to resolve. Due to the lack of an accurate calibration, the fluorometer data for DSJ9807 will not be presented.

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[4]CTD Data Acquisition software, SEASOFT Version 4.227, October 1997, 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.

[5]SURFER FOR WINDOWS, Golden Software, Inc., 809 14th Street, Golden, Colorado 80402, USA. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Dynamic height was calculated for stations occupied during DSJ9807 using a 500-db base. CTD casts conducted in areas with bottom depths less than 500 m were not included in this analysis. The dynamic height topography of the 0-db surface relative to the 500-db surface and the 200-db surface relative to the 500-db surface for the three sweeps of DSJ9807 were output from the DERIVE module of SEASOFT Version 4.227[4] and these data were gridded in SURFER FOR WINDOWS[5]. A 0.01 contour interval was chosen for the 0 db surface relative to the 500-db surface maps and a 0.005 contour interval for the 200-db surface relative to the 500-db surface (Appendix 8).

To date, no attempt has been made to calculate vertical sections of geostrophic velocity because the large number of shallow stations during the juvenile rockfish surveys necessitates the extrapolation of isopycnals into the shore, a procedure that is subject to great uncertainty. In addition, recent studies (Berryman 1989; Tisch 1990) suggest that geostrophic velocities calculated for stations spaced closer than the internal Rossby radius frequently feature alternating current bands of reversed flow, which are thought to be associated with inertial currents. The Rossby radius in the survey region is generally about 10-20 km, which is similar to the typical station spacing of the rockfish surveys. We are presently investigating the method that best determines geostrophic velocities from dynamic heights, based on closely spaced shallow water stations, before attempting to calculate the geostrophic velocity field during these surveys.

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: List of CTD Stations Summarized from Cruise DSJ9807

The station list includes, 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 DSJ9807, Sweep 1 (May 7-13) includes 73 standard stations (casts 31-103), Sweep 2 (May 14-20) includes 71 standard stations (casts 104-175), and Sweep 3 (May 23-30) includes 74 standard stations (casts 176-249).

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

The locations of the standard CTD stations for DSJ9807 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

Time series of daily-averaged SST and alongshore wind are presented for January-June 1998 based on data available from the four NOAA NDBC buoys located within the survey region. In each plot, the bold solid line represents the daily-mean values of the parameter. The bold dotted line represents the biharmonic fit to the climatology derived from daily data over the operating period of the buoy to date. The gray shaded envelope about the biharmonic fit line is ±1 standard error of the daily values on each Julian day. Negative values denote southward (upwelling-favorable) winds. The "PCA direction" on the alongshore wind plots represent the direction of the alongshore wind relative to north, which was derived from a principal component analysis.

Because of the very limited amount of buoy wind data available for 1998, this memorandum includes daily time series of the coastal upwelling index at 36°N and 39°N (Figure 1). This index is derived from the alongshore component of the geostrophic wind stress computed from sea level pressure fields (Bakun 1973; Schwing et al. 1996), and is a reasonable representation of local wind conditions.

Appendix 4: AVHRR Satellite Images of Multichannel SST

SSTs along the central and northern California coast from radiances sensed by channel 4 and 5 of the NOAA-11 polar orbiting satellite are presented for each of the three sweeps during DSJ9807. Each image represents a single pass during the afternoon hours, local time. The temperature color spectrum ranges from 8-17°C. Areas experiencing upwelling appear as blue and dark blue, whereas areas with warmer water appear as orange and red. Cloud cover and/or fog appear as blacked out areas.

Appendix 5: Regression Comparisons of CTD, TS, and Bucket

The plots presented show comparisons between CTD, TS, and bucket temperatures and CTD and TS salinities. 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:

CTD temperature versus TS temperature,
CTDtemp. = TStemp. x 0.994 + 0.015
$R^2 = 0.99$
CTD temperature versus bucket temperature,
CTDtemp. = buckettemp. x 0.991 + 0.006
$R^2 = 0.97$
TS temperature versus bucket temperature,
TStemp. = buckettemp. x 0.999 - 0.042
$R^2 = 0.98$
CTD salinity versus TS salinity,
CTDsal. = TSsal. x 0.911 + 3.062
$R^2 = 0.94$
CTD salinity versus bucket salinity,
CTDsal. = bucketsal. x 0.917 + 2.804
$R^2 = 0.94$
TS salinity versus bucket salinity,
TSsal. = bucketsal. x 0.968 + 0.958
$R^2 = 0.92$

Appendix 6: Horizontal Maps of CTD and TS

a) Maps of TS temperature and salinity

Maps of surface temperature (°C) and salinity obtained from the vessel's TS continuous profiling unit are presented for each sweep of DSJ9807. The TS maps are located in front of the corresponding horizontal map for the CTD at 2 m. The contour intervals are 0.5 °C for temperature and 0.05 for salinity. They are included to provide some verification of hydrographic spatial patterns inferred from the CTD data. The 2-m CTD and surface TS maps display good agreement, despite the fact that the data used to generate each were collected by different instrument packages.

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

Horizontal maps of temperature (°C), salinity, 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 3). The 30-m depth was contoured to coincide with the standard midwater trawl depth during the surveys. The contour intervals are 0.5°C, 0.1, and 0.1 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, and 0.02 kg/m^3.

Appendix 7: Vertical sections

Vertical sections of temperature, salinity and density are presented for four cross-shelf transects off Pt. Reyes, the Farallones, Pescadero, and Davenport for DSJ9807. Station maps denote the location of each transect and the offshore extent of stations (marked by a +) used to generate plots for each sweep. The locations of CTD casts used in generating the vertical sections are shown on each section by a ◆. The contour intervals are 0.5°C for temperature, 0.1 for salinity, and 0.2 kg/m^3 for density.

Appendix 8: Dynamic Height Topography

Horizontal maps of dynamic height (0/500 m and 200/500 m) are presented for the three sweeps of DSJ9807. Contour intervals are 0.01 for the 0/500 m maps and 0.005 for the 200/500-m maps. The locations of the CTD casts used in generating the horizontal contours are shown by a + symbol. Geostrophic currents have higher dynamic heights on their right, and are proportional to the distance between lines of constant height.

Synopsis of Meteorological and Hydrographic Conditions

Large-scale Oceanic and Atmospheric Climate Patterns

During much of 1998, many atmosphere and ocean fields in the equatorial and north Pacific, including sea level pressure (SLP), wind stress, and SST, typified classic El Niño patterns (cf. Murphree and Reynolds 1995). In the tropical Pacific, the first half of 1998 was marked by one of the strongest El Niño events of this century (Figure 2). This El Niño event reached a second peak in intensity in early 1998 (Figure 2) and the first clear effects on the North Pacific Ocean appeared. Some of the clearest El Niño impacts occurred during February 1998, when much of the northeast Pacific was dominated by strong negative SLP anomalies and strong northeastward wind anomalies (NCEP 1998a). West coast winds were strongly downwelling-favorable during this time (Figure 1). SST anomalies in the central and eastern North Pacific were negative, while positive SST anomalies were confined to a relatively narrow band next to the west coast. Early 1998 was a period of exceptionally intense winter storm activity along the west coast.

From March through May 1998, El Niño conditions in the equatorial Pacific weakened considerably, with negative SST anomalies developing in the central and eastern equatorial Pacific during May (NCEP 1998b). A clear transition toward La Niña conditions was seen in the tropical Pacific. The North Pacific High pressure system, centered near 35°N 130°W, intensified during April-May 1998 (Lynn et al. 1998). The resulting trade winds were stronger than usual, a precursor to the developing La Niña. This anomalously strong clockwise atmospheric circulation pattern contributed to greater southward winds near the west coast, which favored upwelling and cooler SSTs. This atmospheric pattern also is likely to produce lower coastal sea level, a shallower thermocline, and increased equatorward flow in the California Current System (CCS). The opposite can be expected during El Niño events. Coastal winds off California were southward but unseasonably weak at this time (Figure 1).

Coastal wind and SST time series

Based on west coast NDBC buoy winds (Lynn et al. 1998), the 1997-1998 winter featured numerous episodes of greater than normal northward winds (more downwelling-favorable), and generally highly variable wind speeds. These were associated with heavy winter storm activity and copious precipitation for much of the Pacific Northwest. This is illustrated locally by the unusual northward (positive) wind state during January and February in the Gulf of the Farallones. Spring winds, available only at the Bodega buoy, varied on synoptic (10-30 day) time scales, with frequent periods of weaker than normal southward (less upwelling-favorable) winds. Notable downwelling wind events occurred in early May (prior to the survey), and during sweep 3 in late May.

From a peak in August-September 1997, when temperatures were as much as 6°C above average, buoy SSTs gradually cooled and returned to their climatological values by spring 1998 at many west coast sites (Lynn et al. 1998). However central California coastal SSTs, as represented at the Bodega buoy and at the Farallon Islands (Table 1), remained 1-3°C above normal before and during the cruise. SSTs fluctuated on synoptic scales in response to individual wind events, warming in response to the aforementioned downwelling events.

After a period of very strong downwelling (negative upwelling index values) in early 1998, upwelling (positive indices) began in late February (Figure 1). Upwelling was slightly stronger than normal in March and April. Upwelling rates in May and June were generally weaker to much weaker than average. May upwelling rates were only 56% and 35% of normal at 36°N and 39°N, respectively. Monthly SST anomalies in the CCS closely reflected these perturbations in coastal upwelling (Roy Mendelssohn, NOAA/PFEL, pers. comm.). A period of strong downwelling immediately preceded the cruise. Upwelling was anomalously weak during most of the survey, especially in sweep 3. Two brief episodes of stronger upwelling occurred early in sweep 1 and near the end of sweep 2. These events were seen at the Bodega buoy as well.

Regional circulation and water mass structure

Upper ocean ADCP currents during all three sweeps were dominated by a strong (30-40 cm/s) generally southward alongshelf flow. This pattern is consistent with the southward wind stress and a geostrophic current in balance with the underlying density field. The highest velocities were associated with the strongest cross-shelf density gradients. Currents were substantially weaker below 75 m, as the flow transitioned into the poleward California Undercurrent. By sweep 3, the upper ocean circulation appeared to be evolving into a poleward Slope Countercurrent, similar to that observed frequently in this region (Steger et al. 1999).

The upper ocean was unusually warm and fresh during 1998, suggesting unseasonably weak upwelling prior to and during the survey. Near-surface temperatures were 12-14°C and salinities were generally less than 33.0. Cooler (10-12°C) and more saline (33.4-33.6) water was seen over the course of the survey at upwelling sites north of Pt. Reyes (38.25°N) and at Pt. Año Nuevo (37°N). The meandering alongshore gradient between coastal upwelled water and warmer, less saline offshore (>14°C, <32.8) water was much stronger in sweep 3, probably an effect of onshore relaxation of offshore water in response to weaker wind.

The Pt. Reyes upwelling jet, a feature commonly seen in these surveys, was apparent in all three sweeps with westward velocities exceeding 40 cm/s. The jet also had a southward tongue evident in the ADCP and CTD data west of the Gulf of the Farallones during sweep 1. This water carried the cool and saline signature of recent upwelling, but it was still much warmer and fresher than most years.

Baltz (1997) analyzed CTD data from the rockfish surveys for 1987-96 and found three persistent clockwise eddy-like features. These were seen in the 1998 ADCP fields, but nearer the coast than usual. The Monterey Bay eddy, centered at 36.75°N, 122.25°W, was present throughout the cruise and was especially clear during sweep 2. The Pioneer Seamount eddy, off Half Moon Bay, was centered at 37°N, 123°W during sweep 1 but was seen near 37.5°N thereafter. A third eddy was seen off Bodega Bay, north of the Pt. Reyes jet. All were surface-intensified, with maximum velocities in the upper 100 m. At depth, the eddies had warm, fresh centers, indicating local depressions of the density field in adjustment to their circulation.

The ADCP circulation features were generally reflected in the dynamic topography. The topography indicated a complex circulation, even in the poleward California Undercurrent as implied by the 200/500 m heights (e.g., sweep 1). The upper layer was generally 5 dynamic cm thicker than in 1997. Surface heights were up to 10 dynamic cm higher than in "cool" years (e.g. 1991, 1994), but similar in magnitude to those observed in the 1992 and 1993 El Niño years. This thicker upper layer was the product of unusually warm and fresh water occupying the area. The 200/500-m heights were lower in 1998 than in the previous year. The implication of this is that 1997 was a period of enhanced poleward flow, possibly an attribute of El Niño, which brought relatively warm, saline water into the region from the south. In contrast, the Undercurrent was relatively weak in 1998, a conclusion supported by the ADCP data.

A shallow (<30 m) low salinity (<32.4) lens, presumably San Francisco Bay outflow, was seen off Half Moon Bay in 1998. It appeared to move offshore and become smaller during the survey. A second near-surface area of very low salinity (32.0-32.2) water was evident off Monterey Bay in sweep 3. This feature did not have a distinct temperature signal. It was persistent, having been observed in the same location in April 1998 (Curtis Collins, NPS, pers. comm.). It may have been advected west of the survey region prior to the cruise by offshore Ekman transport, then returned onshore during the wind relaxation event at the start of sweep 3. A likely source of this extremely fresh feature was an unusual onshore displacement of the core of the California Current, which is less saline than coastal water (Lynn et al. 1982). The strong coherent southward currents are consistent with this. However there likely was a southward displacement of California Current water as well, as climatologies show comparably low salinities are typically found no further south than northern California or Oregon (Churgin and Halminski 1974). The lowest salinity recorded at this site in the CalCOFI data set (1950-84) was 32.51 in April 1958 (Ron Lynn, NMFS/SWFSC, pers. comm.). Another possible source is Salinas and Pajaro River outflow. Both had discharges in February of 10-15 times their normal flow, in association with heavy winter rains. However a freshwater budget analysis reveals that local rivers are not the likely source (Curtis Collins, NPS, pers. comm.).

Relative to the mean conditions during the rockfish surveys (Baltz 1997), upper ocean temperatures were ca. 2°C and salinities .2-.5 lower in 1998. Table 2 compares the range of values observed in 1998 to those from previous rockfish surveys, summarized by Baltz (1997), and to the regional climatologies of Churgin and Halminski (1974). Table 1 compares SSTs and surface salinities based on daily measurements at the Farallon Islands during spring 1998 to historical averages. The mean May 1998 temperature and salinity were +1.5 and -2 standard deviations from their long-term climatologies, respectively, making this the warmest May since 1992 and freshest May since 1983. Salinities of this magnitude have been seen at the Farallones only after El Niños in 1941, 1958, 1967, and 1983. The mean salinity for June was even more extreme, exceeding -7 standard deviations from the norm and smashing the previous lowest salinity for the month by nearly .9.

In summary, the very low salinities in 1998 were due to a combination of an anomalous onshore displacement of the California Current, reduced coastal upwelling, and possibly more freshwater inflow and an increased southward transport of the Current. Higher temperatures were the result of the onshore displacement, reduced upwelling, less wind mixing, and possibly greater solar heating.

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TABLE 1. Comparison of monthly averaged daily SSTs and salinities at the Farallon Islands. Climatologies are monthly means for 1925-42, 1955-94 period, ± one standard deviation.

	CLIMATOLOGY (1925-42, 55-94)	1997	1998	1998 ANOMALY
April Temperature	11.34 ± 1.10 °C	10.53 °C	12.41 °C	+1.07 °C (+1SD)
April Salinity	33.30 ± .57	33.87	32.59	- .71 (-1.2SD)
May Temperature	11.31 ± 1.07 °C	12.31 °C	12.87 °C	+1.56 °C (+1.5SD)
May Salinity	33.62 ± .37	33.56	32.90	- .72 (-2SD)
June Temperature	11.68 ± .89 °C	11.70 °C	13.60 °C	+1.92 °C (+2SD)
June Salinity	33.76 ± .23	33.84	32.17	- 1.59 (-7SD)

TABLE 2. Comparison of temperatures and salinities at 10 m and 30 m during 1998 rockfish surveys to previous years. The general range is shown, excluding outliers. 1987-96 means and ranges were determined by analysis of CTD data from annual rockfish CTD surveys for those years (Baltz 1997). Churgin and Halminski (1974) climatologies are averages for the region 36-38°N, 121-126°W for April-June.

	10m Temperature	10m Salinity	30m Temperature	30m Salinity
1998 RANGE				
sweep 1	12-14 °C	32.6-33.0	11-13 °C	32.6-33.4
sweep 2	11.5-14 °C	32.6-33.3	10-13 °C	32.8-33.5
sweep 3	12-13 °C	32.4-33.2	10-14 °C	32.8-33.8
1987-96 MEAN	11.6 °C	33.45	10.4 °C	33.55
1987-96 RANGE			8.5-12 °C	33.1-33.8
Churgin and Halminski (1974)	10.90 °C	33.17	11.01 °C	33.29

NOAA/NMFS PACIFIC FISHERIES ENVIRONMENTAL LABORATORY - PACIFIC GROVE, CALIFORNIA

COASTAL UPWELLING INDICES, DAILY AND WEEKLY MEANS

1998

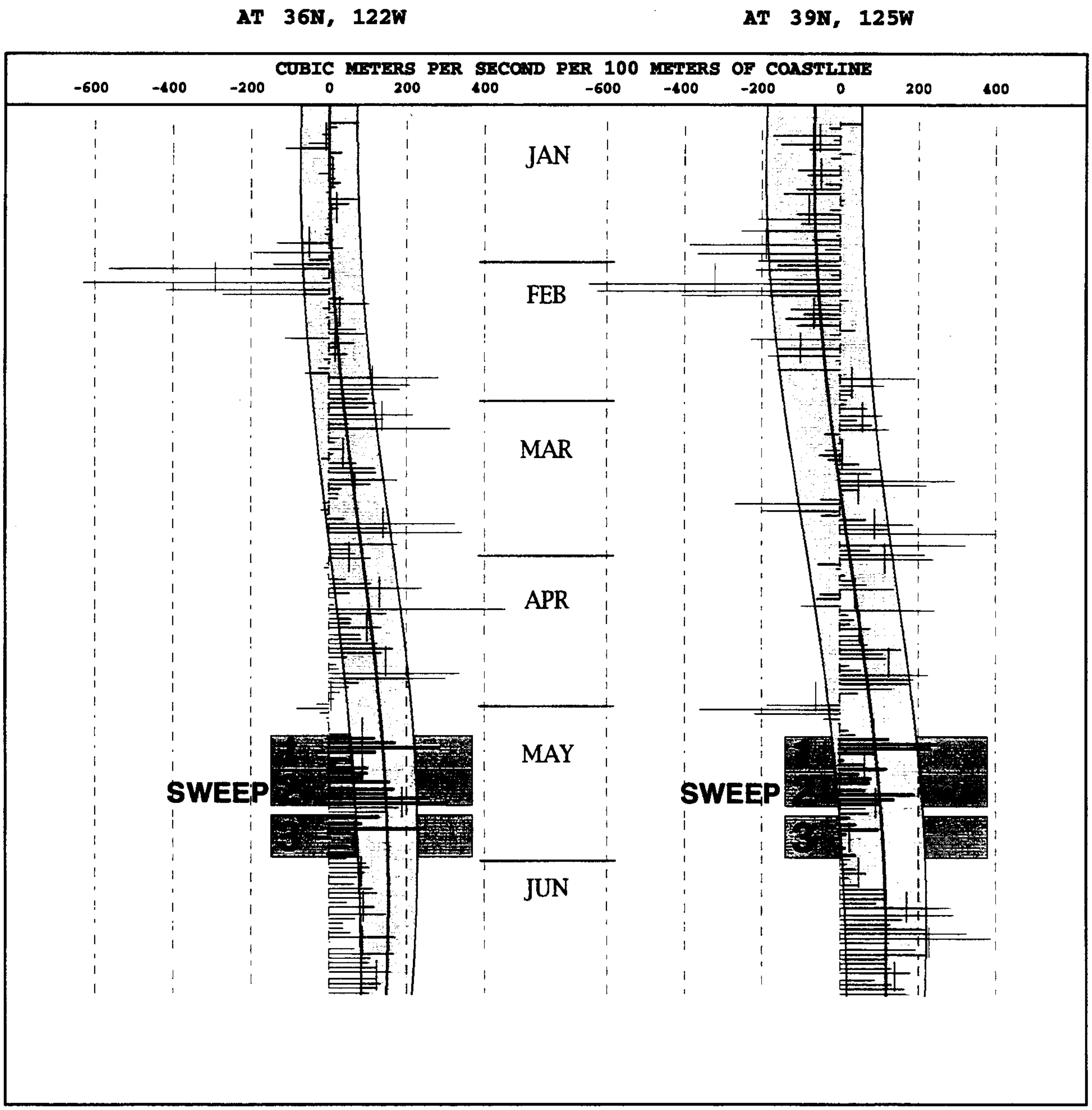


Figure 1. Daily upwelling indices at 36°N, 122°W and 39°N, 125°W, January-June 1998. Positive values are upwelling-favorable. Weekly averages shown as vertical bars. Indices during sweeps are bold horizontal lines. The bold curves are biharmonic fits to the daily indices at each location for the period 1967-91. The shaded areas around each biharmonic curve denotes one standard error for each Julian Day.

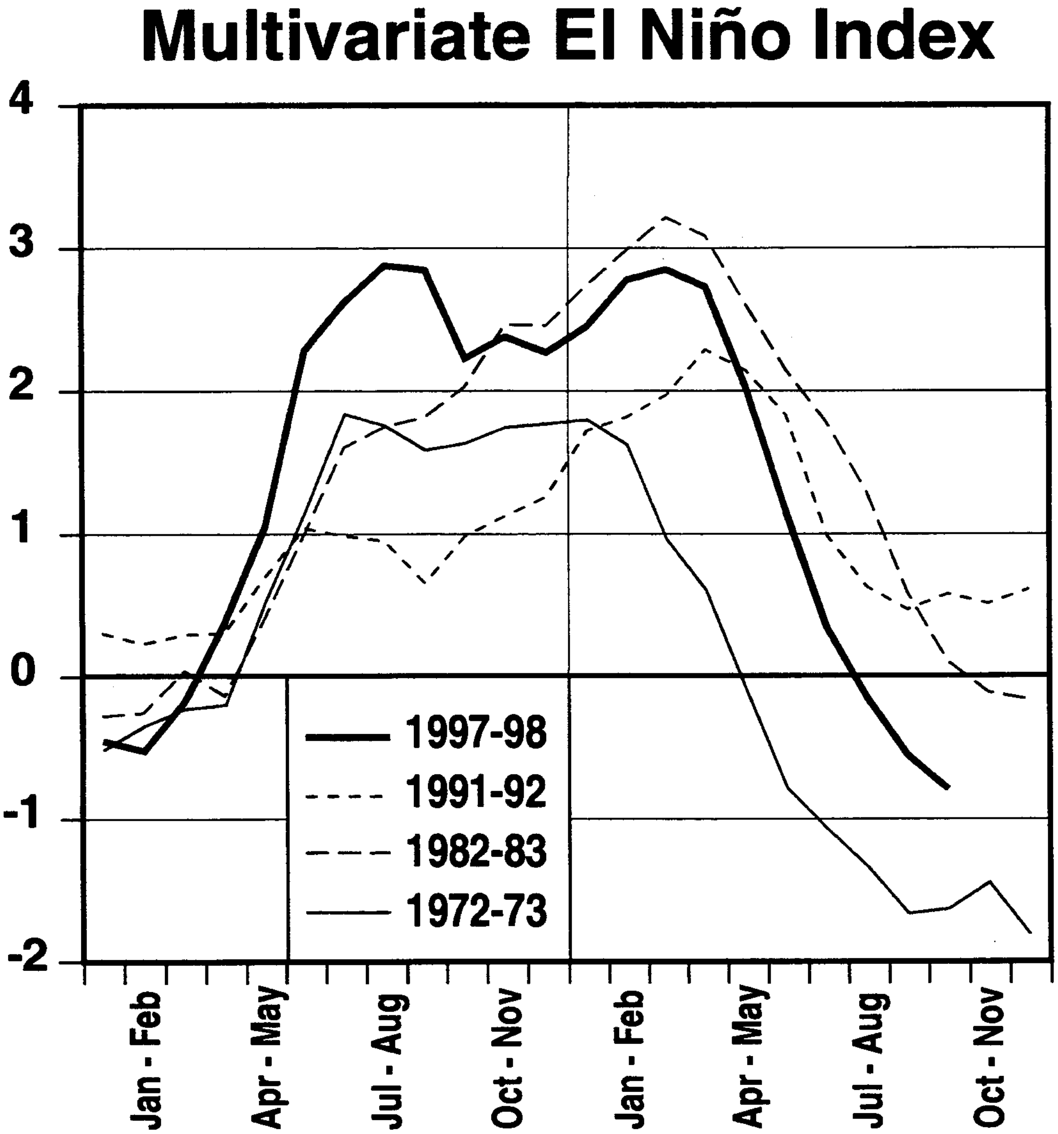


Figure 2. A monthly multivariate ENSO index, or MEI (Wolter and Timlin 1998). The MEI is based on six observed variables in the tropical Pacific: sea level pressure, zonal and meridional surface wind, SST, surface air temperature, and cloudiness. Positive values denote El Niño conditions. The figure compares the intensity of the 1997-1998 El Niño relative to three recent strong El Niño events.

APPENDIX 1: LIST OF CTD STATIONS SUMMARIZED FROM CRUISE DSJ9807

DSJ9807 Sweep 1

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
31	07MAY98	16:57	36 52.94	121 55.98	38
32	07MAY98	20:15	36 50.77	121 58.83	88
33	07MAY98	22:40	36 45.26	121 50.37	35
34	07MAY98	23:34	36 44.44	121 58.66	320
35	08MAY98	1:23	36 41.99	121 52.62	71
36	08MAY98	2:01	36 38.52	121 51.56	38
37	08MAY98	4:23	36 40.21	121 58.30	96
38	08MAY98	5:45	36 40.06	122 10.08	1063
39	08MAY98	7:11	36 46.52	122 16.21	804
40	08MAY98	8:40	36 40.02	122 22.27	1738
41	08MAY98	10:05	36 46.43	122 28.46	2100
42	08MAY98	11:30	36 40.10	122 34.73	2360
43	08MAY98	13:02	36 33.71	122 28.37	2708
44	08MAY98	14:31	36 33.70	122 16.21	2562
45	08MAY98	19:59	36 35.02	122 10.56	2379
46	09MAY98	0:35	36 36.11	122 02.37	667
47	09MAY98	1:30	36 38.81	122 03.20	877
48	09MAY98	5:55	36 42.54	122 07.08	1680
49	09MAY98	7:40	36 52.65	122 10.06	97
50	09MAY98	9:19	36 52.78	122 22.37	1130
51	09MAY98	10:48	36 52.68	122 34.74	1550
52	09MAY98	12:19	36 52.73	122 47.13	2433
53	09MAY98	13:49	36 58.98	122 53.21	1382
54	09MAY98	15:20	37 05.01	122 47.12	591
55	09MAY98	16:54	37 05.08	122 34.57	110
56	09MAY98	18:11	37 05.08	122 22.24	56
57	09MAY98	20:16	36 59.22	122 17.71	83
58	09MAY98	23:12	36 57.07	122 20.46	136
59	10MAY98	0:04	36 59.04	122 25.47	444
60	10MAY98	5:25	36 58.91	122 35.47	421
61	10MAY98	7:13	37 10.86	122 28.09	65
62	10MAY98	8:35	37 10.82	122 40.80	110
63	10MAY98	10:55	37 10.75	122 53.04	411
64	10MAY98	11:28	37 10.72	123 05.35	830
65	10MAY98	12:50	37 16.50	123 11.48	1302
66	10MAY98	14:07	37 22.35	123 05.34	748
67	10MAY98	15:31	37 22.32	122 53.07	192
68	10MAY98	16:40	37 22.36	122 40.76	84
69	10MAY98	17:50	37 22.25	122 28.50	31
70	10MAY98	20:19	37 16.53	122 34.10	84
71	10MAY98	22:51	37 15.00	122 37.90	94
72	11MAY98	0:04	37 16.41	122 48.98	173
73	11MAY98	5:11	37 16.08	122 59.52	515
74	11MAY98	7:11	37 30.93	122 59.32	202
75	11MAY98	8:31	37 30.86	123 11.57	1242
76	11MAY98	10:08	37 30.93	123 24.11	2400
77	11MAY98	11:42	37 30.83	123 36.26	3200
78	11MAY98	13:13	37 38.44	123 36.40	3330
79	11MAY98	14:33	37 46.19	123 36.11	2708
80	11MAY98	16:04	37 46.08	123 23.98	1561
81	11MAY98	17:37	37 46.12	123 11.55	109
82	11MAY98	20:15	37 39.56	123 02.59	102
83	11MAY98	23:04	37 41.51	123 13.62	1000
84	12MAY98	0:07	37 44.62	123 08.30	82
85	12MAY98	3:06	37 54.61	123 18.32	102
86	12MAY98	5:05	37 51.71	123 28.98	1295
87	12MAY98	7:40	38 01.49	123 30.05	141
88	12MAY98	8:52	38 01.60	123 42.48	2525

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
89	12MAY98	9:22	38 01.49	123 54.87	3477
90	12MAY98	11:08	38 09.98	124 07.01	3632
91	12MAY98	12:59	38 18.46	123 54.85	2836
92	12MAY98	14:28	38 18.46	123 42.28	1395
93	12MAY98	16:03	38 18.26	123 30.73	265
94	12MAY98	17:22	38 18.42	123 17.74	104
95	12MAY98	20:24	38 10.22	123 22.24	180
96	13MAY98	0:13	38 08.34	123 16.49	116
97	13MAY98	1:05	38 10.06	123 09.96	90
98	13MAY98	2:47	38 09.47	123 03.08	69
99	13MAY98	3:53	38 09.78	123 02.23	66
100	13MAY98	6:24	38 01.58	123 17.91	115
101	13MAY98	7:36	38 01.72	123 05.45	61
102	13MAY98	20:20	37 47.98	122 53.20	57
103	13MAY98	23:02	37 40.97	122 53.32	59

DSJ9807 Sweep 2

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
104	14MAY98	18:00	36 53.03	121 56.22	36
105	14MAY98	20:32	36 50.77	121 59.05	85
106	14MAY98	23:00	36 46.13	121 54.18	295
107	14MAY98	23:43	36 44.46	121 58.61	312
108	15MAY98	1:35	36 41.56	121 53.20	76
109	15MAY98	2:10	36 38.53	121 51.60	40
110	15MAY98	4:41	36 40.04	121 57.73	93
111	15MAY98	6:01	36 40.07	122 10.07	1046
112	15MAY98	7:18	36 46.34	122 16.06	782
113	15MAY98	8:36	36 40.07	122 22.43	1800
114	15MAY98	9:53	36 46.45	122 28.55	2104
115	15MAY98	11:45	36 39.89	122 34.87	2375
116	15MAY98	13:07	36 33.82	122 40.71	3000
118	15MAY98	16:38	36 33.47	122 26.40	3000
119	15MAY98	18:53	36 33.69	122 16.24	2500
120	15MAY98	20:37	36 35.00	122 10.24	2287
121	16MAY98	0:52	36 35.68	122 03.25	861
122	16MAY98	1:48	36 38.67	122 03.03	795
123	16MAY98	5:16	36 44.77	122 09.06	919
124	16MAY98	6:39	36 52.66	122 10.08	96
125	16MAY98	7:51	36 52.66	122 22.11	1016
126	16MAY98	9:27	36 52.77	122 34.70	1526
127	16MAY98	11:01	36 52.66	122 46.98	2379
128	16MAY98	12:36	36 52.63	122 59.29	2800
129	16MAY98	13:59	36 58.99	122 53.06	1340
130	16MAY98	15:15	37 04.99	122 47.08	635
131	16MAY98	16:45	37 05.00	122 34.56	110
132	16MAY98	17:54	37 05.01	122 22.26	58
133	16MAY98	20:33	36 59.12	122 17.46	82
134	16MAY98	22:34	36 57.64	122 20.53	121
135	16MAY98	23:16	36 59.08	122 25.36	318
136	17MAY98	4:23	36 58.62	122 34.83	427
137	17MAY98	6:09	37 10.79	122 28.39	67
138	17MAY98	7:21	37 10.79	122 40.73	109
139	17MAY98	8:34	37 10.74	122 52.94	404
140	17MAY98	9:58	37 10.78	123 05.21	818
141	17MAY98	11:43	37 22.31	123 05.21	755
142	17MAY98	13:09	37 22.31	122 53.02	189
143	17MAY98	14:25	37 22.31	122 40.71	83

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
144	17MAY98	15:38	37 22.27	122 28.35	31
145	17MAY98	20:25	37 16.40	122 34.26	83
146	18MAY98	3:34	37 14.73	122 48.51	190
147	18MAY98	5:24	37 14.70	122 58.52	470
148	18MAY98	7:42	37 30.92	122 59.56	220
149	18MAY98	9:04	37 30.85	123 11.67	1000
150	18MAY98	10:43	37 30.84	123 24.04	2300
151	18MAY98	12:26	37 30.84	123 36.28	3500
152	18MAY98	13:49	37 38.39	123 36.33	3600
153	18MAY98	15:18	37 46.24	123 36.41	3200
154	18MAY98	16:52	37 46.30	123 23.90	1361
155	18MAY98	18:47	37 46.13	123 11.64	112
156	19MAY98	2:30	37 39.09	123 02.57	113
157	19MAY98	4:40	37 39.37	123 12.27	1280
158	19MAY98	7:14	37 52.98	123 19.03	85
159	19MAY98	8:26	37 53.08	123 30.15	1300
160	19MAY98	9:53	38 01.62	123 30.21	148
161	19MAY98	11:17	38 01.71	123 42.58	2500
162	19MAY98	12:39	38 01.65	123 54.79	3800
163	19MAY98	14:28	38 09.97	124 07.01	4000
164	19MAY98	16:11	38 18.45	123 54.92	2790
165	19MAY98	17:33	38 18.58	123 42.37	1365
166	19MAY98	18:55	38 18.51	123 30.12	251
167	19MAY98	20:34	38 09.81	123 22.03	177
168	20MAY98	0:26	38 09.21	123 15.57	111
169	20MAY98	1:09	38 10.09	123 09.95	89
170	20MAY98	2:54	38 08.62	123 03.97	71
171	20MAY98	4:04	38 11.07	123 00.70	59
172	20MAY98	6:02	38 01.67	123 05.56	63
173	20MAY98	7:20	38 01.64	123 17.92	118
174	20MAY98	20:44	37 47.51	122 52.00	56
175	20MAY98	23:13	37 41.46	122 53.51	58

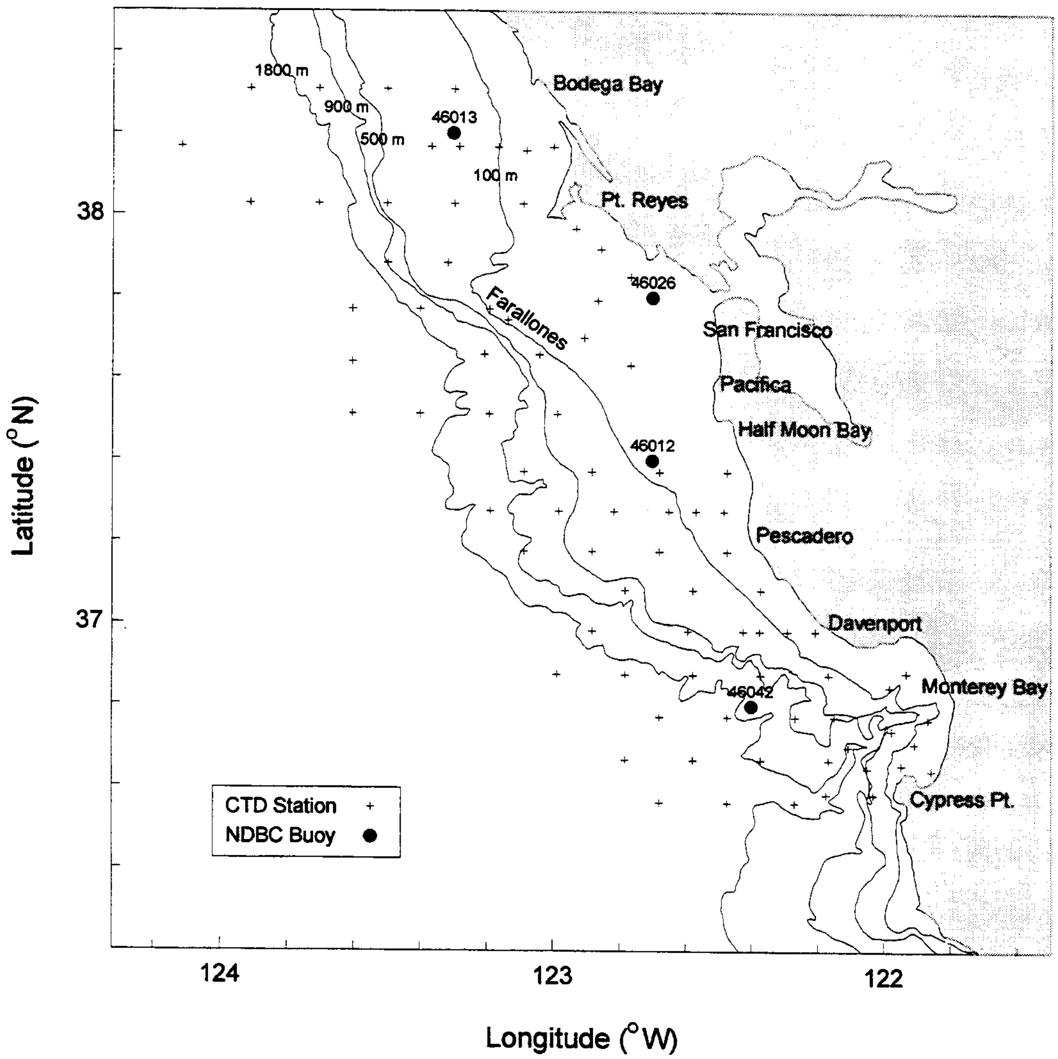
DSJ9807 Sweep 3

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
176	23MAY98	22:09	37 42.82	122 55.08	56
177	24MAY98	0:11	37 47.16	122 50.39	54
178	24MAY98	18:56	36 53.04	121 56.04	37
179	24MAY98	20:31	36 50.97	121 59.23	83
180	24MAY98	23:11	36 44.95	121 53.82	86
181	24MAY98	23:48	36 44.48	121 58.68	340
182	25MAY98	1:32	36 41.95	121 53.74	80
183	25MAY98	2:09	36 38.61	121 51.66	42
184	25MAY98	4:33	36 40.42	121 56.90	90
185	25MAY98	6:01	36 39.99	122 10.07	1063
186	25MAY98	7:26	36 46.33	122 16.08	778
187	25MAY98	8:45	36 39.99	122 22.39	1700
188	25MAY98	10:07	36 46.47	122 28.48	2100
189	25MAY98	11:30	36 40.12	122 34.88	2370
190	25MAY98	13:00	36 33.80	122 40.80	2800
191	25MAY98	14:16	36 33.70	122 52.70	2900
192	25MAY98	16:40	36 33.84	122 28.48	2700
193	25MAY98	18:14	36 33.72	122 16.24	2520
194	25MAY98	20:33	36 34.51	122 10.32	2200
195	26MAY98	0:47	36 35.96	122 01.94	472
196	26MAY98	1:34	36 38.71	122 03.04	815
197	26MAY98	5:02	36 44.86	122 07.58	1255

CAST	DATE	TIME	LATITUDE	LONGITUDE	DEPTH(M)
198	26MAY98	6:20	36 52.65	122 10.07	96
199	26MAY98	7:34	36 52.67	122 22.40	1110
200	26MAY98	9:12	36 52.65	122 34.79	1500
201	26MAY98	10:46	36 52.71	122 47.18	2340
202	26MAY98	12:30	36 52.80	122 59.54	2740
203	26MAY98	13:46	36 59.16	122 53.09	1591
204	26MAY98	15:00	37 04.97	122 46.92	634
205	26MAY98	16:38	37 05.08	122 34.59	110
206	26MAY98	17:46	37 04.97	122 22.25	58
207	26MAY98	20:53	36 58.99	122 17.45	84
208	26MAY98	23:17	36 57.30	122 21.83	230
209	27MAY98	0:04	36 58.98	122 25.56	421
210	27MAY98	3:43	37 00.22	122 36.57	348
211	27MAY98	6:03	37 10.66	122 28.56	68
212	27MAY98	7:12	37 10.67	122 40.75	108
213	27MAY98	8:50	37 10.62	122 53.03	406
214	27MAY98	10:17	37 10.69	123 05.13	800
215	27MAY98	11:37	37 16.50	123 11.42	1200
216	27MAY98	12:55	37 22.25	123 05.15	755
217	27MAY98	14:30	37 22.22	122 53.14	194
218	27MAY98	15:55	37 22.28	122 40.82	85
219	27MAY98	17:30	37 22.27	122 28.45	31
220	27MAY98	20:46	37 16.46	122 33.93	82
221	27MAY98	23:06	37 17.18	122 39.63	94
222	28MAY98	0:08	37 16.31	122 49.09	180
223	28MAY98	4:06	37 17.92	123 00.00	684
224	28MAY98	6:03	37 30.86	122 59.31	204
225	28MAY98	7:40	37 30.60	123 11.47	1260
226	28MAY98	9:43	37 30.77	123 23.85	2415
227	28MAY98	11:35	37 30.85	123 36.20	3200
228	28MAY98	12:50	37 38.47	123 36.35	3300
229	28MAY98	14:08	37 46.29	123 36.39	2915
230	28MAY98	15:39	37 46.04	123 24.00	1485
231	28MAY98	17:14	37 46.20	123 11.62	110
232	28MAY98	20:48	37 39.46	123 02.31	100
233	28MAY98	23:50	37 41.04	123 10.96	875
234	29MAY98	1:14	37 44.81	123 07.58	66
235	29MAY98	5:27	37 54.71	123 24.45	124
236	29MAY98	6:42	38 01.67	123 30.20	142
237	29MAY98	8:50	38 01.57	123 42.60	2525
238	29MAY98	10:45	38 01.54	123 54.85	3500
239	29MAY98	13:05	38 09.98	124 07.15	3650
240	29MAY98	15:00	38 18.58	123 54.60	2875
241	29MAY98	16:30	38 18.58	123 42.45	1357
242	29MAY98	18:00	38 18.54	123 30.17	249
243	29MAY98	19:18	38 18.55	123 17.74	104
244	29MAY98	20:44	38 10.12	123 22.09	175
245	30MAY98	0:10	38 09.85	123 15.35	109
246	30MAY98	0:48	38 10.60	123 09.96	90
247	30MAY98	2:17	38 09.99	123 03.31	70
248	30MAY98	3:20	38 10.96	123 00.01	51
249	30MAY98	5:49	38 01.62	123 17.81	115

APPENDIX 2: DSJ9807 CTD STATIONS AND BATHYMETRIC MAP OF SURVEY REGION WITH LOCATIONS OF THE NDBC BUOYS

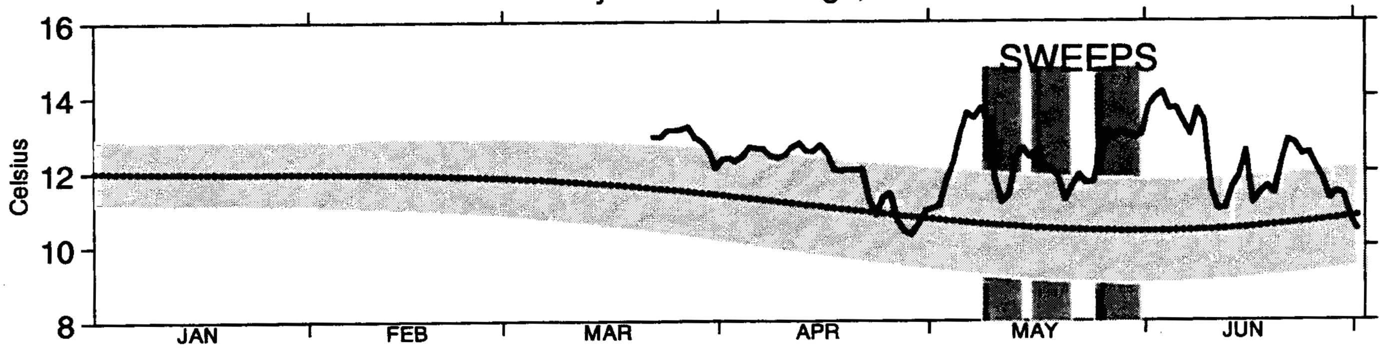
Standard CTD Station Locations



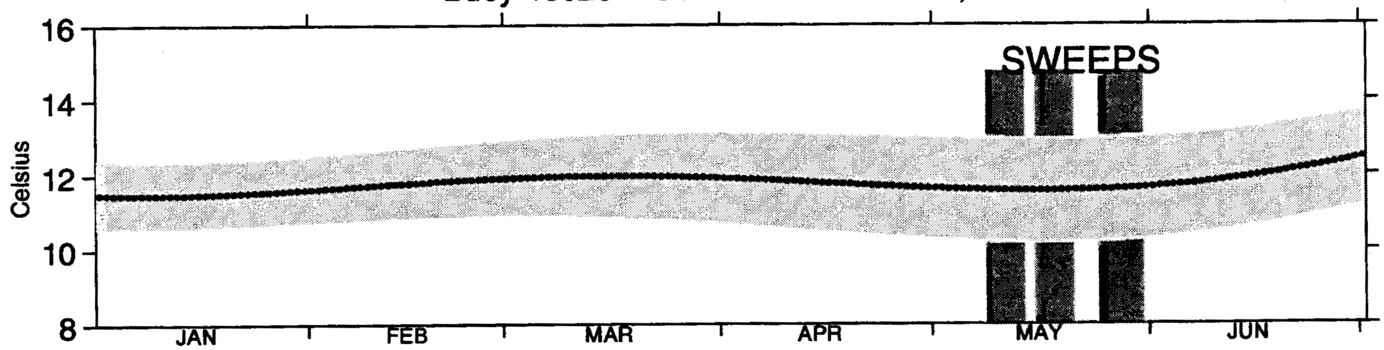
APPENDIX 3: METEOROLOGICAL TIME SERIES

Sea Surface Temperatures from NOAA NDBC Buoys ~1998

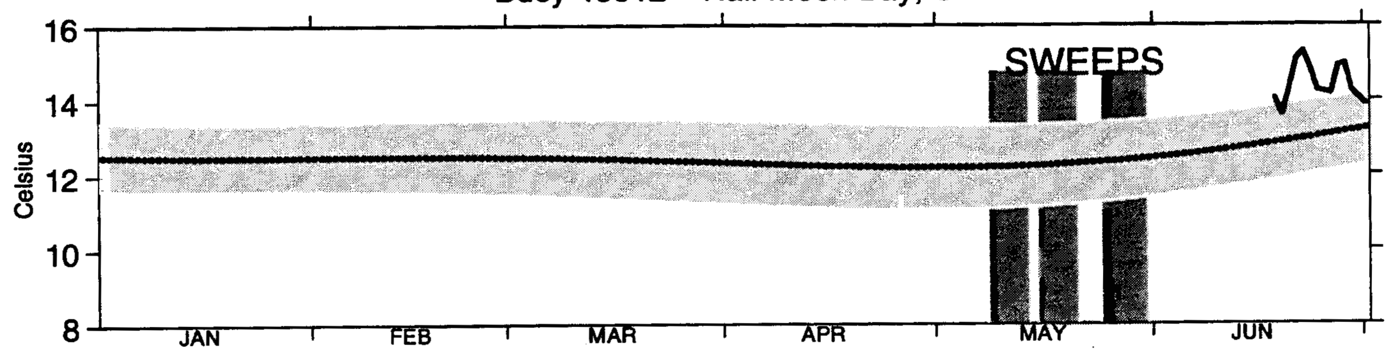
Buoy 46013 ~ Bodega, CA



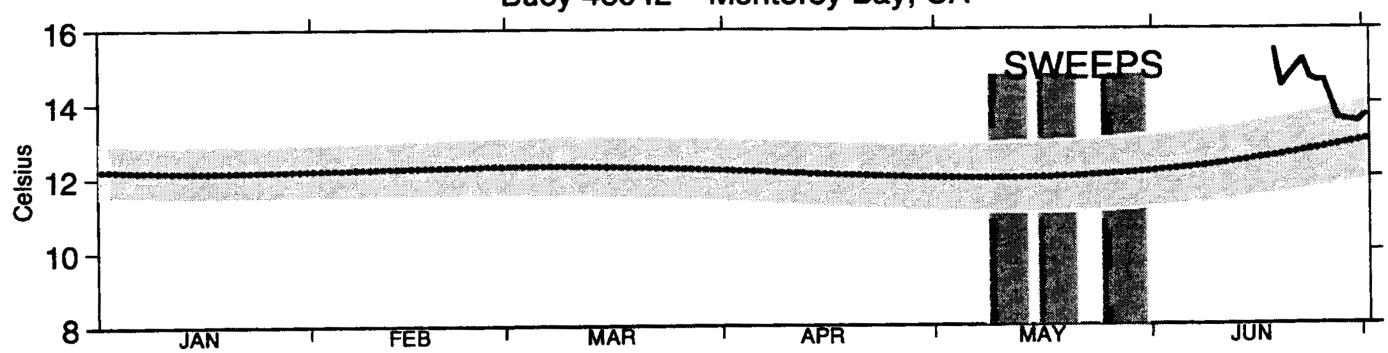
Buoy 46026 ~ Gulf of the Farallones, CA



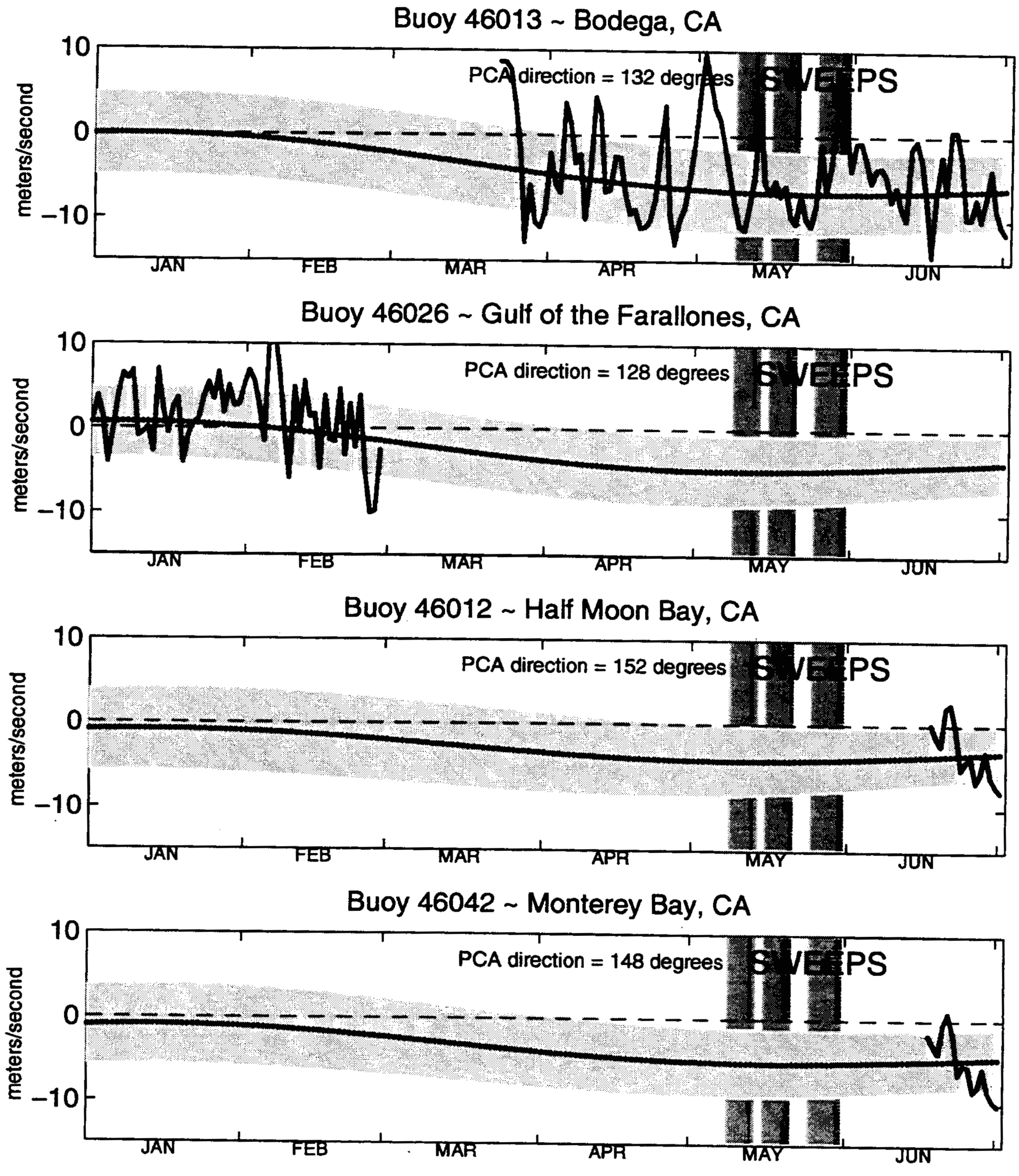
Buoy 46012 ~ Half Moon Bay, CA



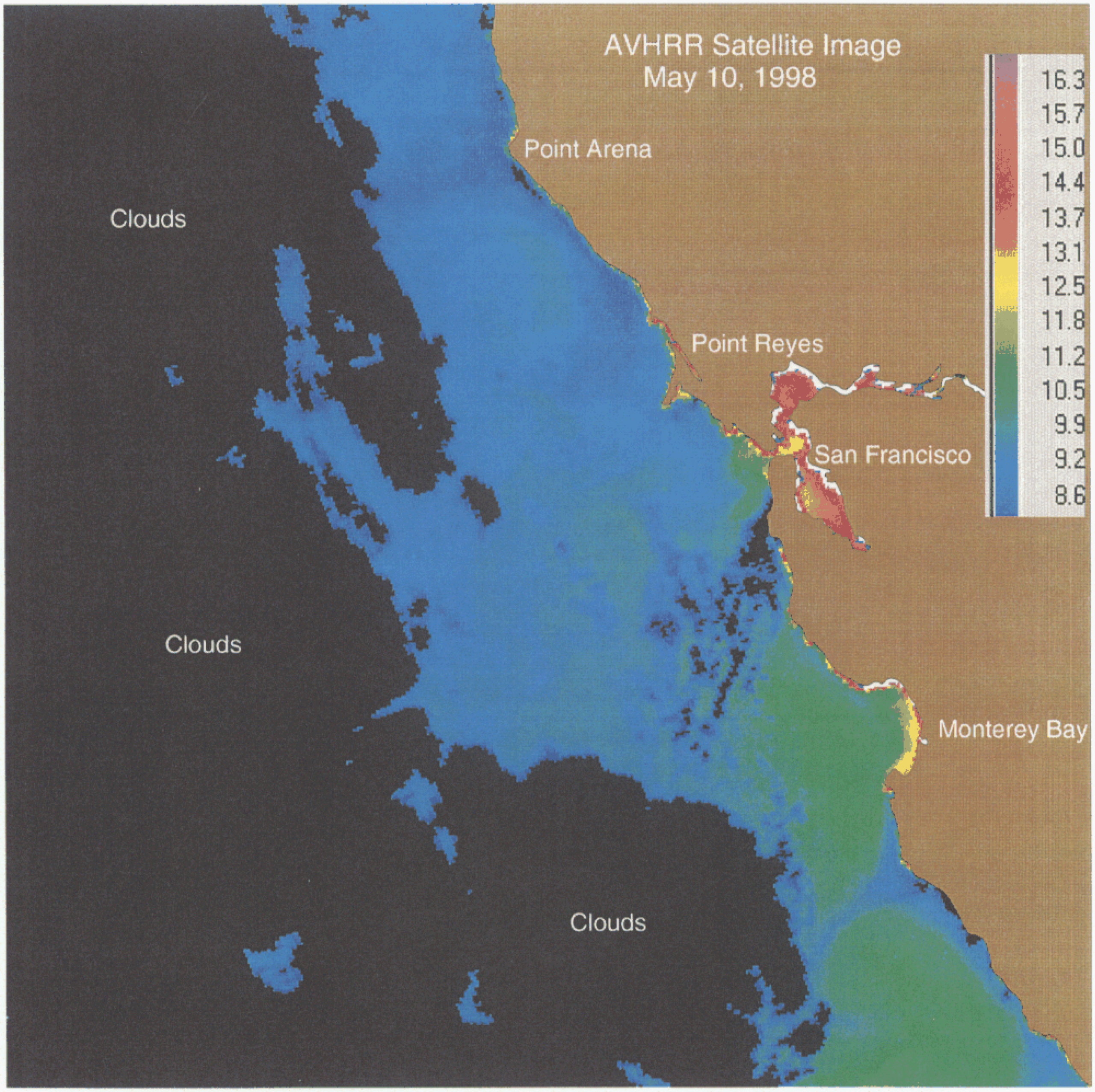
Buoy 46042 ~ Monterey Bay, CA

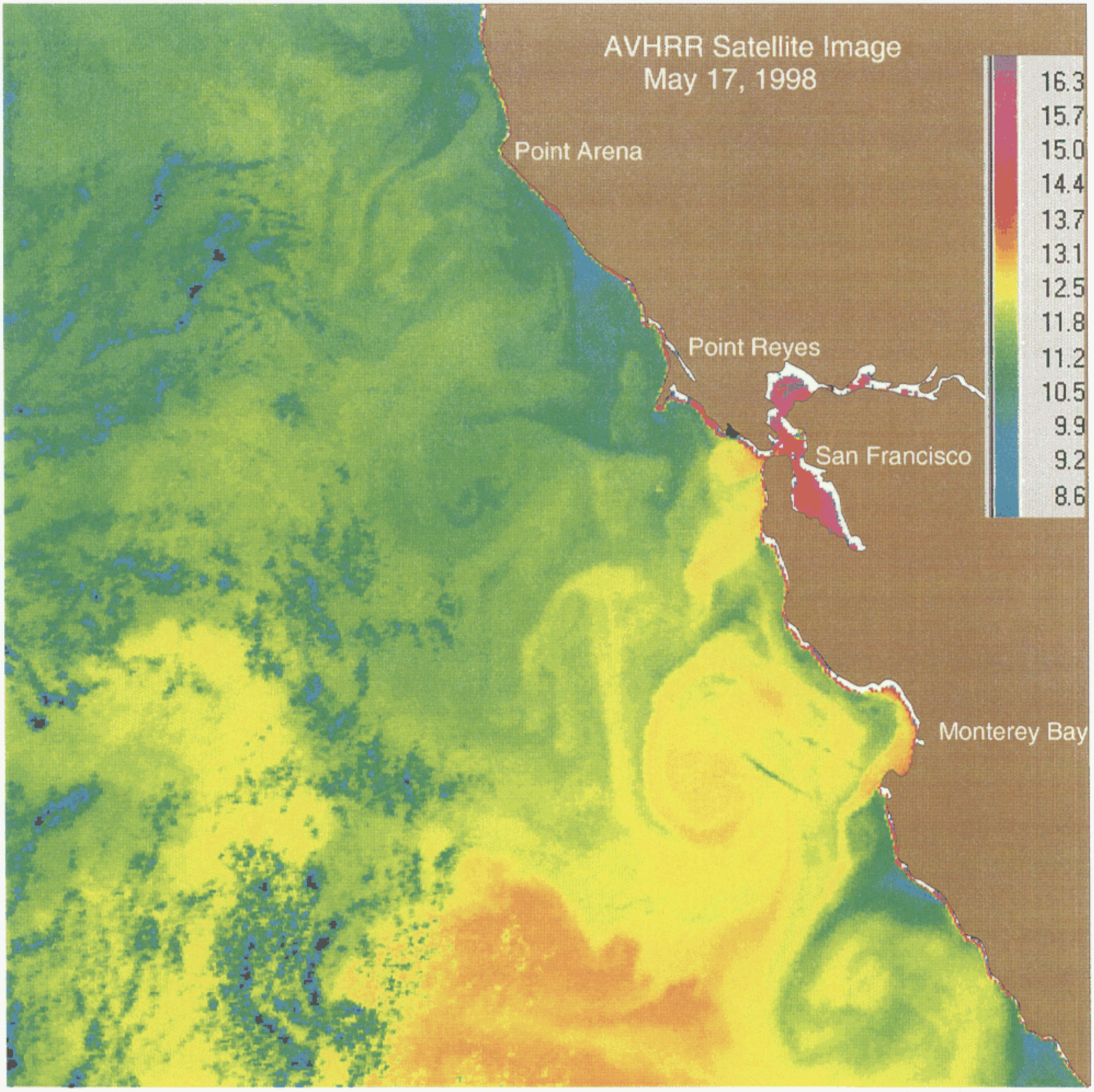


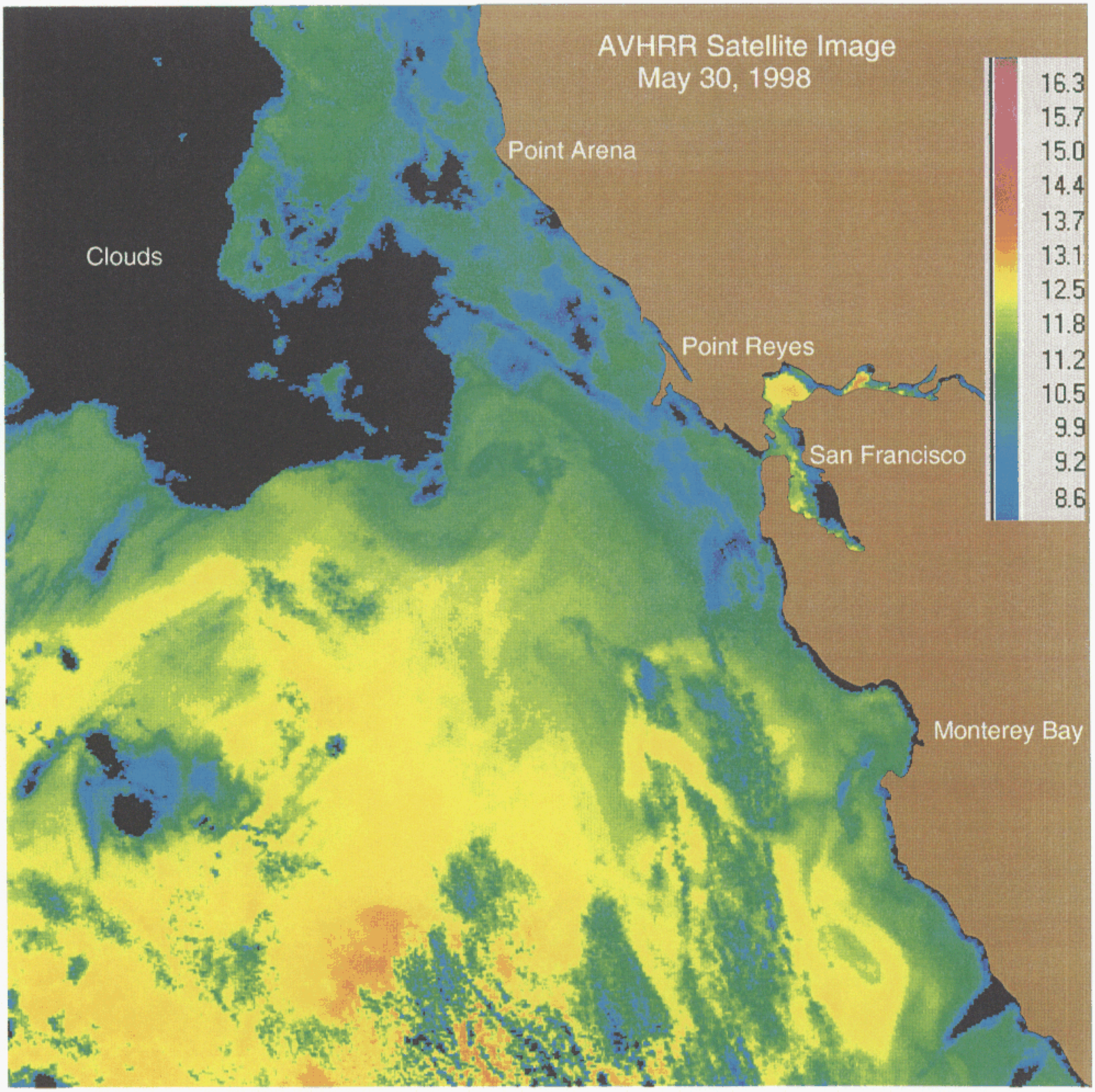
Alongshore Winds from NOAA NDBC Buoys ~ 1998



APPENDIX 4: AVHRR SATELLITE IMAGES OF MULTICHANNEL SST

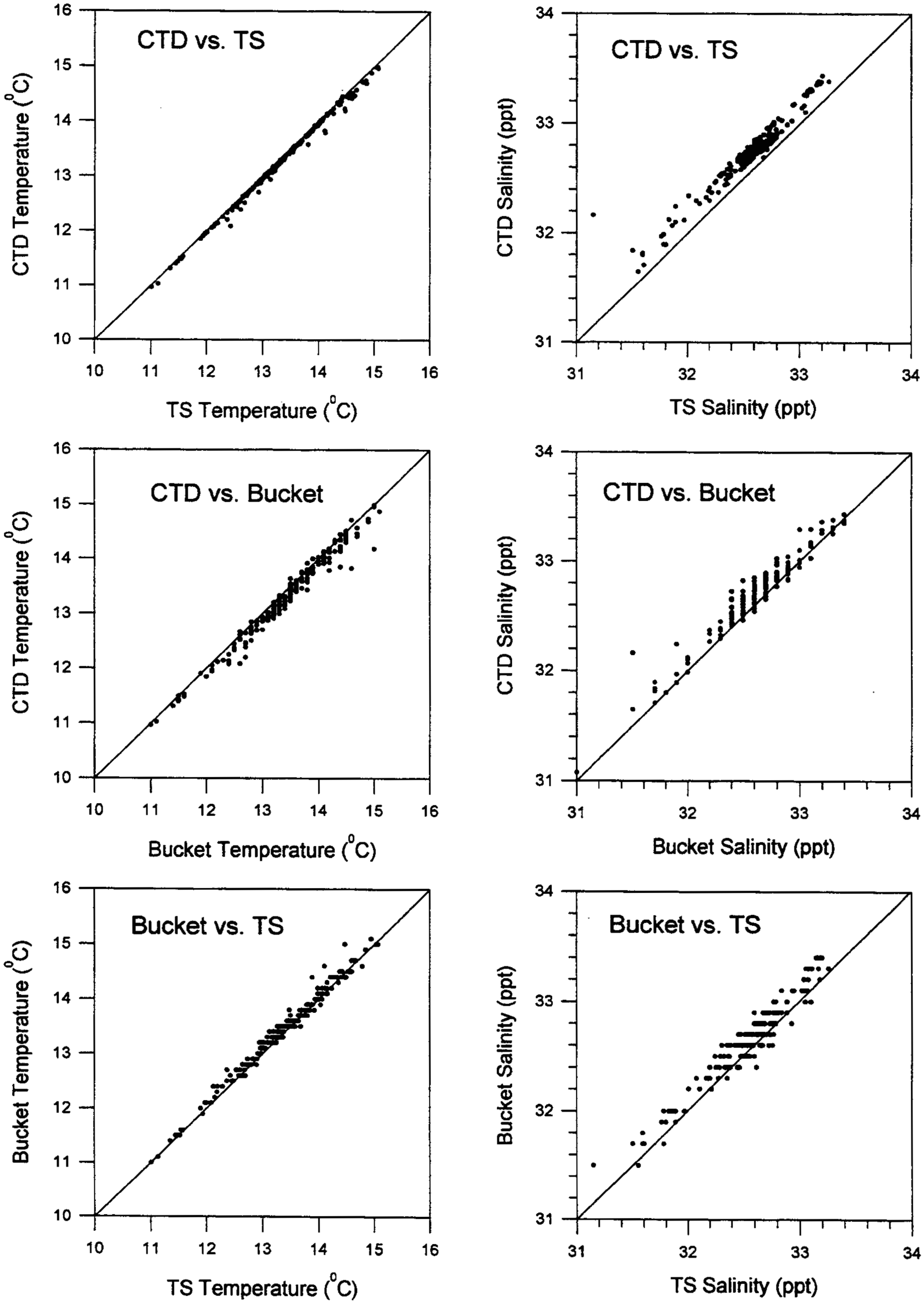

AVHRR Satellite Image
May 10, 1998
Point Arena
Clouds
Point Reyes
San Francisco
Clouds
Monterey Bay
Clouds
16.3
15.7
15.0
14.4
13.7
13.1
12.5
11.8
11.2
10.5
9.9
9.2
8.6


AVHRR Satellite Image
May 17, 1998
Point Arena
Point Reyes
San Francisco
Monterey Bay
16.3
15.7
15.0
14.4
13.7
13.1
12.5
11.8
11.2
10.5
9.9
9.2
8.6

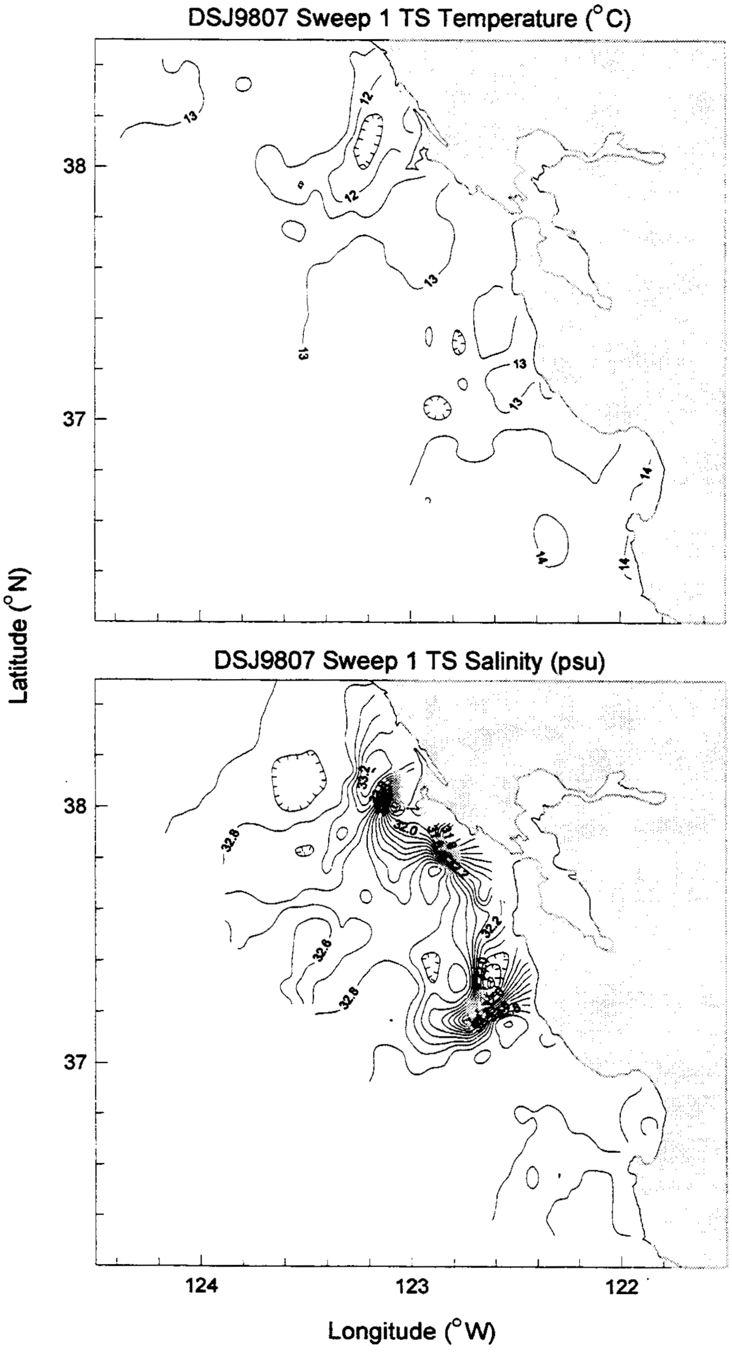

AVHRR Satellite Image
May 30, 1998
Point Arena
Clouds
Point Reyes
San Francisco
Monterey Bay
16.3
15.7
15.0
14.4
13.7
13.1
12.5
11.8
11.2
10.5
9.9
9.2
8.6

APPENDIX 5: REGRESSION COMPARISONS OF CTD, TS, AND BUCKET FOR DSJ9807

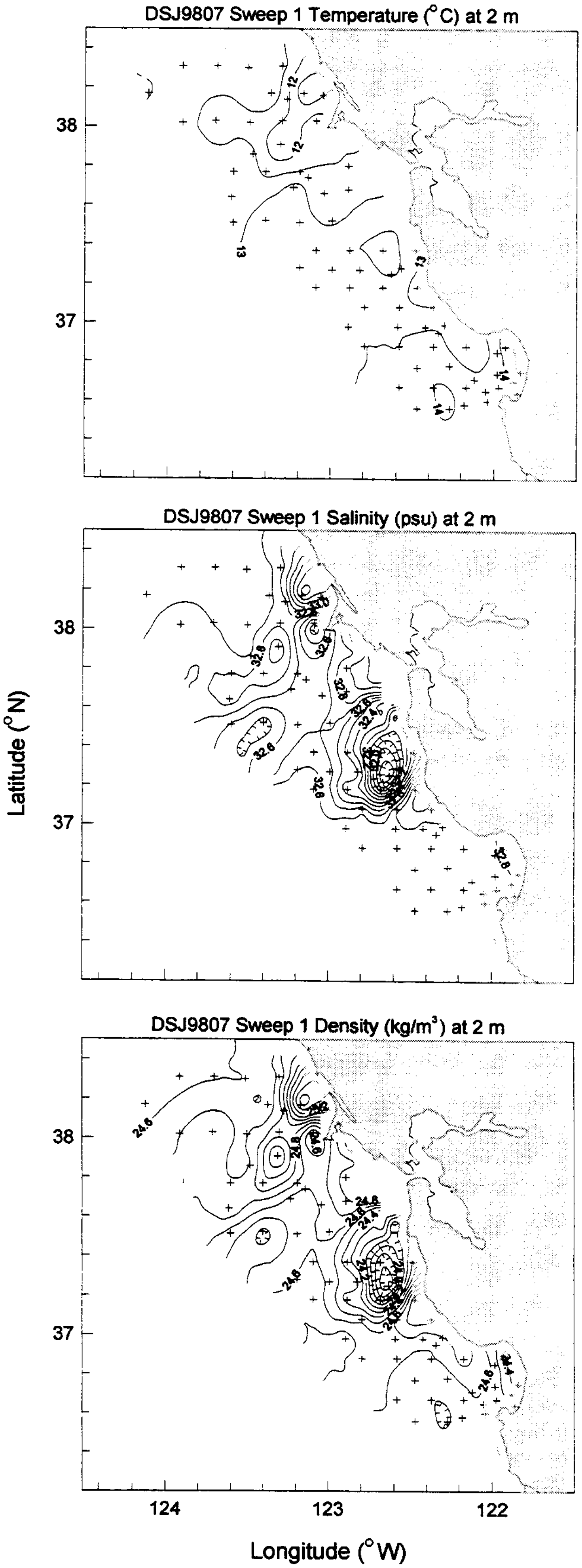
DSJ9807


CTD vs. TS
CTD Temperature (°C)
TS Temperature (°C)
CTD vs. TS
CTD Salinity (ppt)
TS Salinity (ppt)
CTD vs. Bucket
CTD Temperature (°C)
Bucket Temperature (°C)
CTD vs. Bucket
CTD Salinity (ppt)
Bucket Salinity (ppt)
Bucket vs. TS
Bucket Temperature (°C)
TS Temperature (°C)
Bucket vs. TS
Bucket Salinity (ppt)
TS Salinity (ppt)

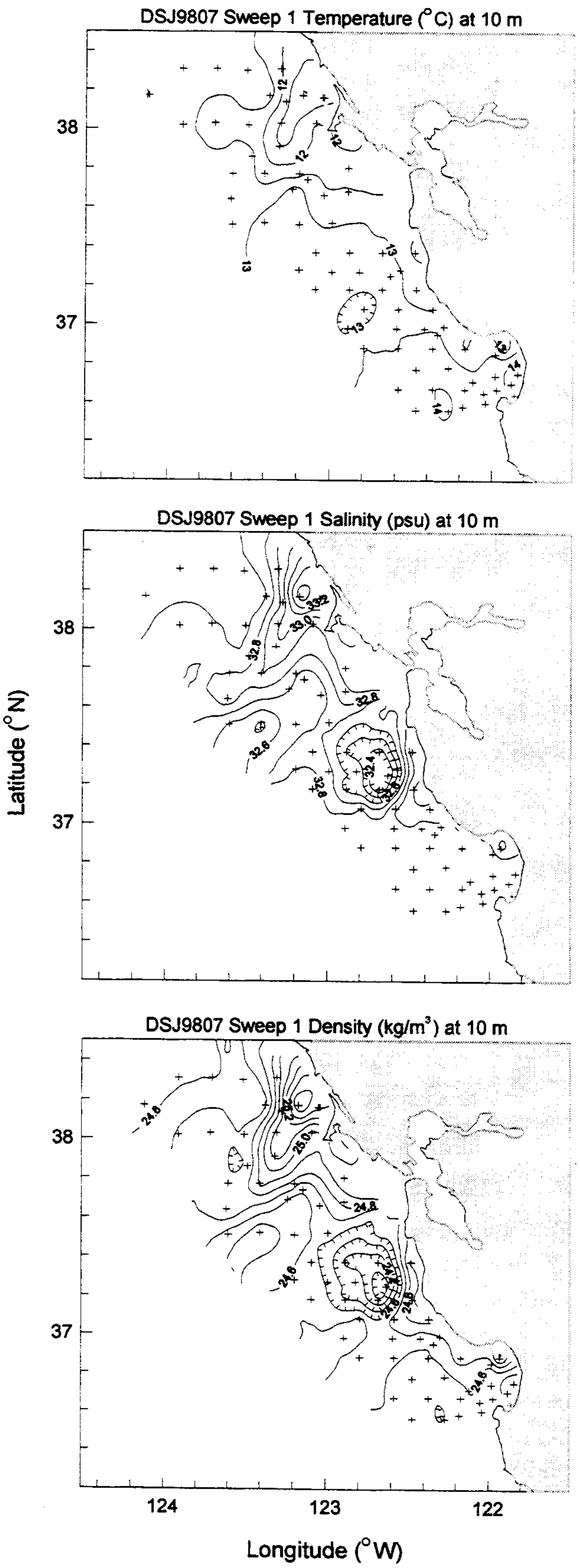
APPENDIX 6.1: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9807, SWEEP 1

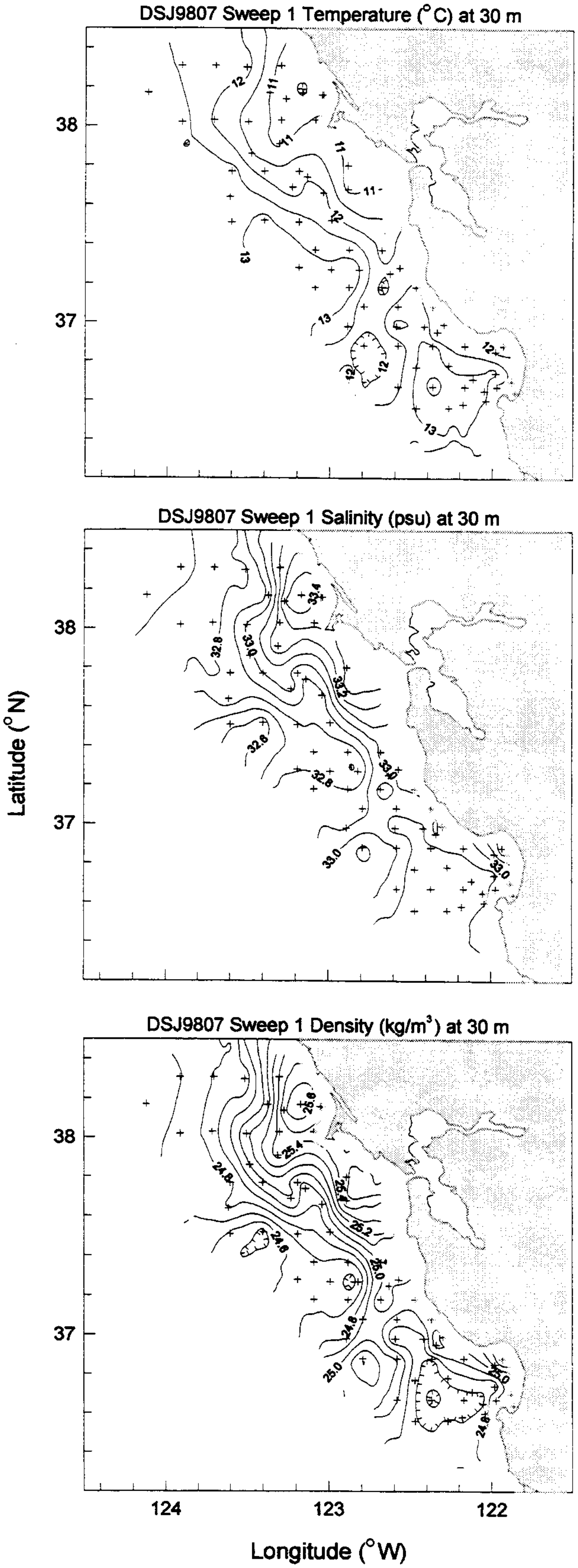


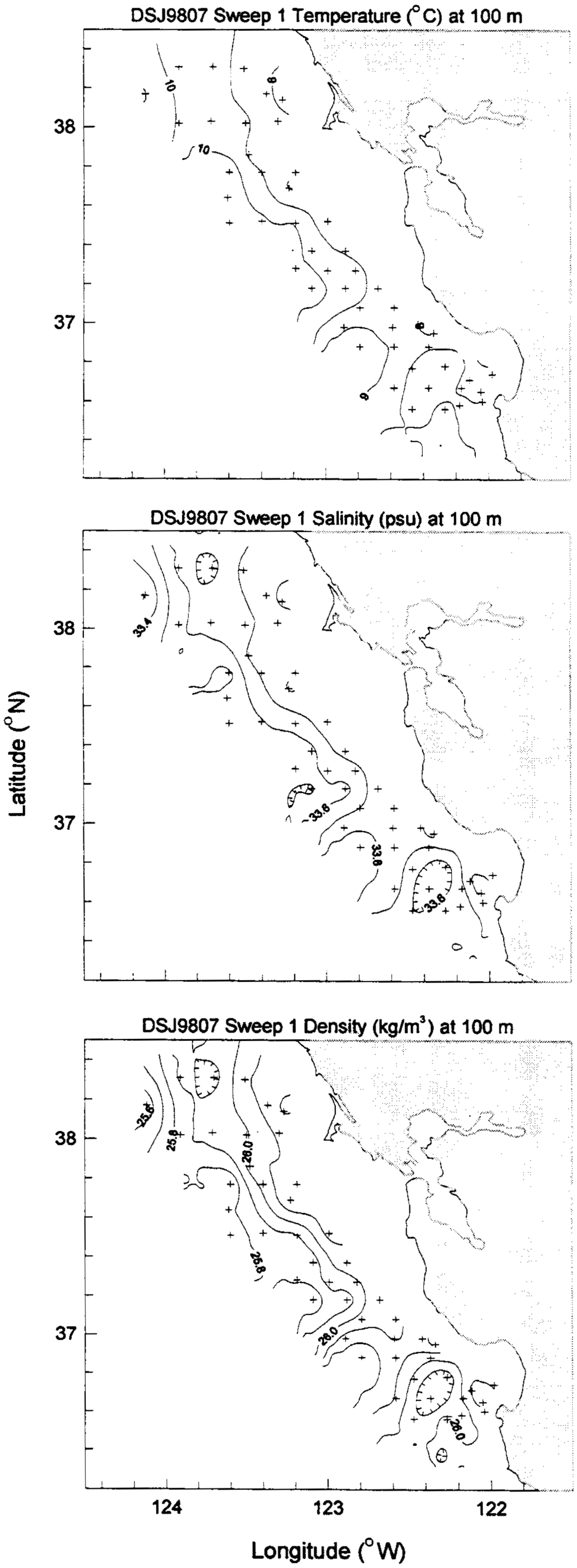
DSJ9807 Sweep 1 TS Temperature (°C)
DSJ9807 Sweep 1 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
12
13
14
32.8
32.6
32.2
32.0

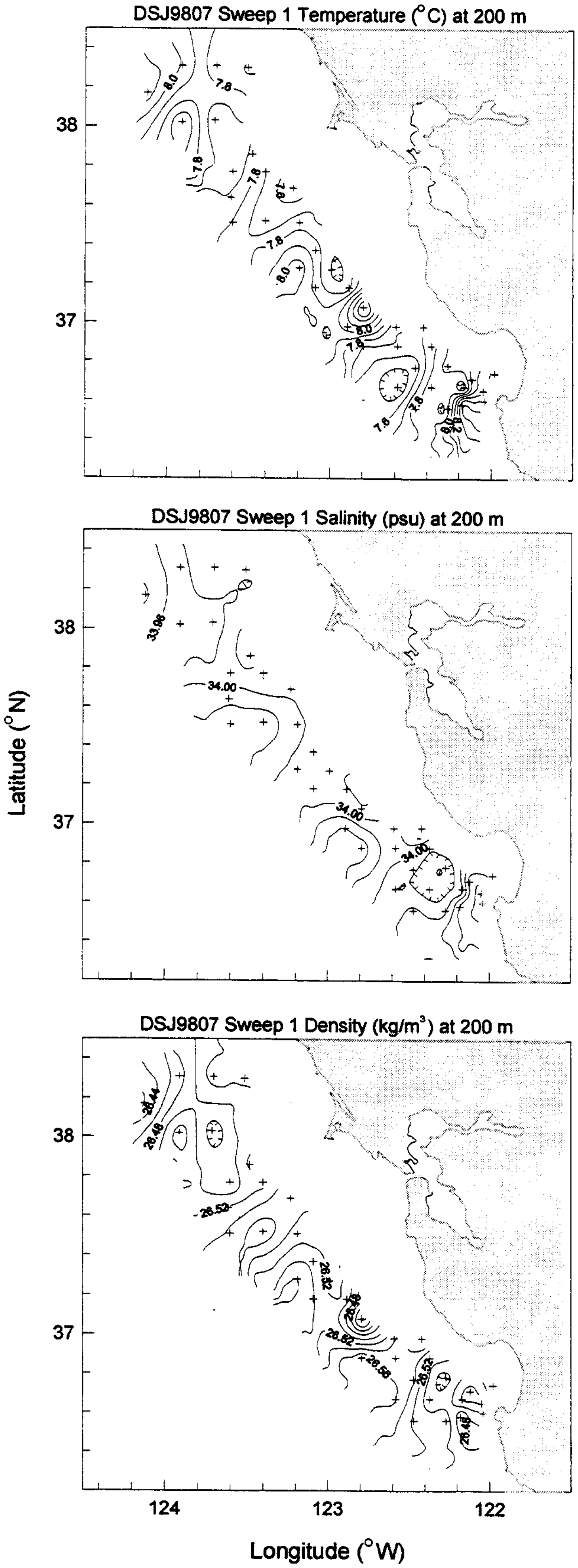


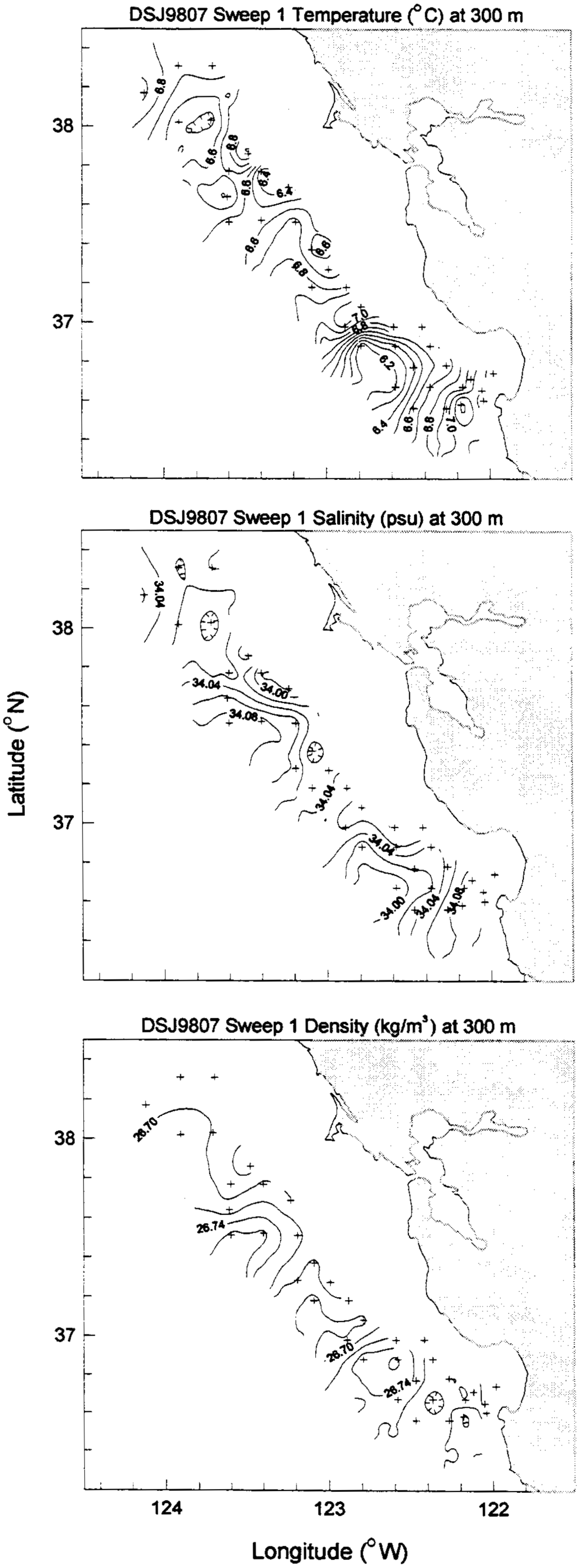
DSJ9807 Sweep 1 Temperature (°C) at 2 m
DSJ9807 Sweep 1 Salinity (psu) at 2 m
DSJ9807 Sweep 1 Density (kg/m³) at 2 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

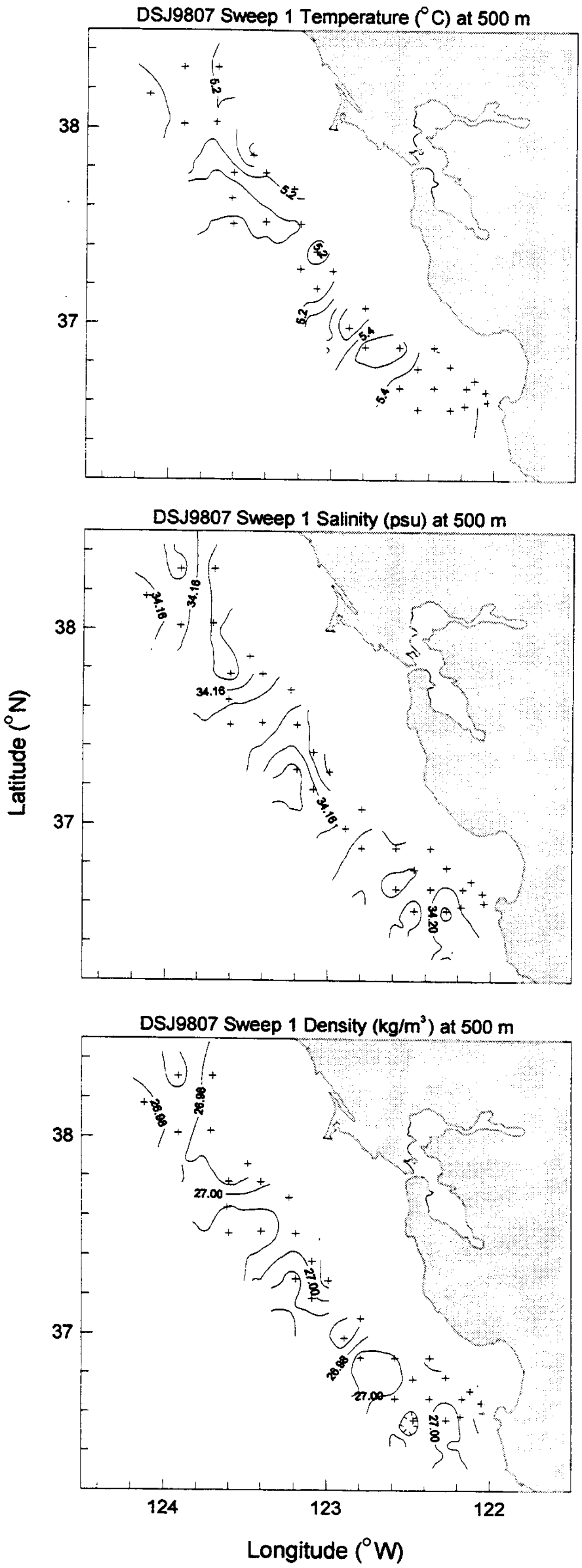

DSJ9807 Sweep 1 Temperature (°C) at 10 m
DSJ9807 Sweep 1 Salinity (psu) at 10 m
DSJ9807 Sweep 1 Density (kg/m³) at 10 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)


DSJ9807 Sweep 1 Temperature (°C) at 30 m
DSJ9807 Sweep 1 Salinity (psu) at 30 m
DSJ9807 Sweep 1 Density (kg/m³) at 30 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

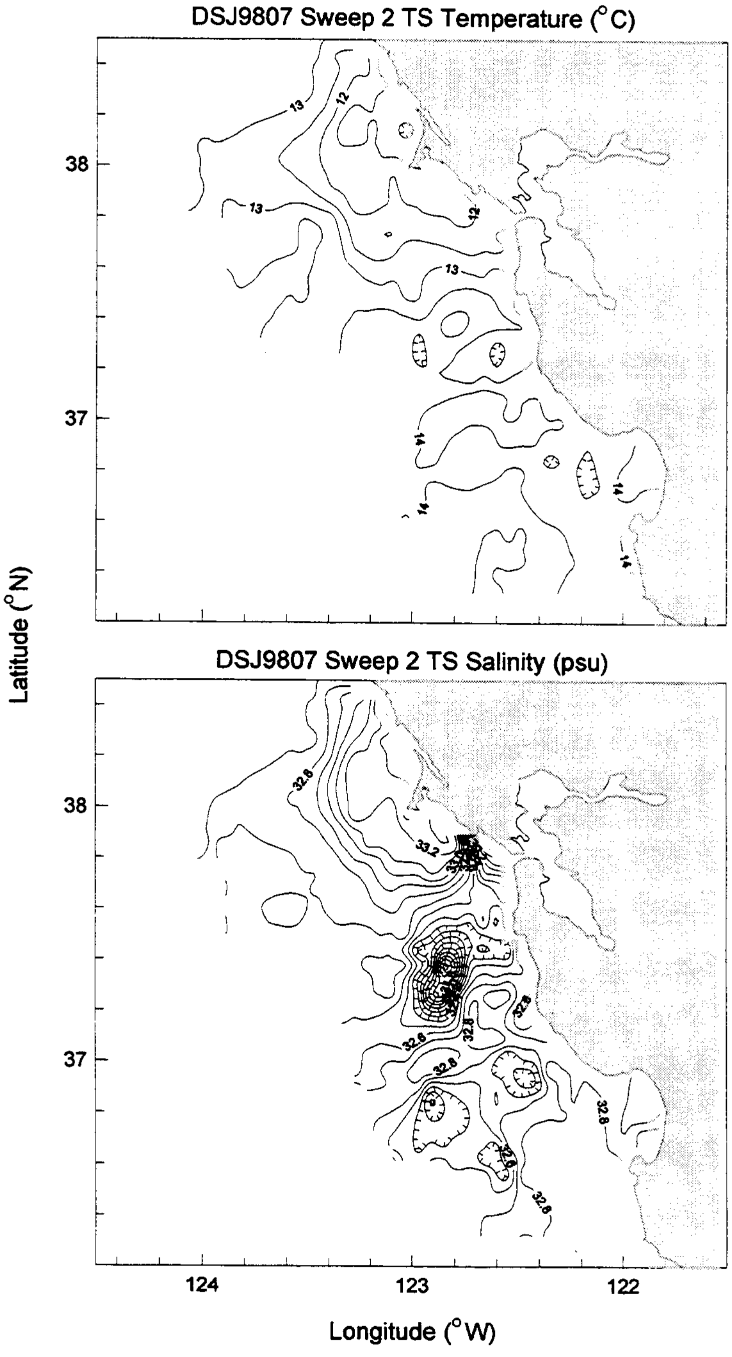

DSJ9807 Sweep 1 Temperature (°C) at 100 m
DSJ9807 Sweep 1 Salinity (psu) at 100 m
DSJ9807 Sweep 1 Density (kg/m³) at 100 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)


DSJ9807 Sweep 1 Temperature (°C) at 200 m
DSJ9807 Sweep 1 Salinity (psu) at 200 m
DSJ9807 Sweep 1 Density (kg/m³) at 200 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

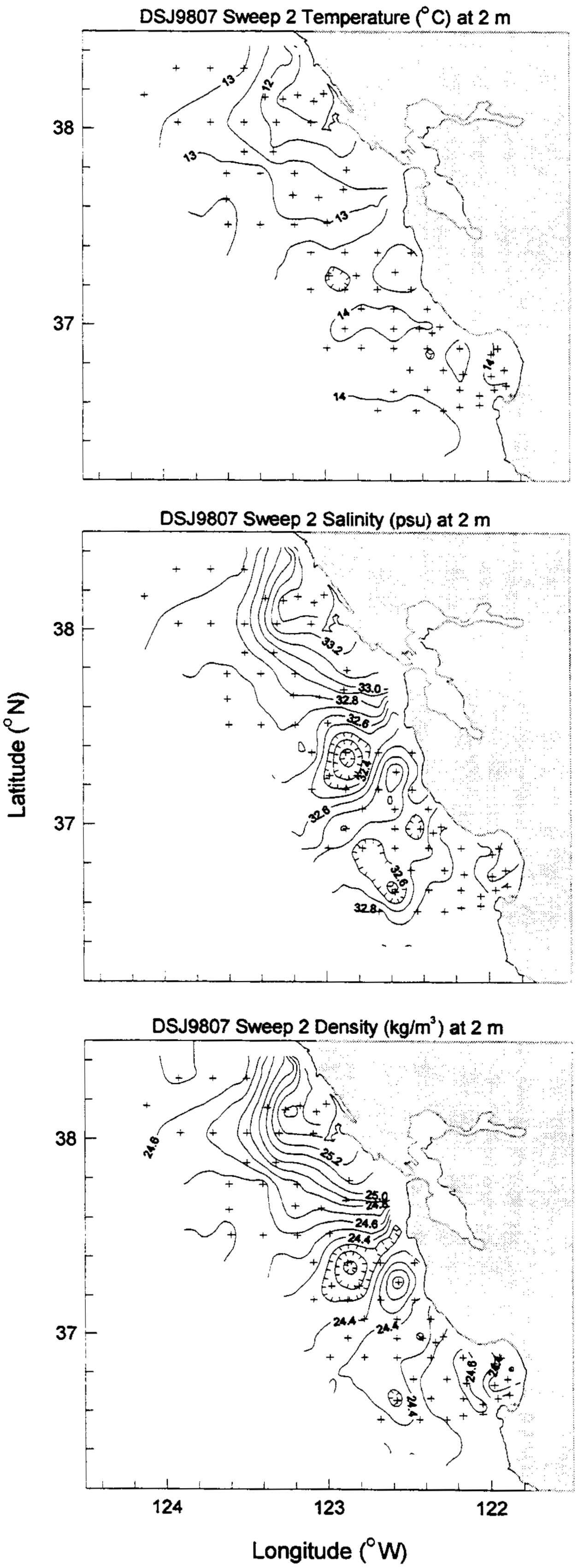

DSJ9807 Sweep 1 Temperature (°C) at 300 m
DSJ9807 Sweep 1 Salinity (psu) at 300 m
DSJ9807 Sweep 1 Density (kg/m³) at 300 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

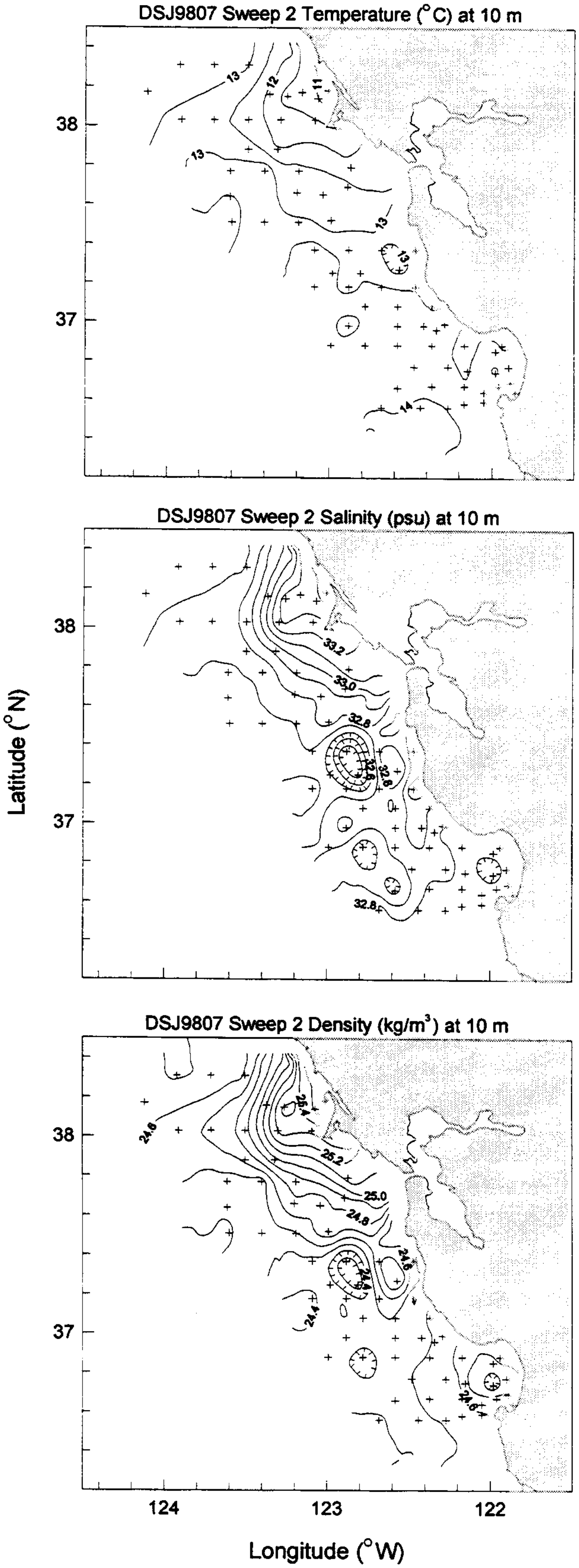

DSJ9807 Sweep 1 Temperature (°C) at 500 m
DSJ9807 Sweep 1 Salinity (psu) at 500 m
DSJ9807 Sweep 1 Density (kg/m³) at 500 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
5.2
5.4
34.16
34.20
26.98
27.00

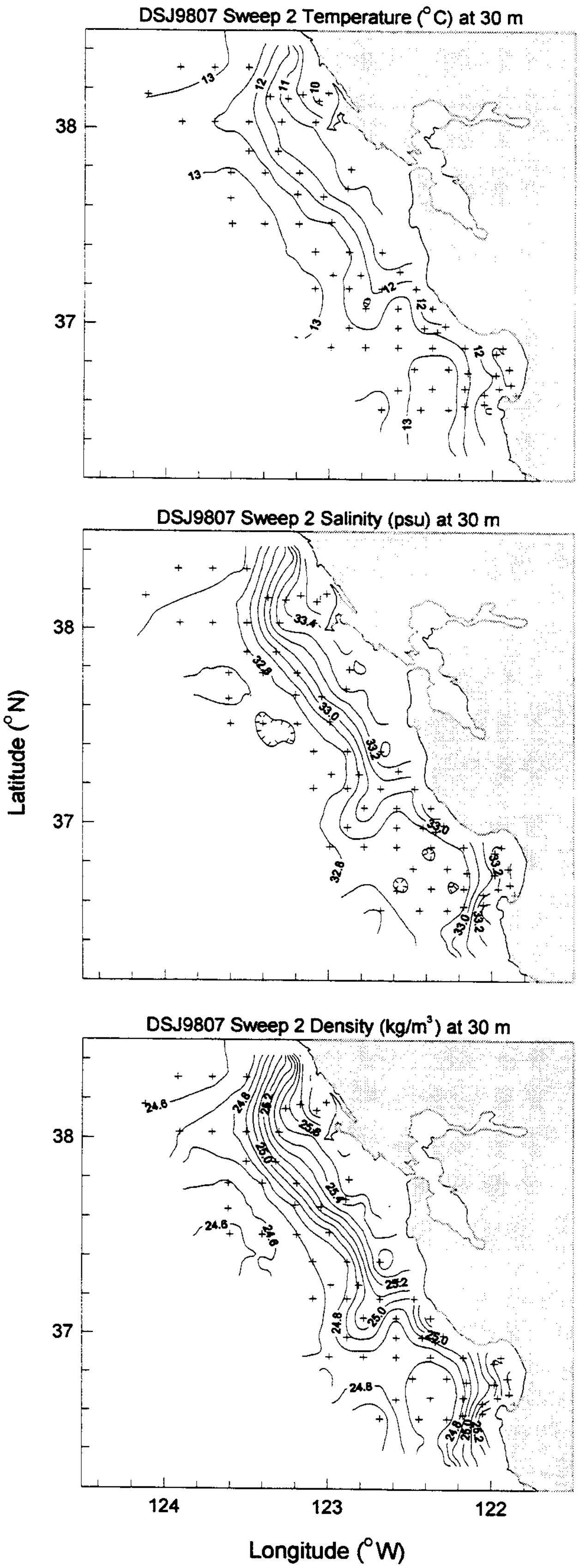
APPENDIX 6.2: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9807, SWEEP 2

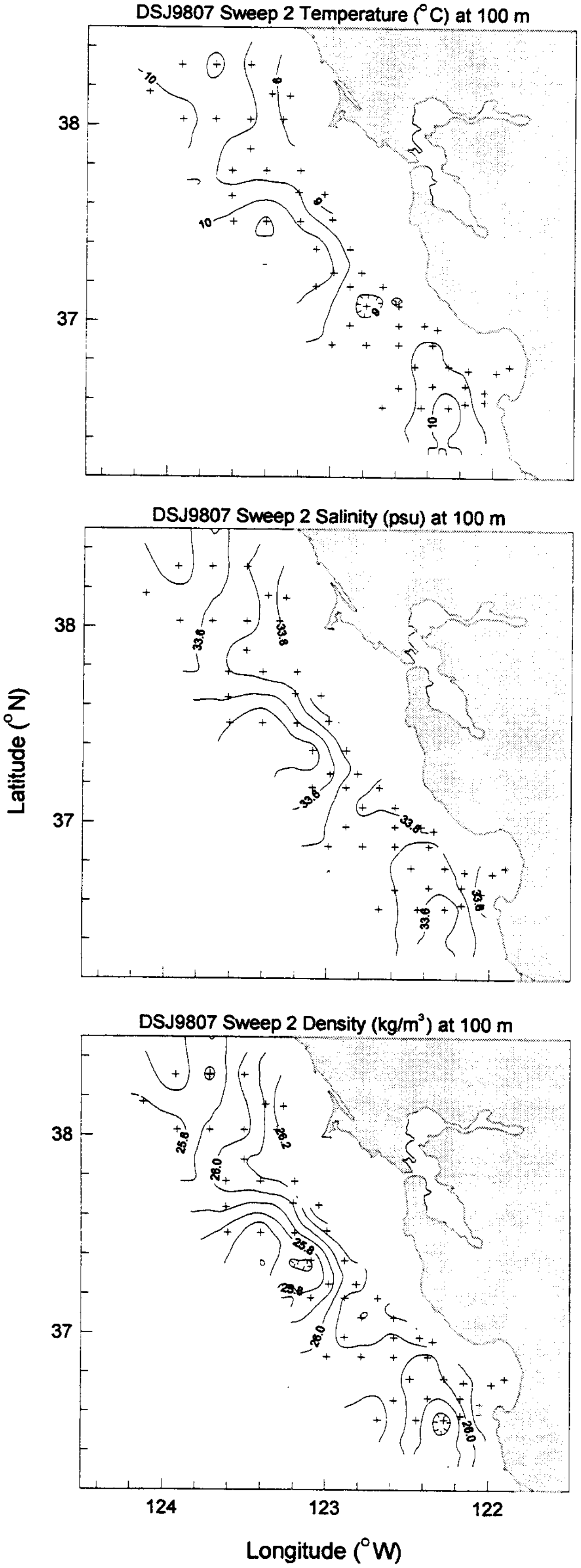


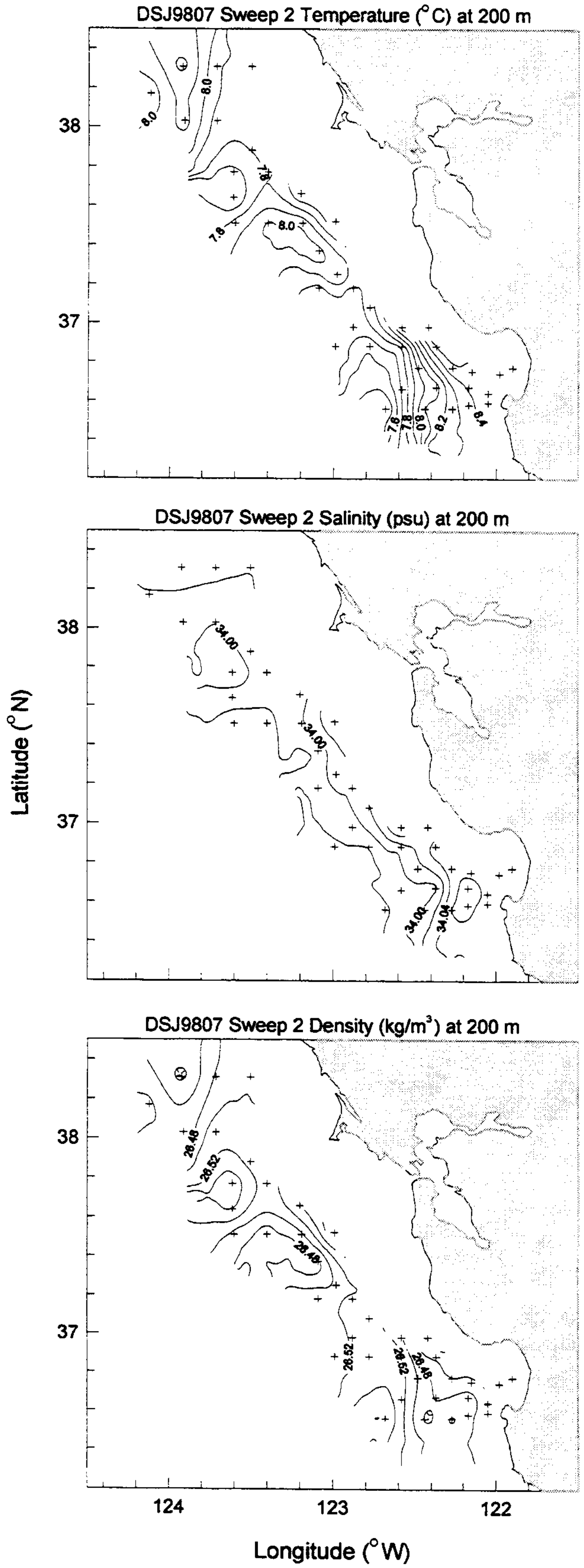
DSJ9807 Sweep 2 TS Temperature (°C)
DSJ9807 Sweep 2 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
13
12
14
32.8
33.2

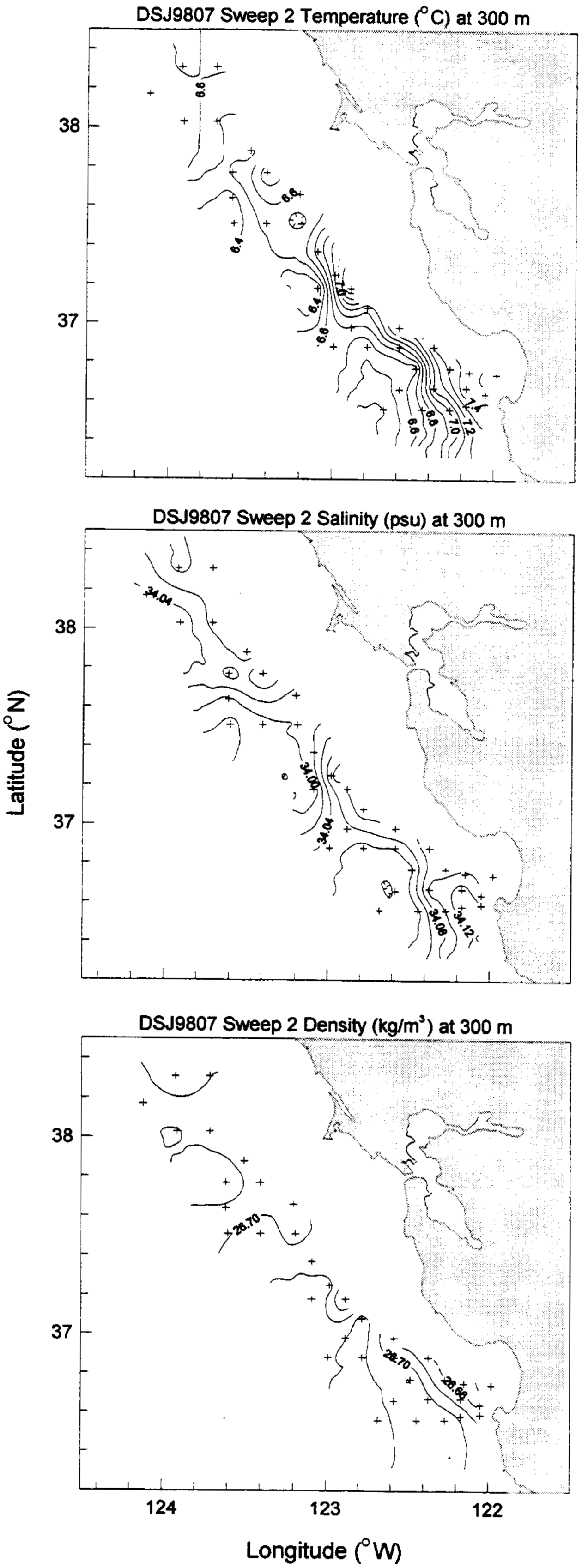

DSJ9807 Sweep 2 Temperature (°C) at 2 m
DSJ9807 Sweep 2 Salinity (psu) at 2 m
DSJ9807 Sweep 2 Density (kg/m³) at 2 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122

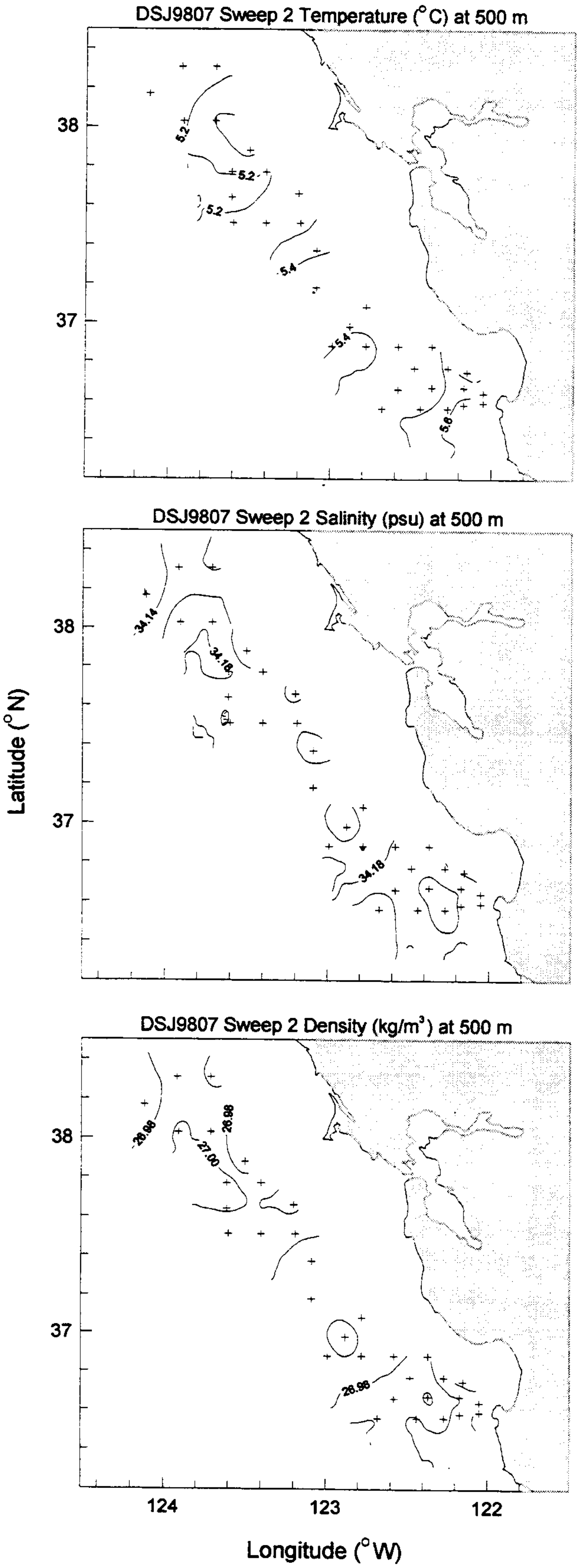

DSJ9807 Sweep 2 Temperature (°C) at 10 m
DSJ9807 Sweep 2 Salinity (psu) at 10 m
DSJ9807 Sweep 2 Density (kg/m³) at 10 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122


DSJ9807 Sweep 2 Temperature (°C) at 30 m
DSJ9807 Sweep 2 Salinity (psu) at 30 m
DSJ9807 Sweep 2 Density (kg/m³) at 30 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

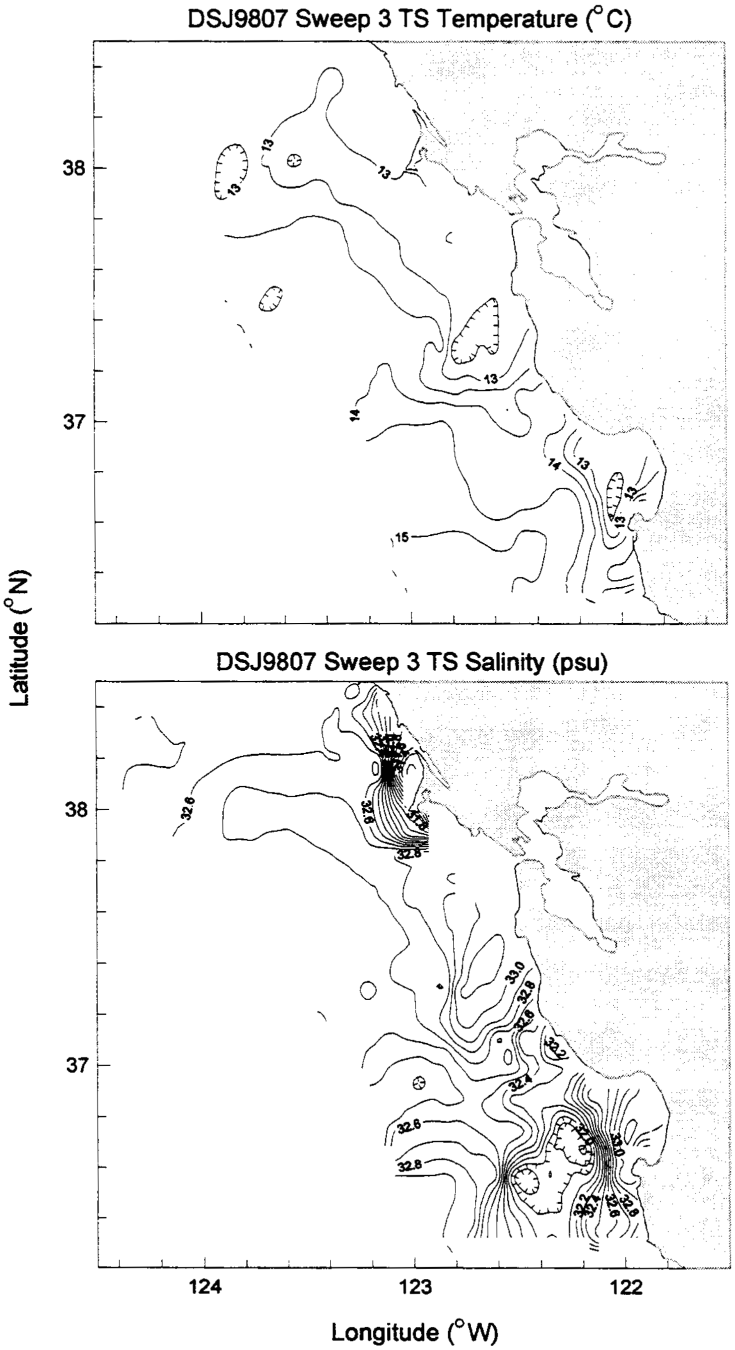

DSJ9807 Sweep 2 Temperature (°C) at 100 m
DSJ9807 Sweep 2 Salinity (psu) at 100 m
DSJ9807 Sweep 2 Density (kg/m³) at 100 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)
10
9
33.6
33.8
25.8
26.0
26.2

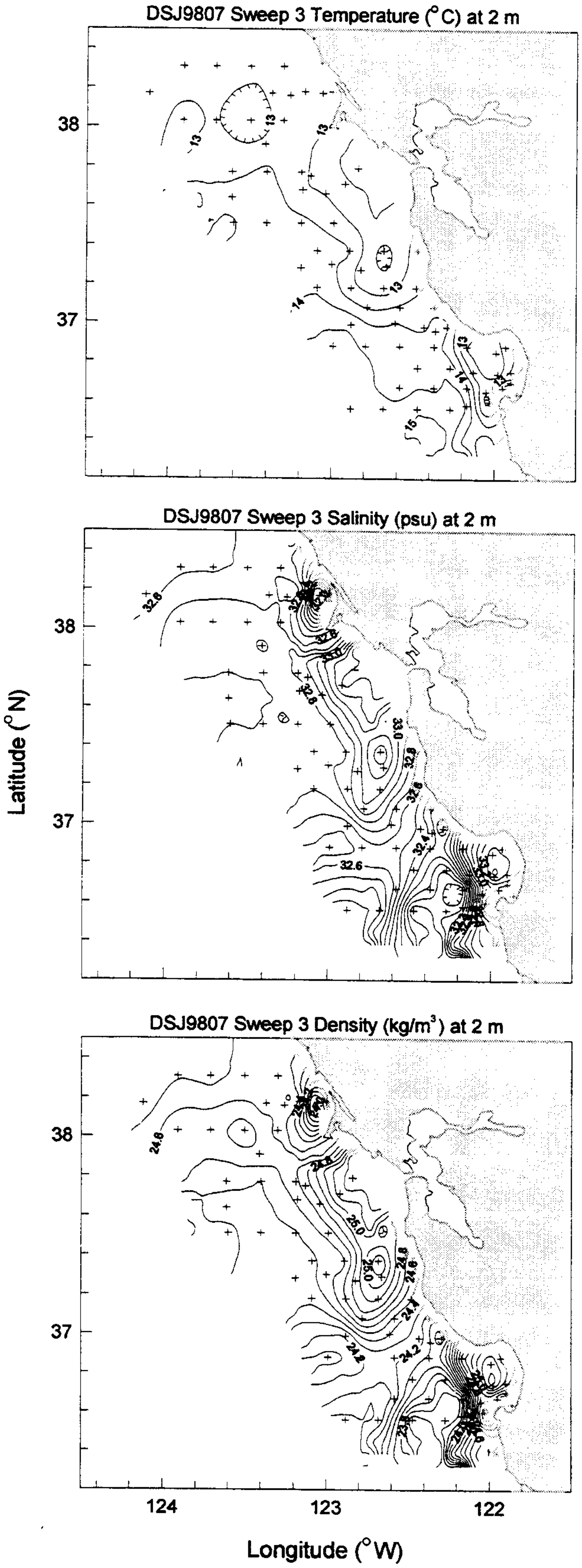

DSJ9807 Sweep 2 Temperature (°C) at 200 m
DSJ9807 Sweep 2 Salinity (psu) at 200 m
DSJ9807 Sweep 2 Density (kg/m³) at 200 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
8.0
7.8
8.2
8.4
34.00
34.04
28.48
28.52

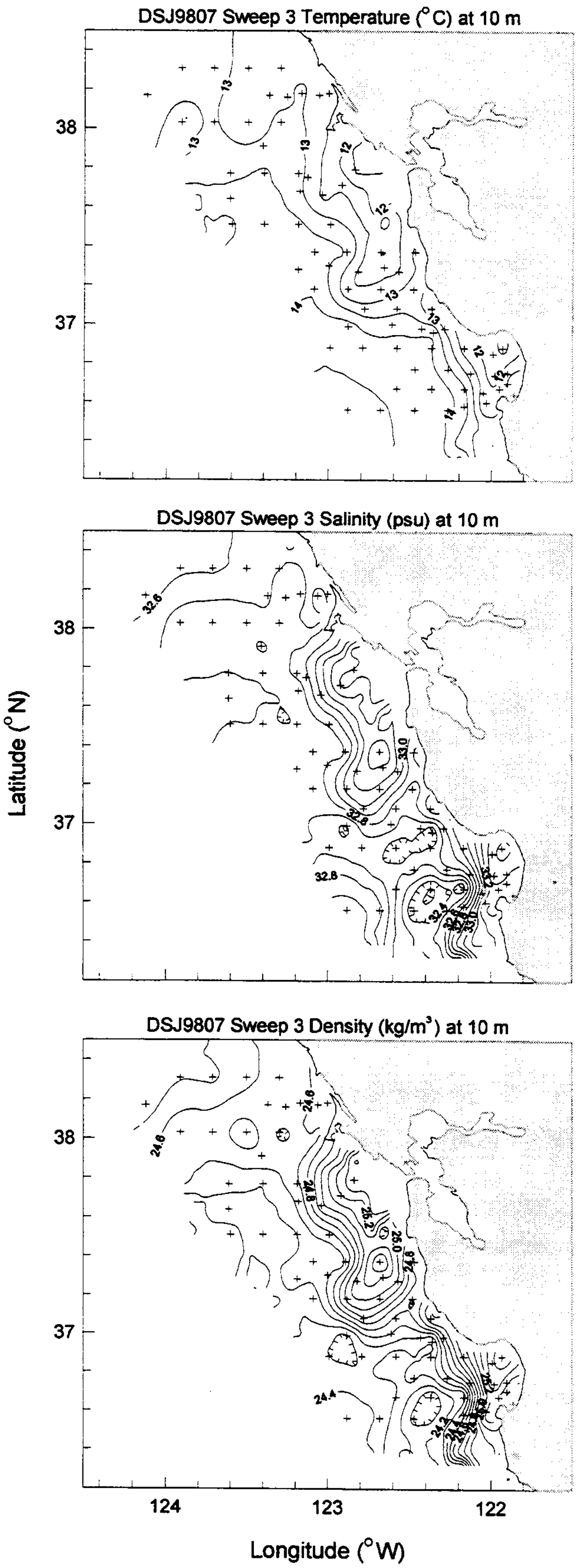

DSJ9807 Sweep 2 Temperature (°C) at 300 m
DSJ9807 Sweep 2 Salinity (psu) at 300 m
DSJ9807 Sweep 2 Density (kg/m³) at 300 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

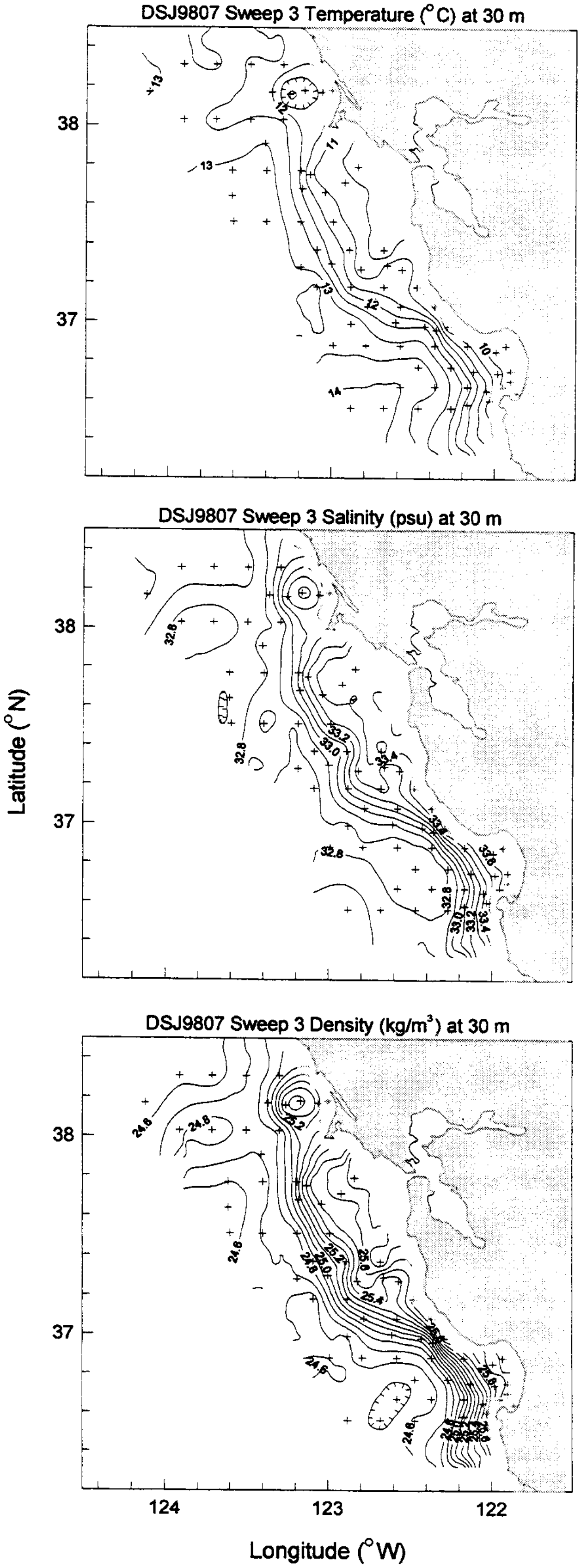

DSJ9807 Sweep 2 Temperature (°C) at 500 m
5.2
5.2
5.2
5.4
5.4
5.6
DSJ9807 Sweep 2 Salinity (psu) at 500 m
34.14
34.18
34.18
DSJ9807 Sweep 2 Density (kg/m³) at 500 m
26.98
26.98
27.00
26.98
38
37
Latitude (°N)
124
123
122
Longitude (°W)

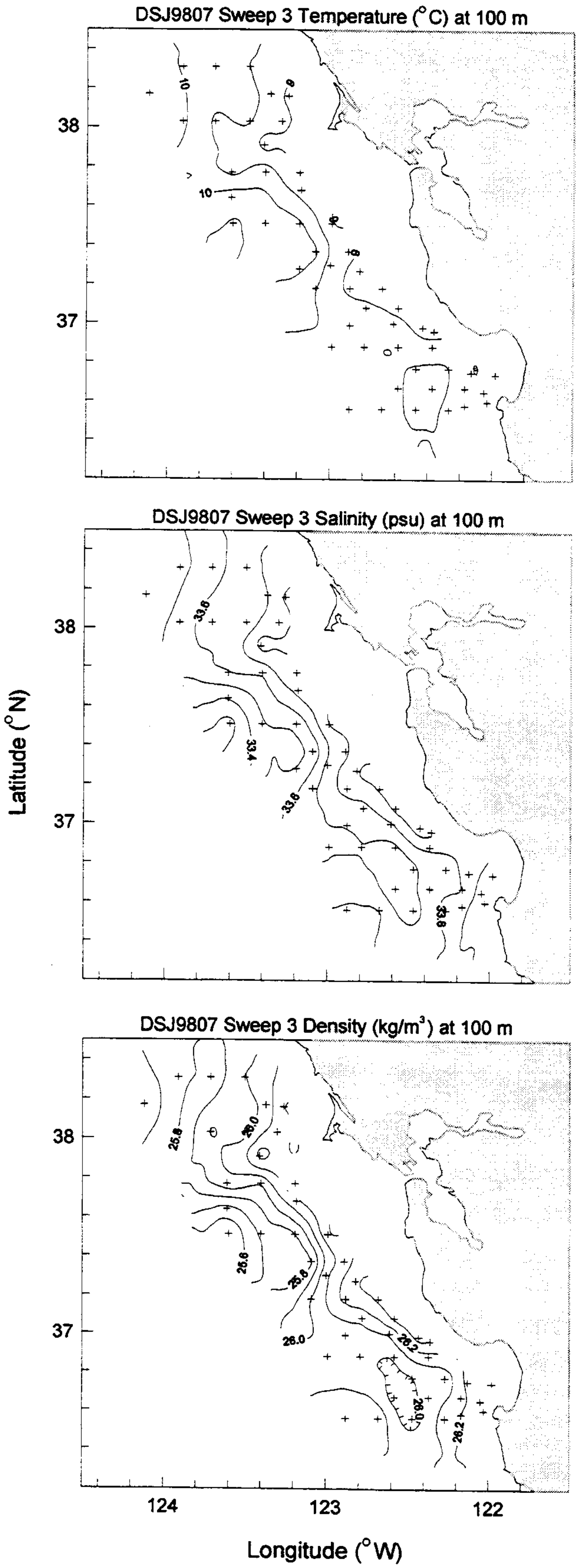
APPENDIX 6.3: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9807, SWEEP 3

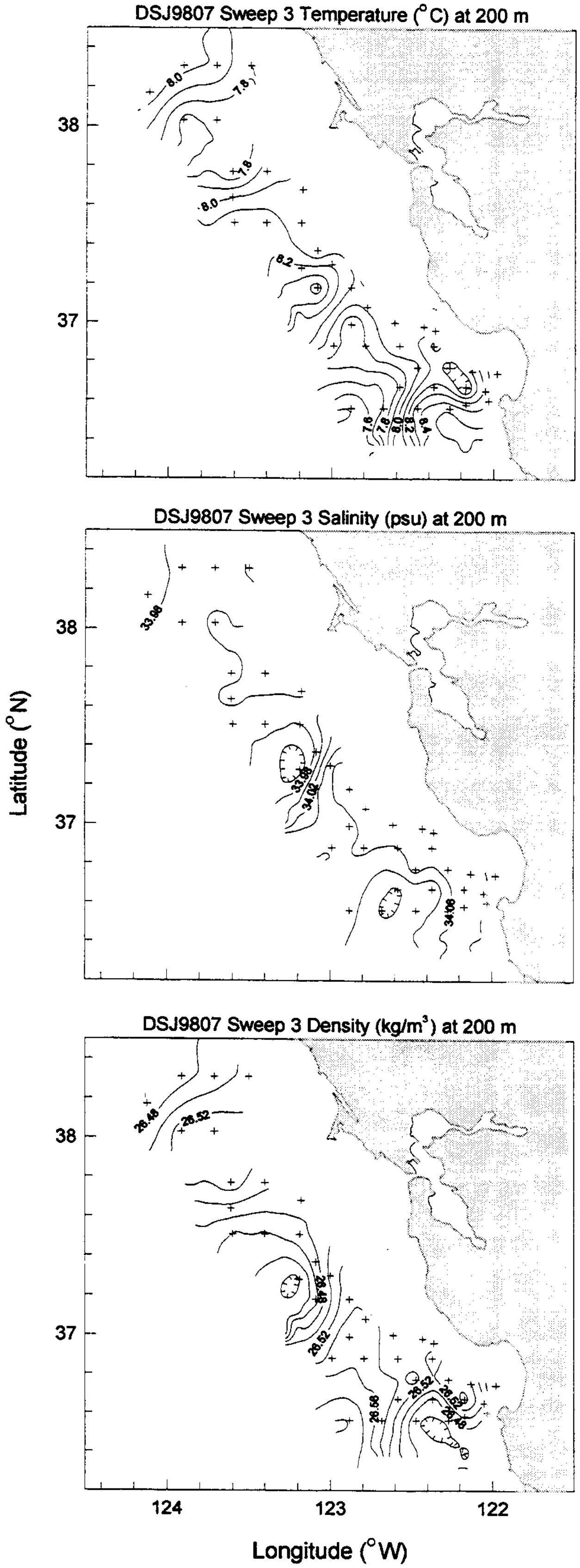

DSJ9807 Sweep 3 TS Temperature (°C)
DSJ9807 Sweep 3 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
13
14
15
32.6
32.8
33.0
32.4
32.2

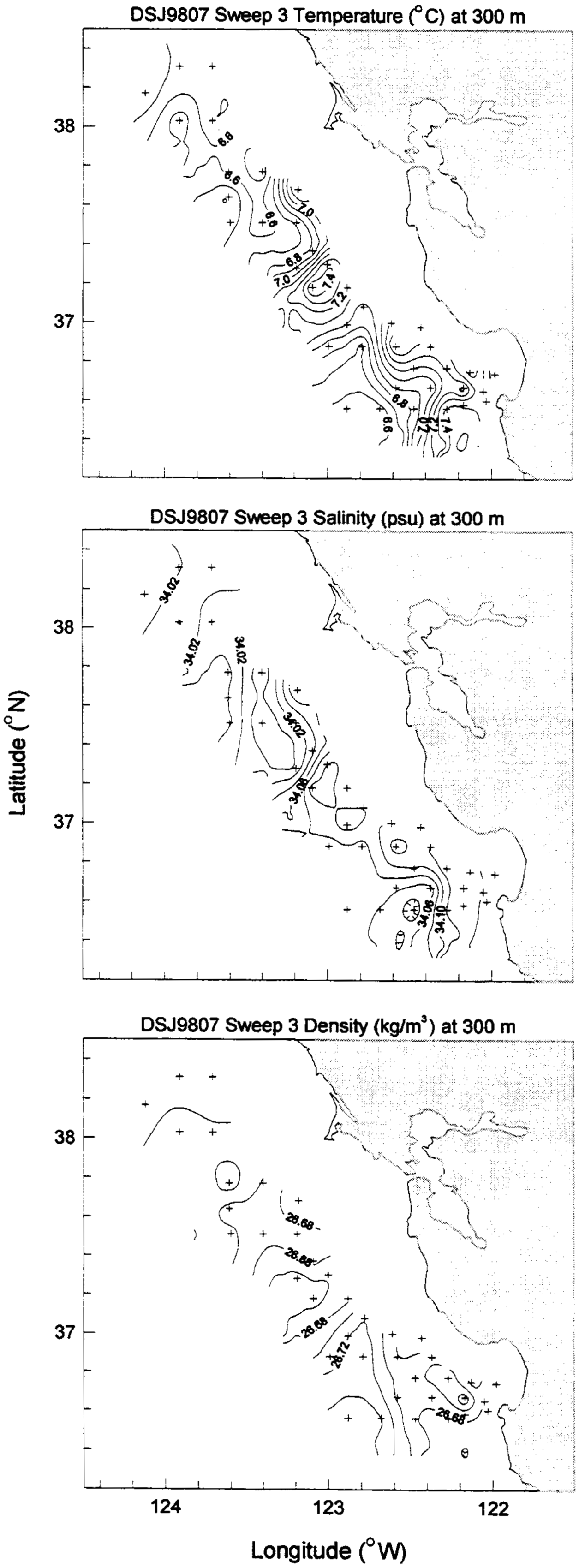

DSJ9807 Sweep 3 Temperature (°C) at 2 m
DSJ9807 Sweep 3 Salinity (psu) at 2 m
DSJ9807 Sweep 3 Density (kg/m³) at 2 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

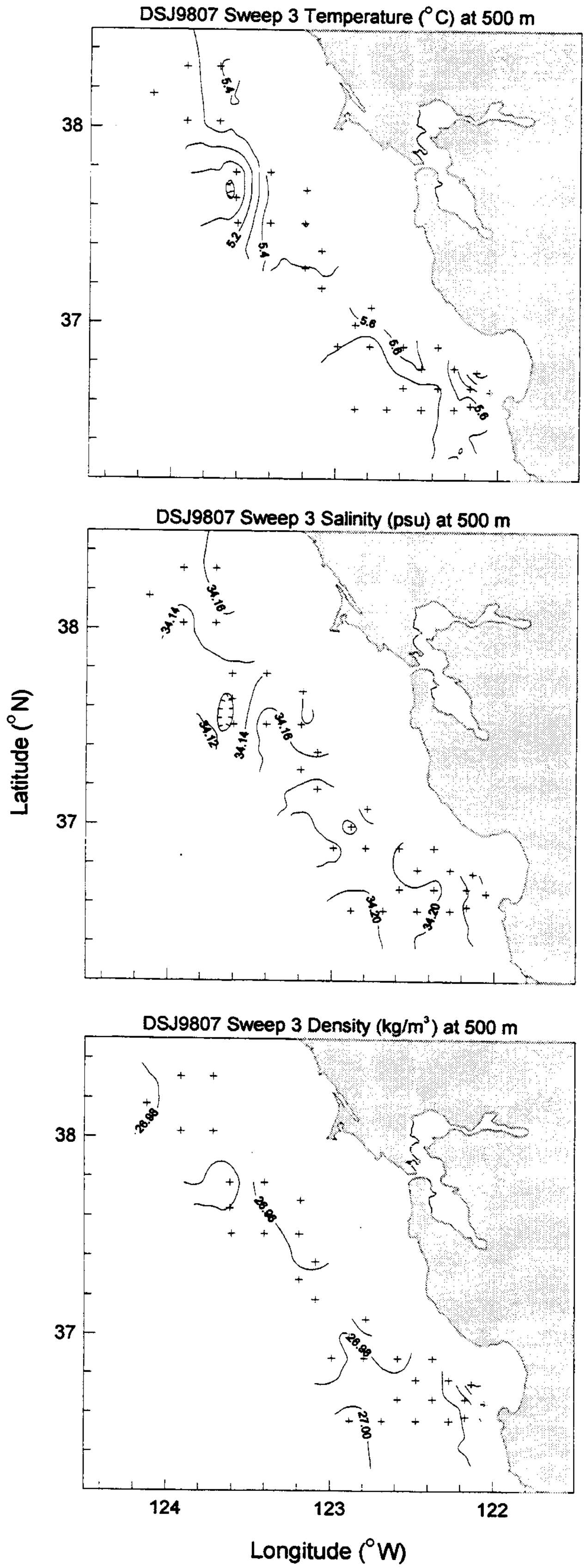

DSJ9807 Sweep 3 Temperature (°C) at 10 m
DSJ9807 Sweep 3 Salinity (psu) at 10 m
DSJ9807 Sweep 3 Density (kg/m³) at 10 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)


DSJ9807 Sweep 3 Temperature (°C) at 30 m
DSJ9807 Sweep 3 Salinity (psu) at 30 m
DSJ9807 Sweep 3 Density (kg/m³) at 30 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)


DSJ9807 Sweep 3 Temperature (°C) at 100 m
DSJ9807 Sweep 3 Salinity (psu) at 100 m
DSJ9807 Sweep 3 Density (kg/m³) at 100 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)
10
9
33.6
33.4
33.8
25.8
26.0
26.2

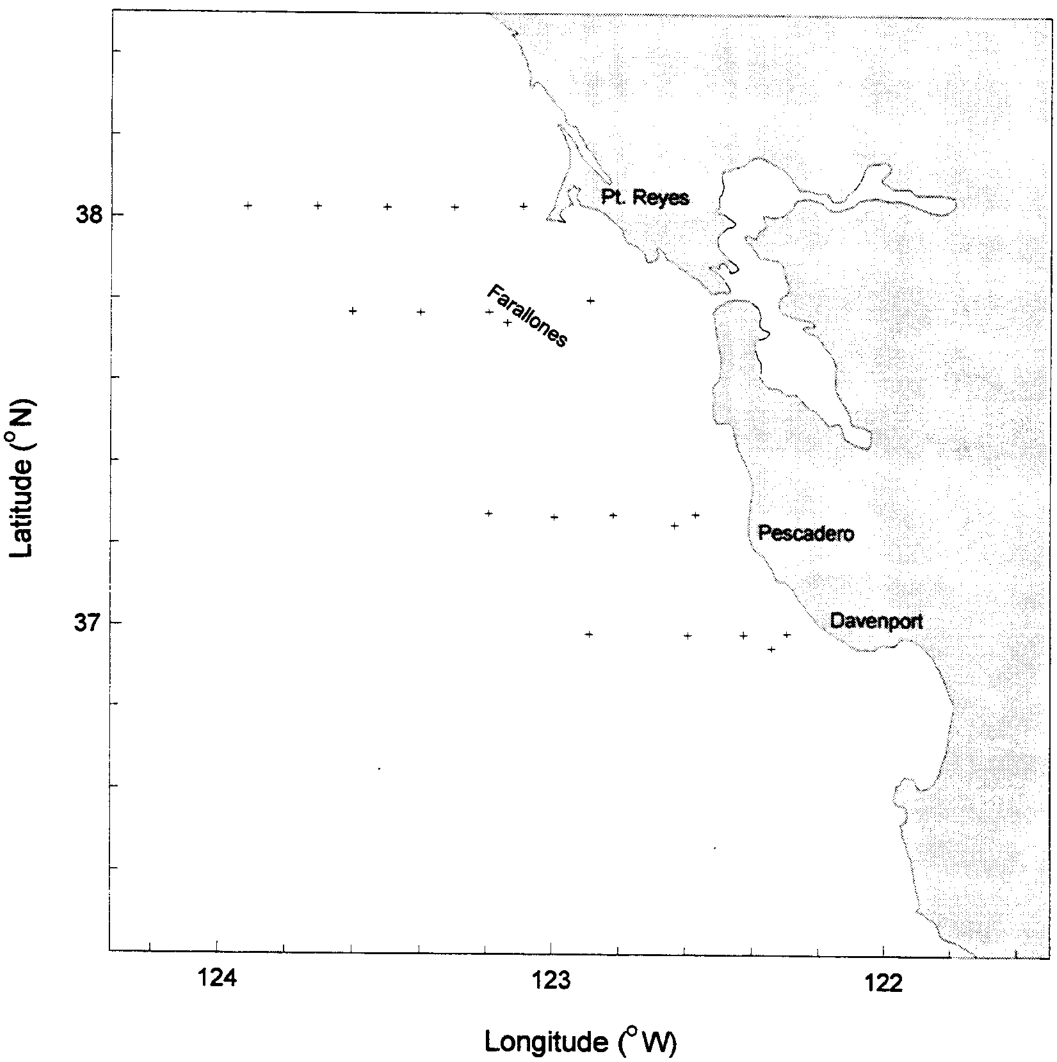

DSJ9807 Sweep 3 Temperature (°C) at 200 m
DSJ9807 Sweep 3 Salinity (psu) at 200 m
DSJ9807 Sweep 3 Density (kg/m³) at 200 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

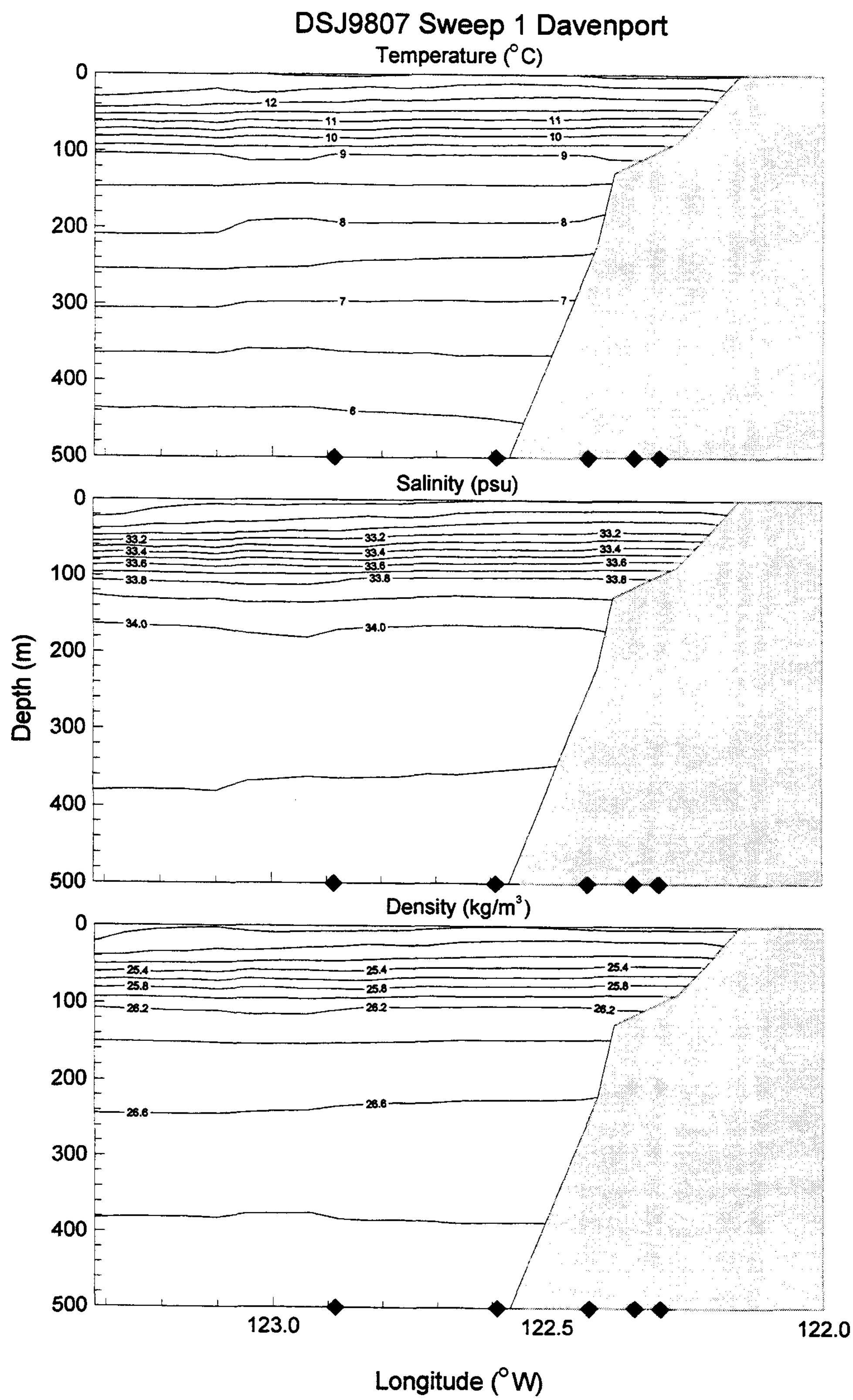

DSJ9807 Sweep 3 Temperature (°C) at 300 m
DSJ9807 Sweep 3 Salinity (psu) at 300 m
DSJ9807 Sweep 3 Density (kg/m³) at 300 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)


DSJ9807 Sweep 3 Temperature (°C) at 500 m
DSJ9807 Sweep 3 Salinity (psu) at 500 m
DSJ9807 Sweep 3 Density (kg/m³) at 500 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

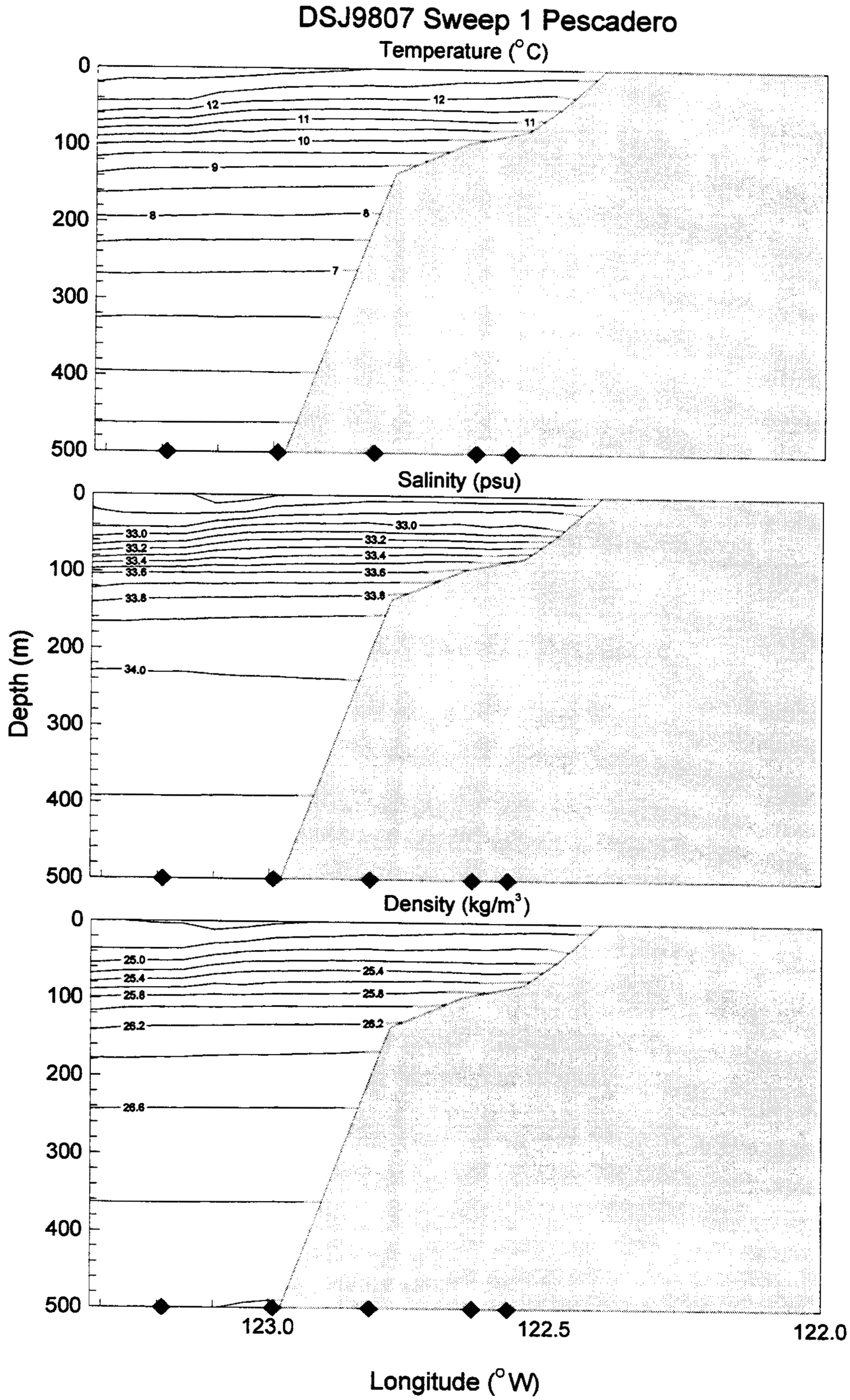
APPENDIX 7: VERTICAL SECTIONS FOR DSJ9807

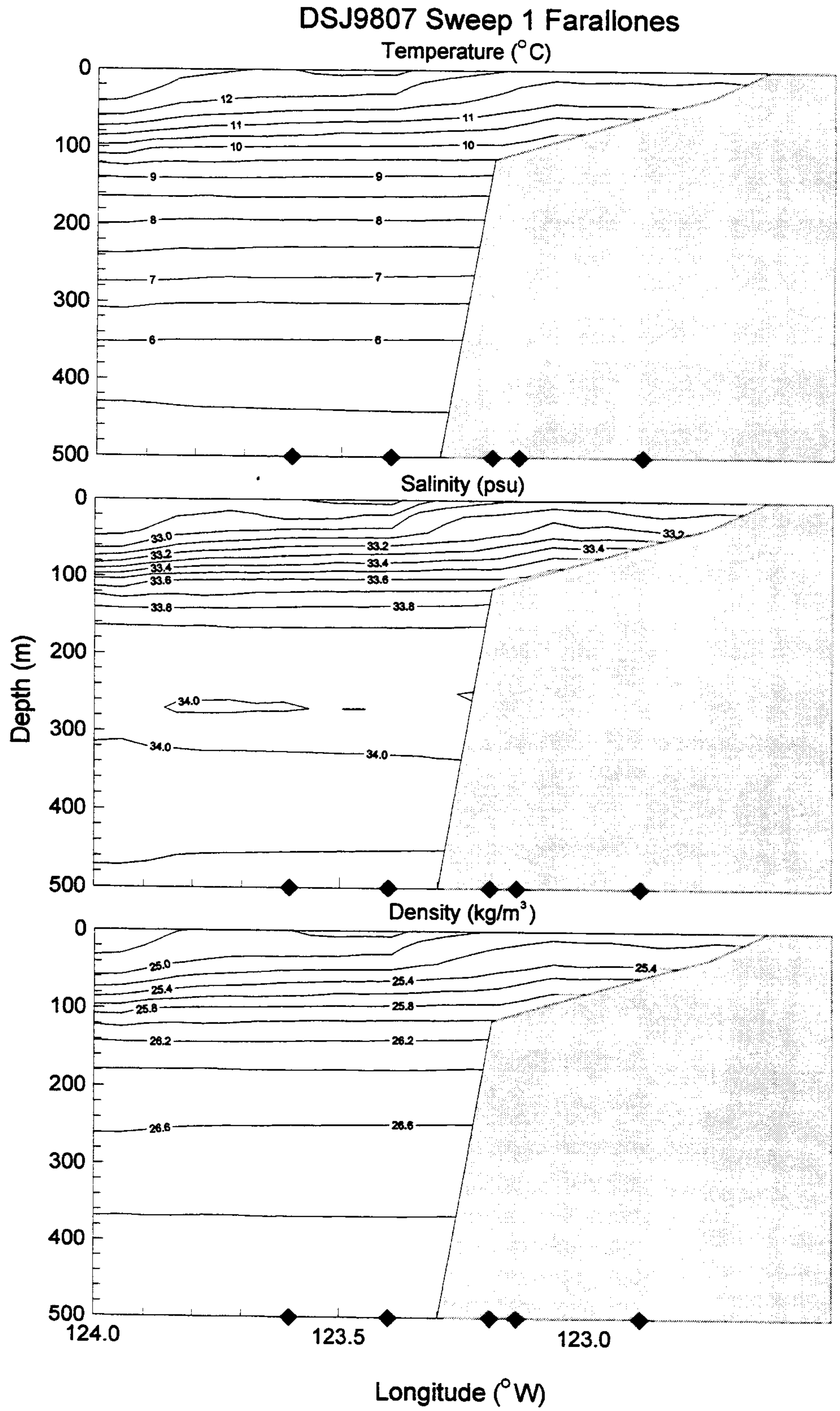
DSJ9807 Sweep 1 Vertical Transect Stations

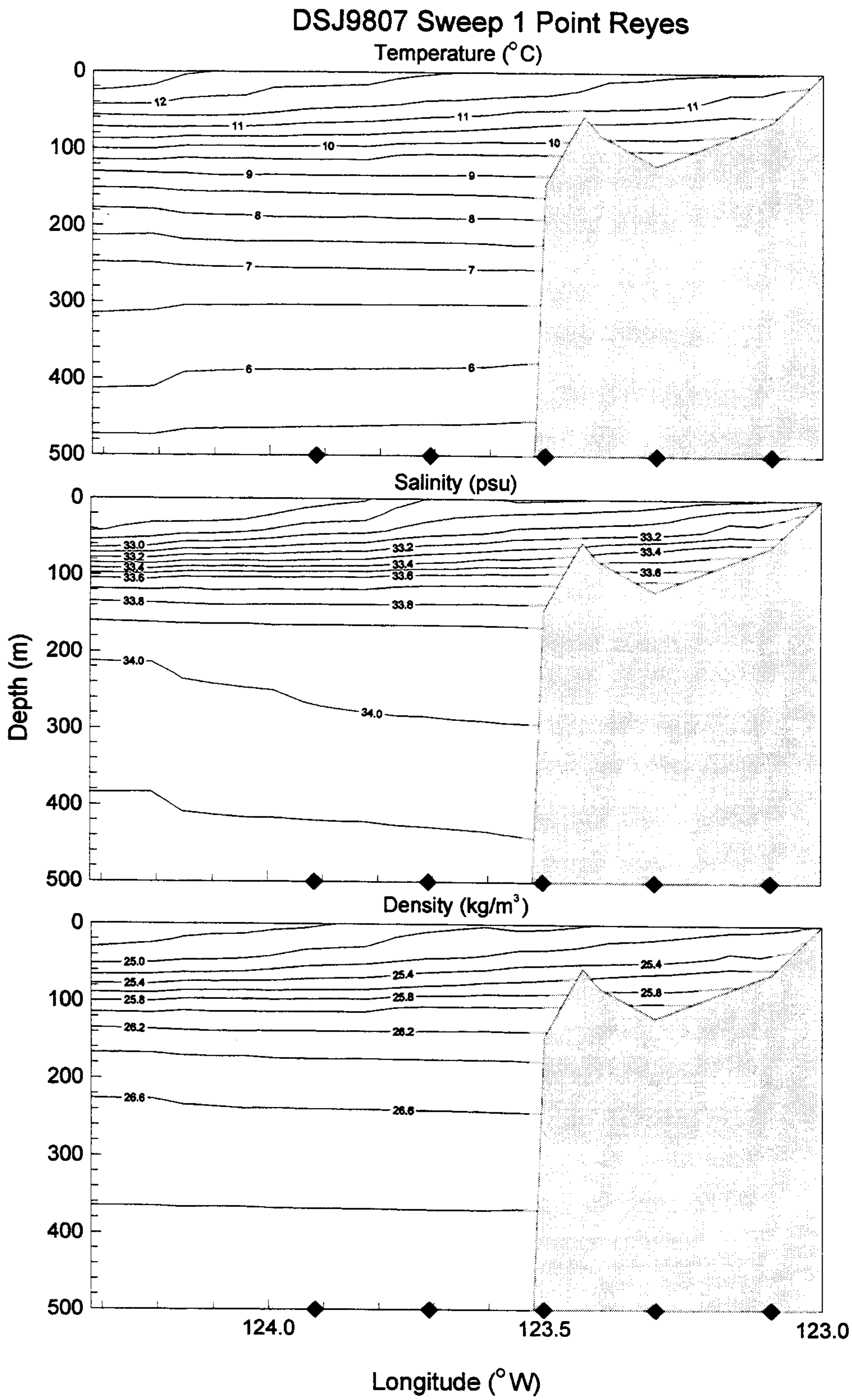




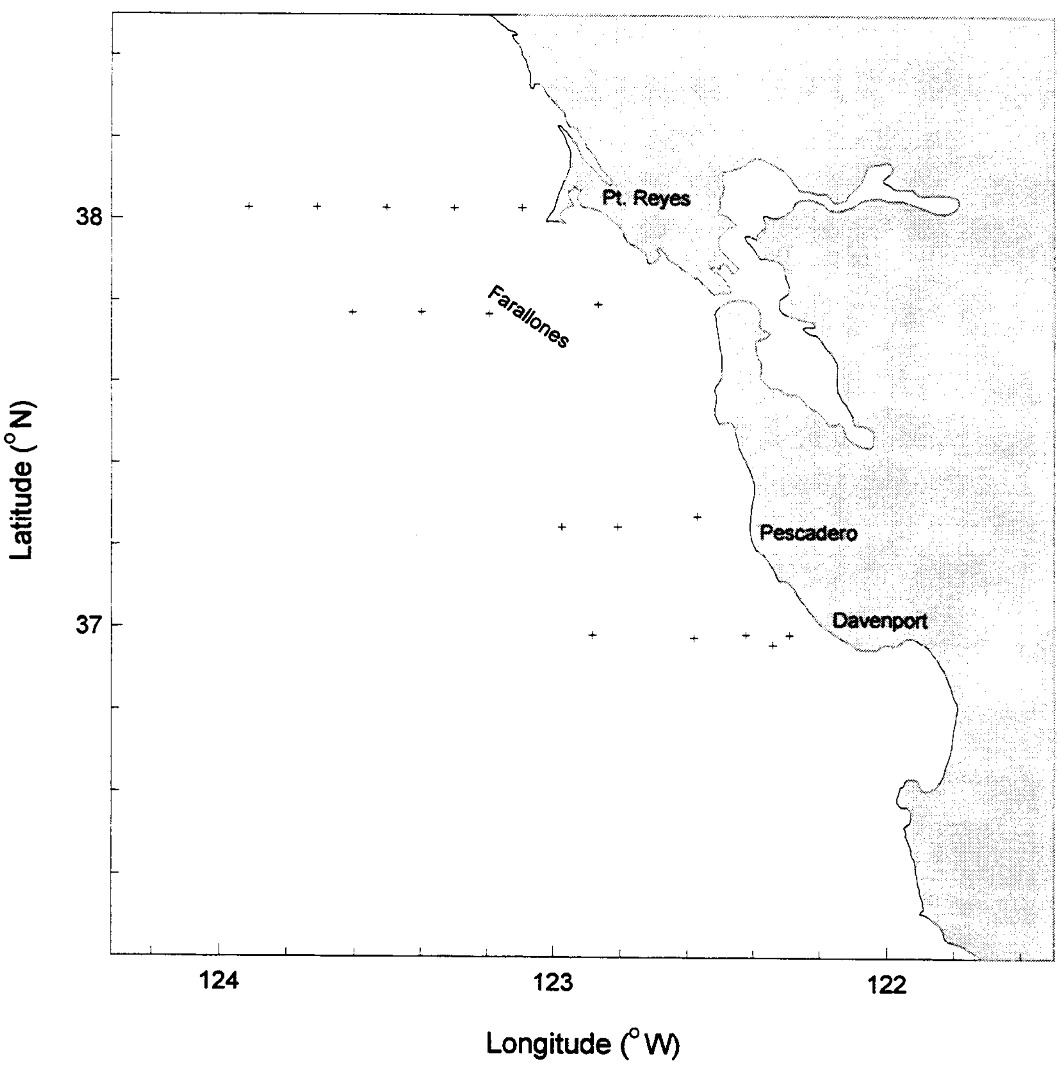
DSJ9807 Sweep 1 Davenport
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
123.0
122.5
122.0
12
11
10
9
8
7
6
33.2
33.4
33.6
33.8
34.0
25.4
25.8
26.2
26.6

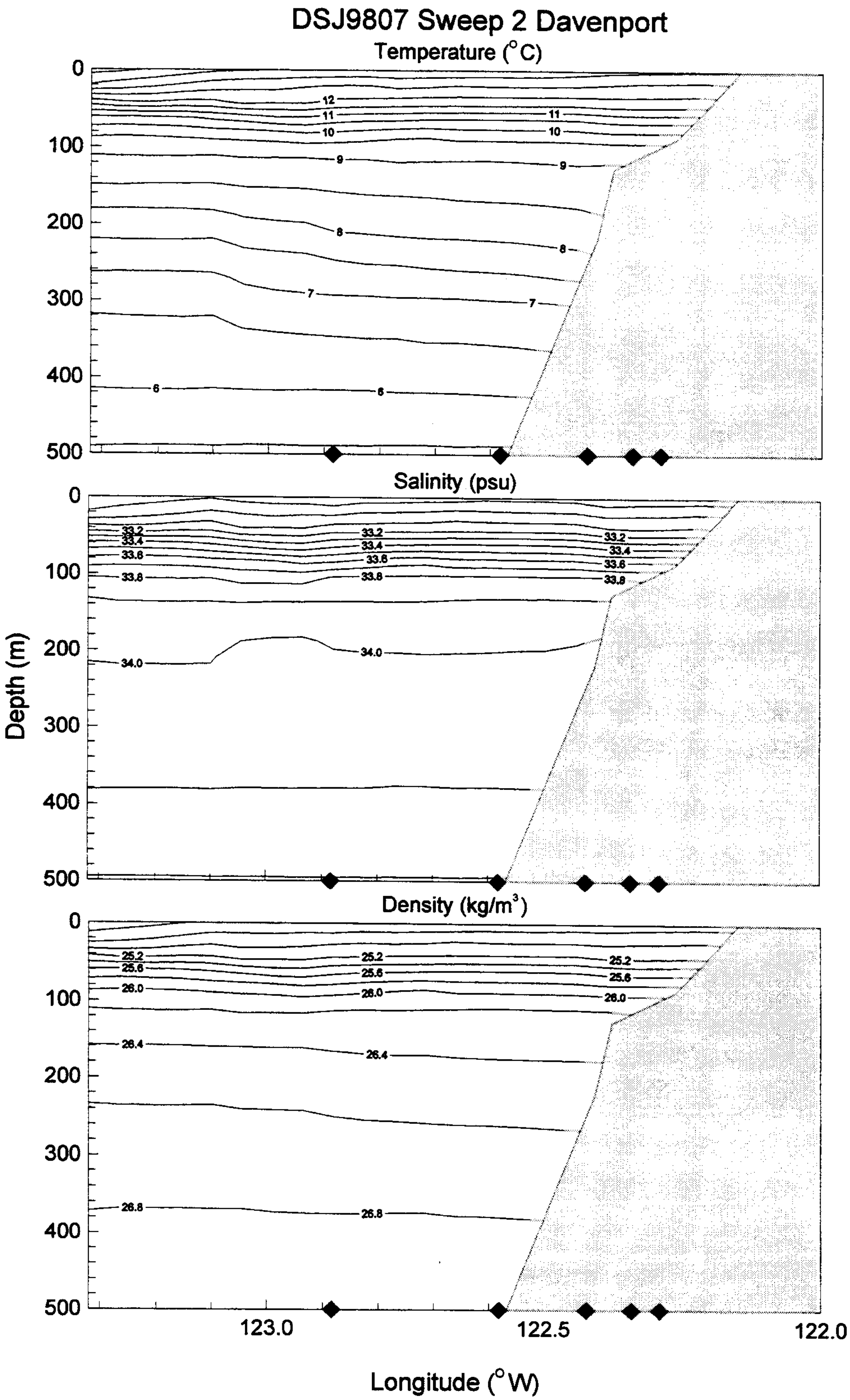

DSJ9807 Sweep 1 Pescadero
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
123.0
122.5
122.0
0
100
200
300
400
500
12
11
10
9
8
7
33.0
33.2
33.4
33.6
33.8
34.0
25.0
25.4
25.8
26.2
26.6

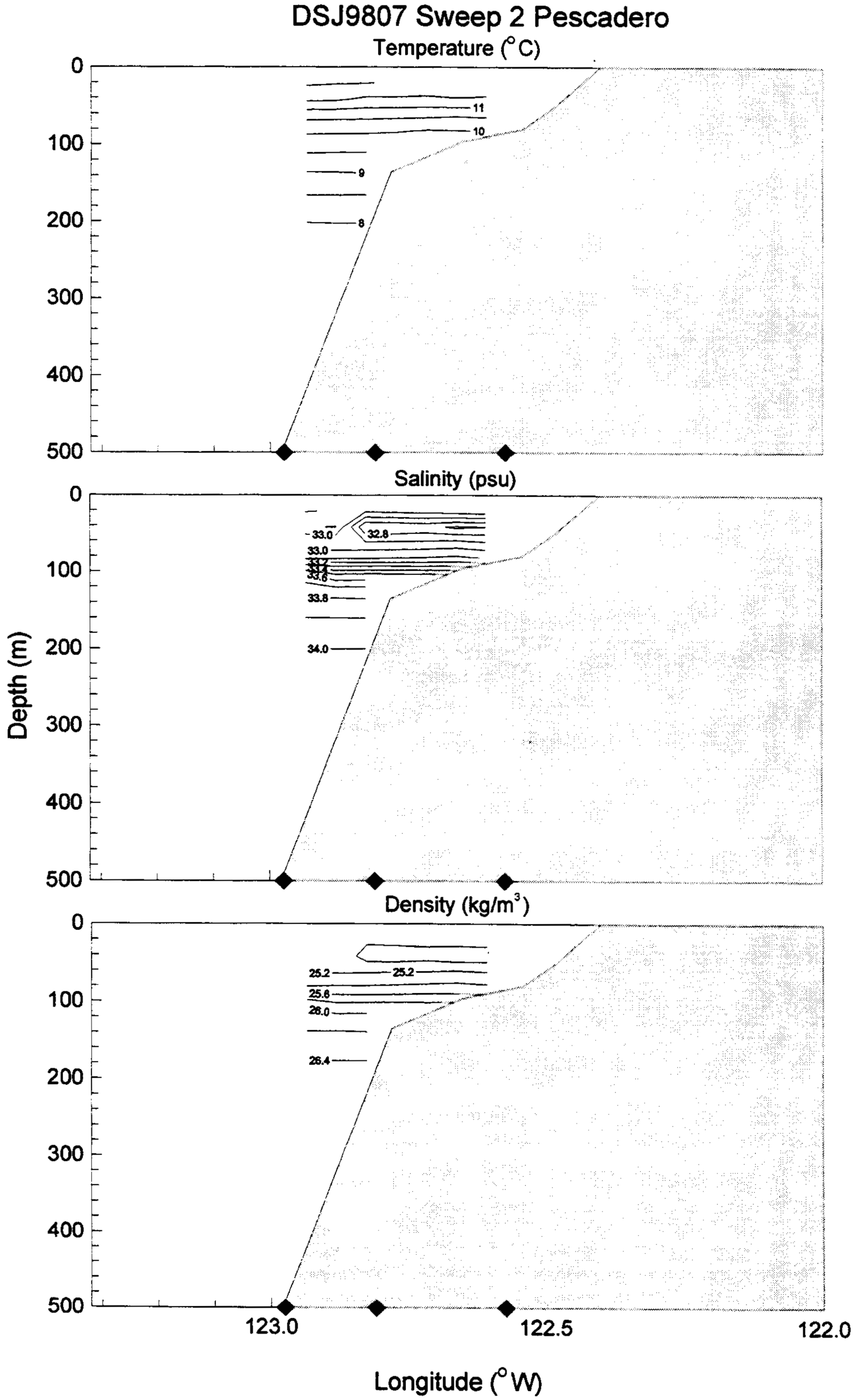

DSJ9807 Sweep 1 Farallones
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
124.0
123.5
123.0
0
100
200
300
400
500
12
11
10
9
8
7
6
33.0
33.2
33.4
33.6
33.8
34.0
25.0
25.4
25.8
26.2
26.6

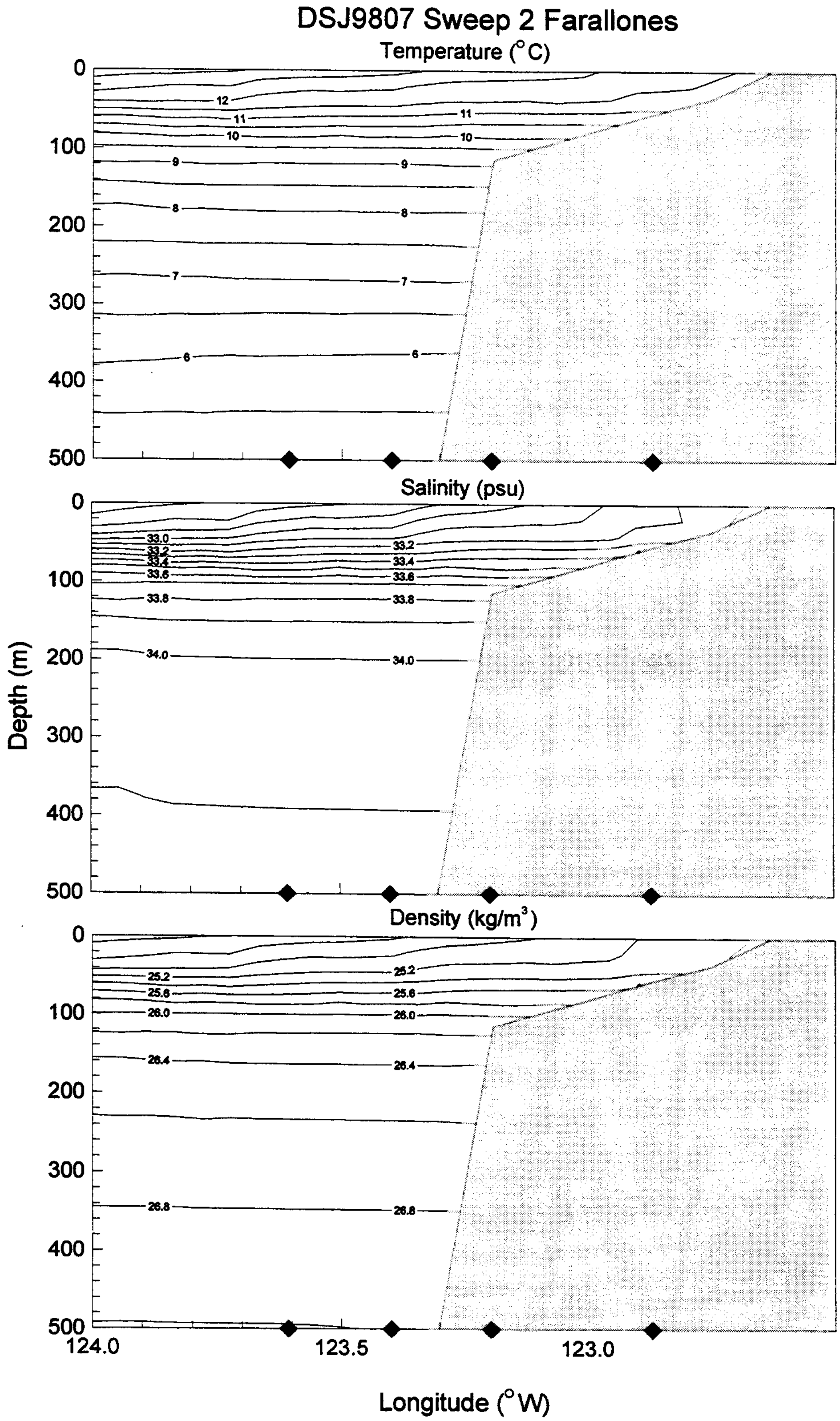

DSJ9807 Sweep 1 Point Reyes
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
124.0
123.5
123.0
0
100
200
300
400
500

DSJ9807 Sweep 2 Vertical Transect Stations

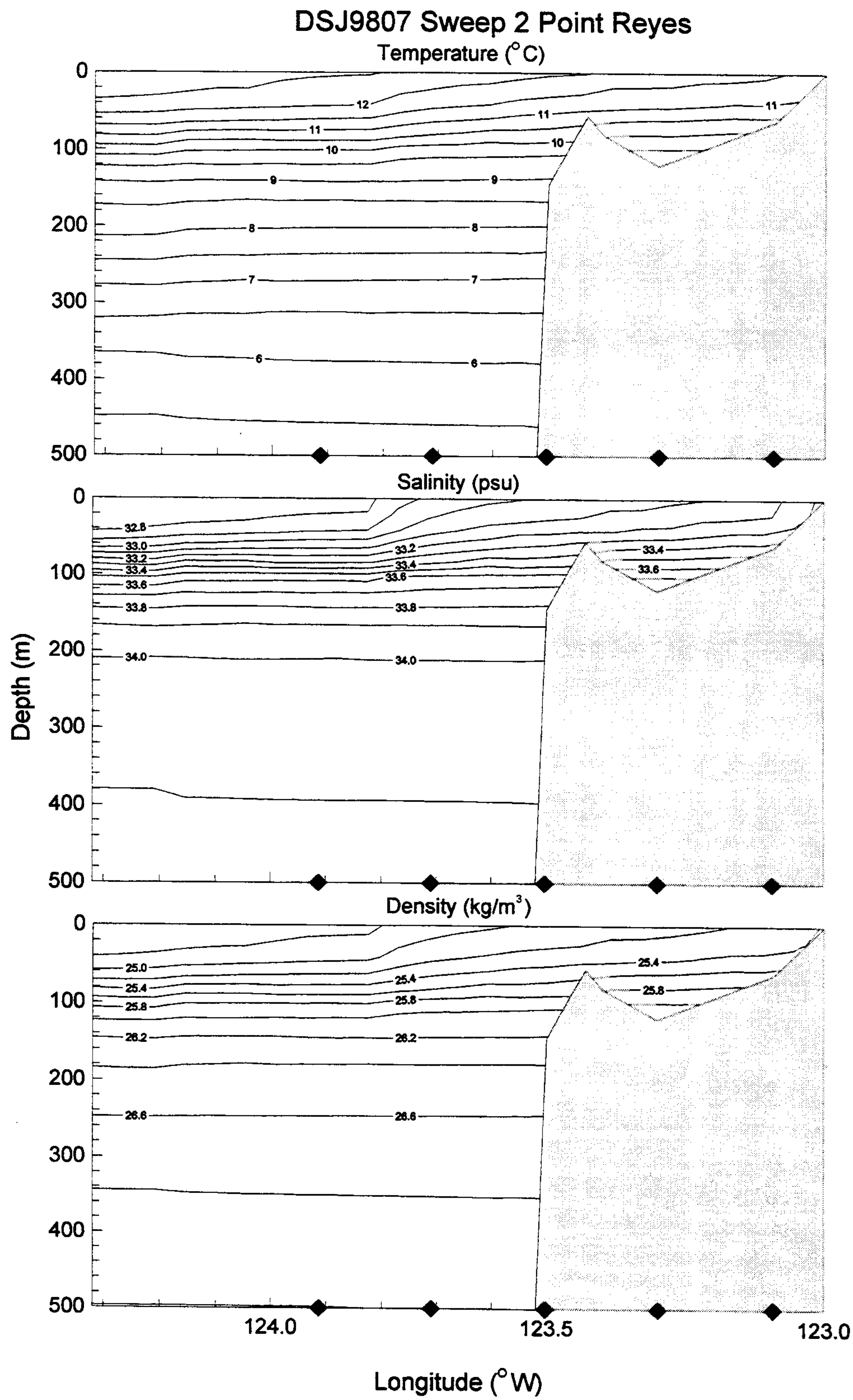



DSJ9807 Sweep 2 Davenport
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
0
100
200
300
400
500
123.0
122.5
122.0
Longitude (°W)

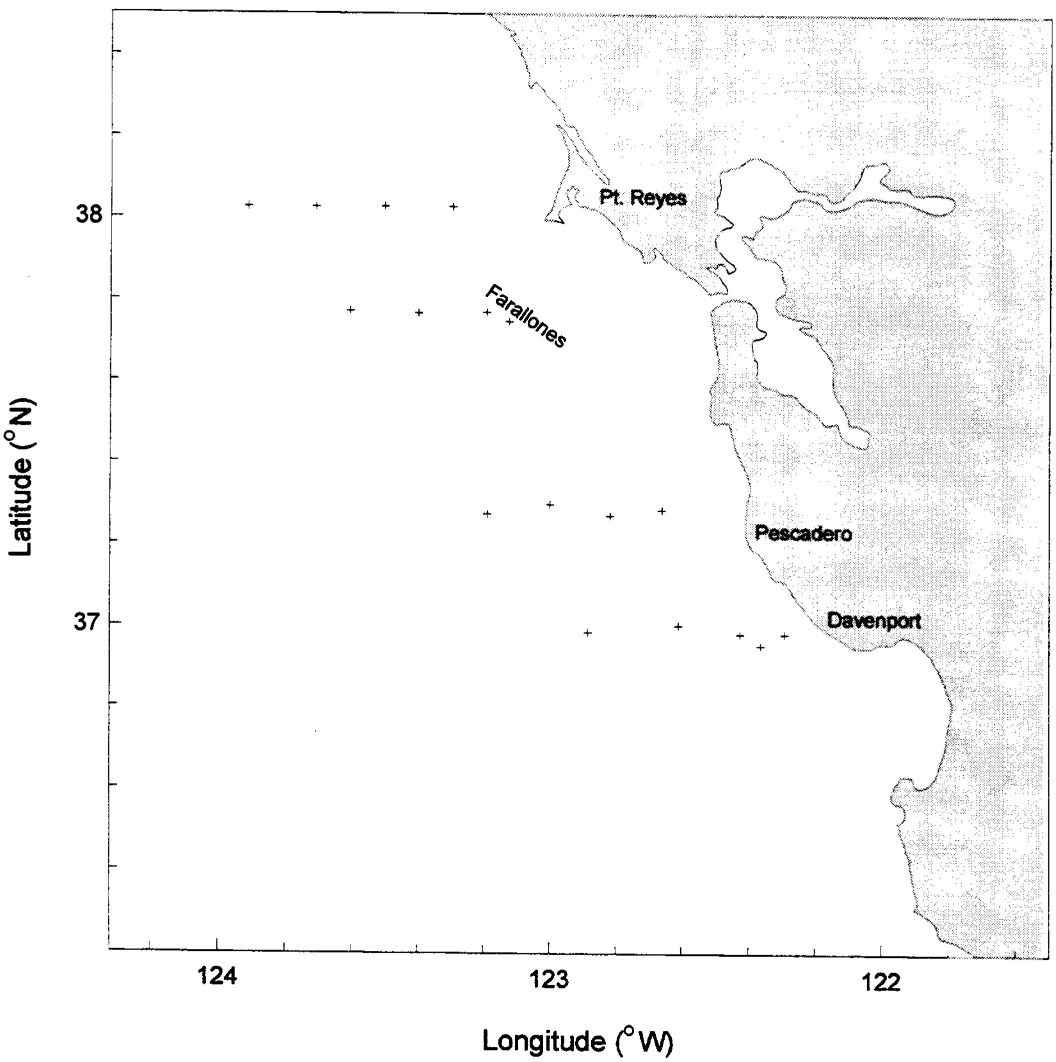

DSJ9807 Sweep 2 Pescadero
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
123.0
122.5
122.0
0
100
200
300
400
500
11
10
9
8
33.0
32.8
33.8
34.0
25.2
25.6
26.0
26.4



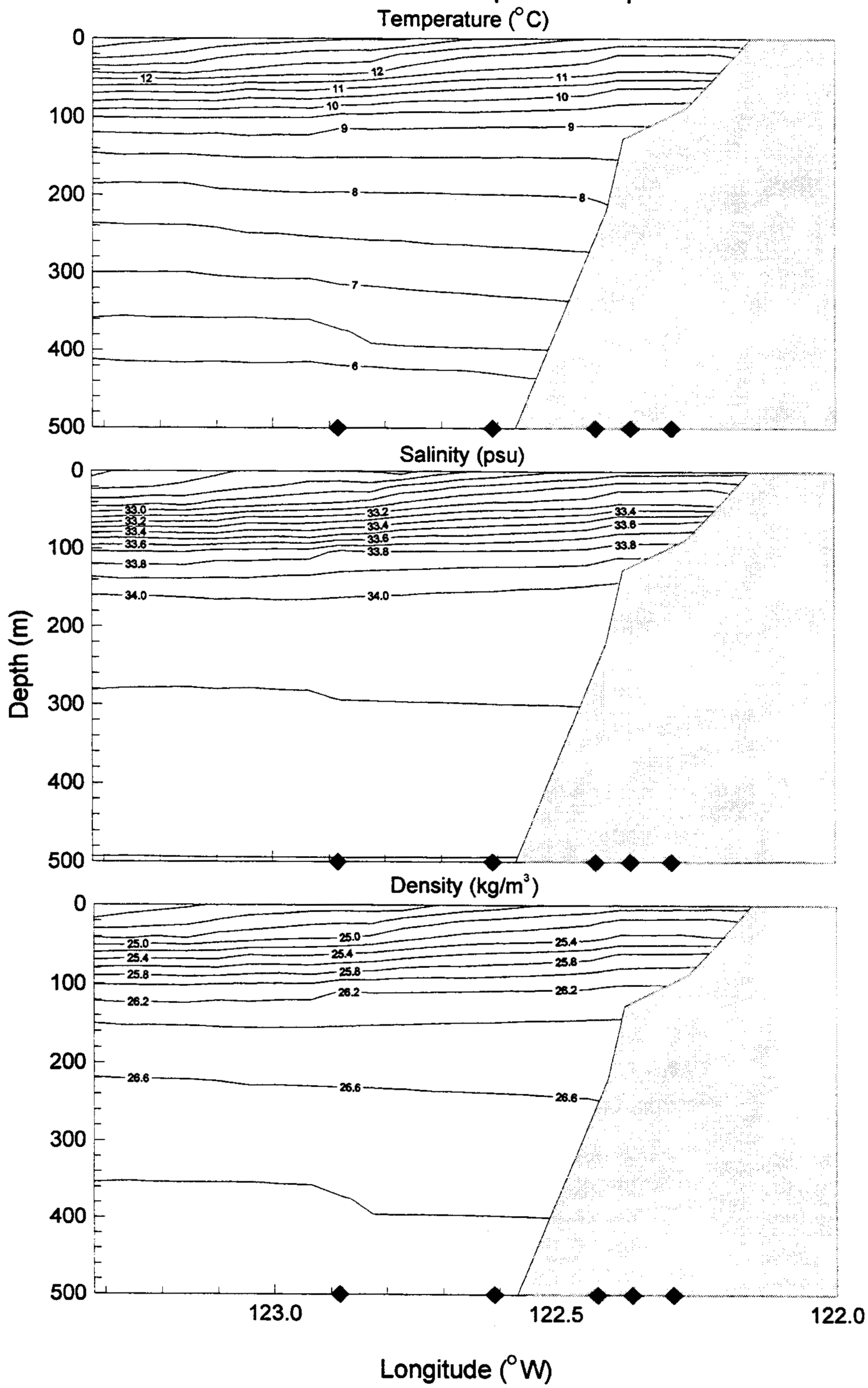
DSJ9807 Sweep 2 Farallones
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
124.0
123.5
123.0
0
100
200
300
400
500
12
11
10
9
8
7
6
33.0
33.2
33.4
33.6
33.8
34.0
25.2
25.6
26.0
26.4
26.8

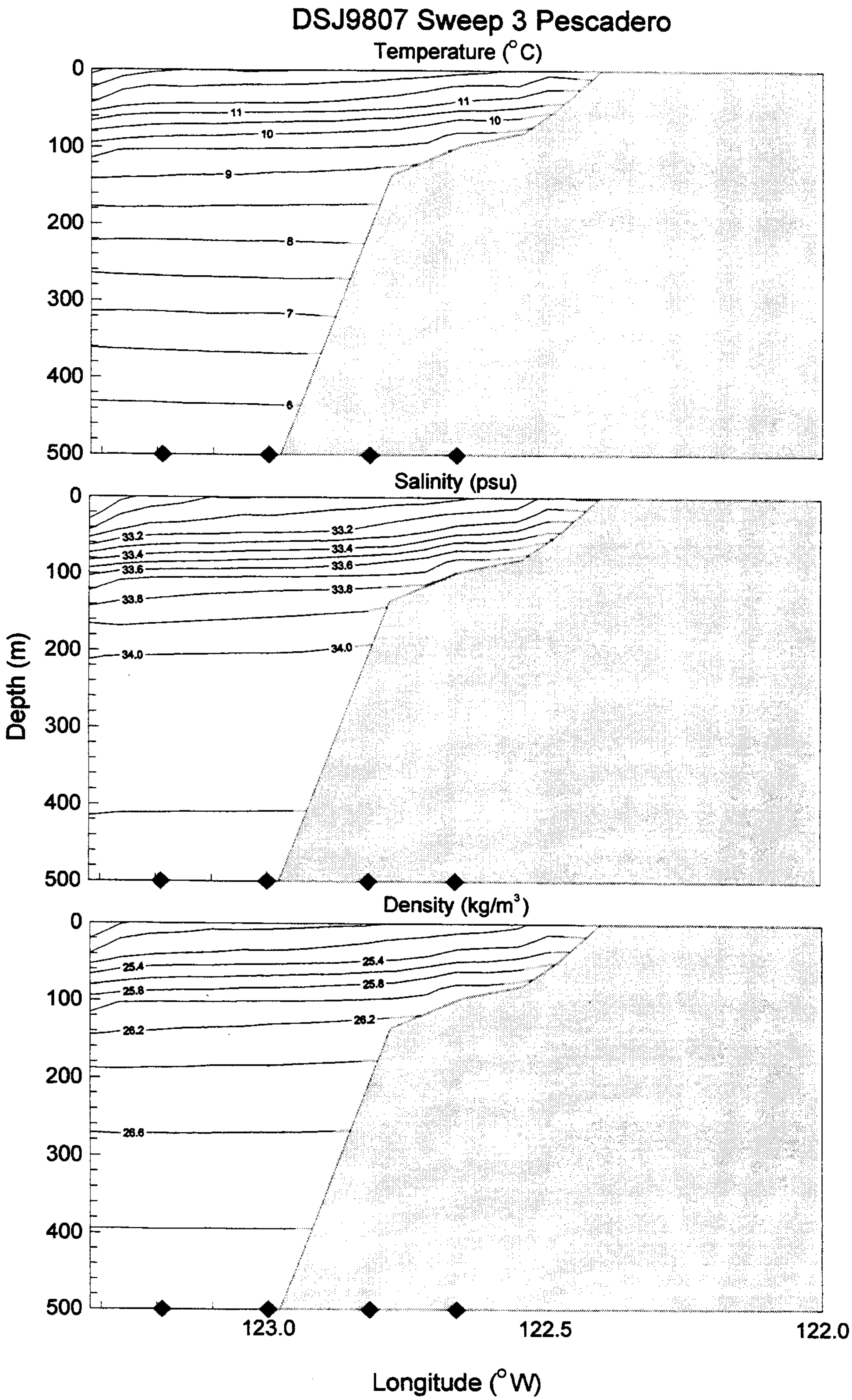

DSJ9807 Sweep 2 Point Reyes
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
124.0
123.5
123.0
0
100
200
300
400
500
12
11
10
9
8
7
6
32.8
33.0
33.2
33.4
33.6
33.8
34.0
25.0
25.4
25.8
26.2
26.6

DSJ9807 Sweep 3 Vertical Transect Stations

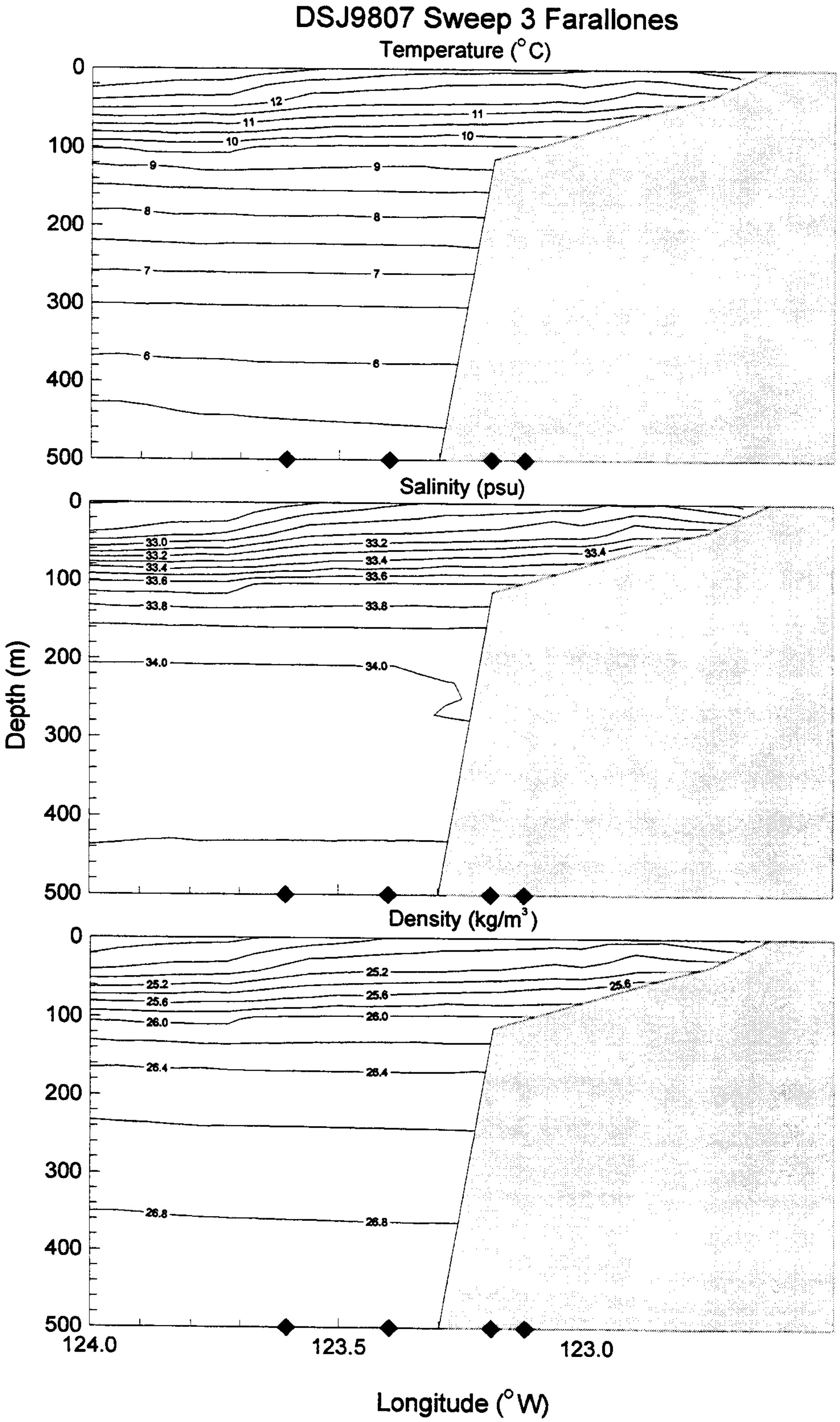


DSJ9807 Sweep 3 Davenport

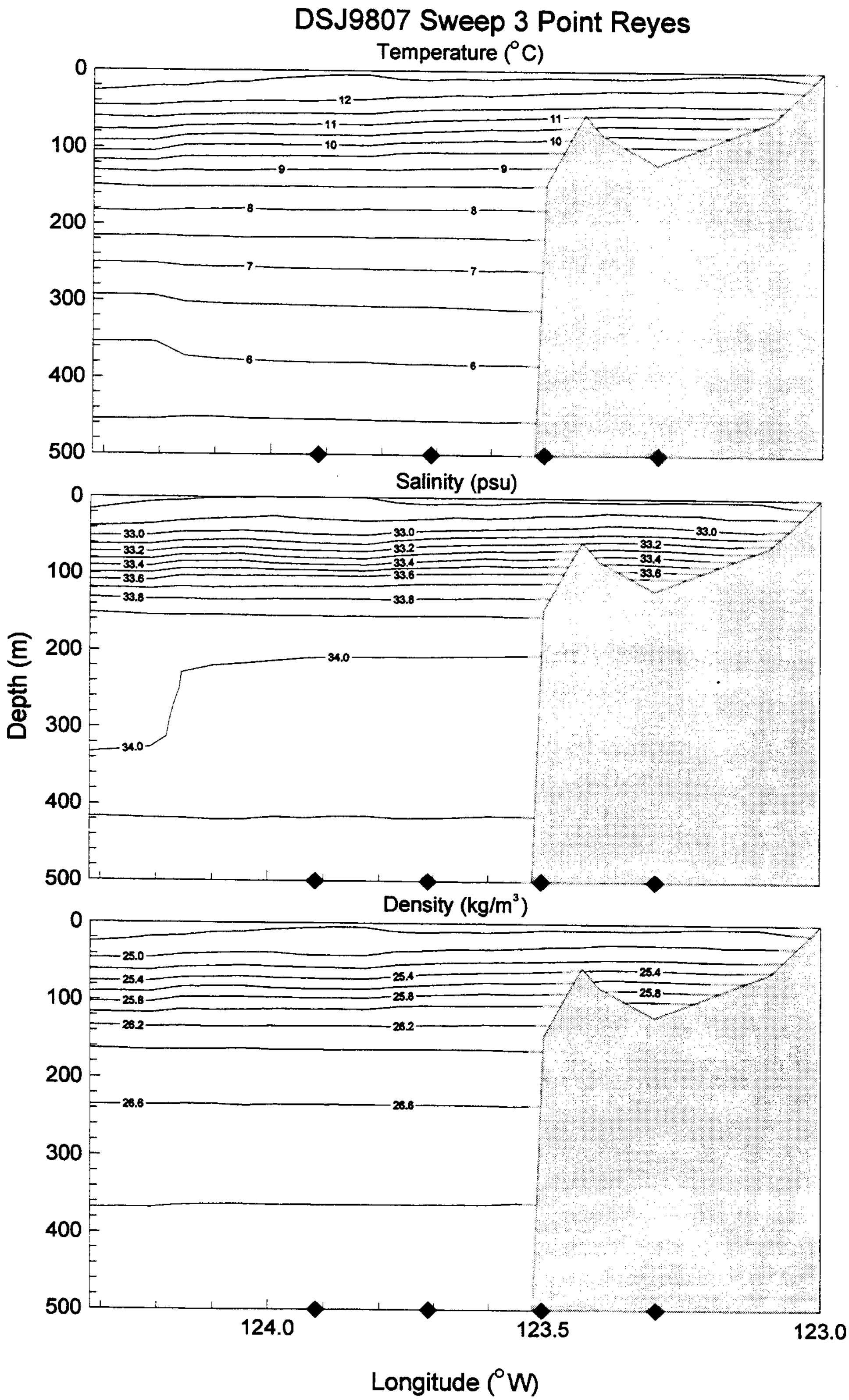




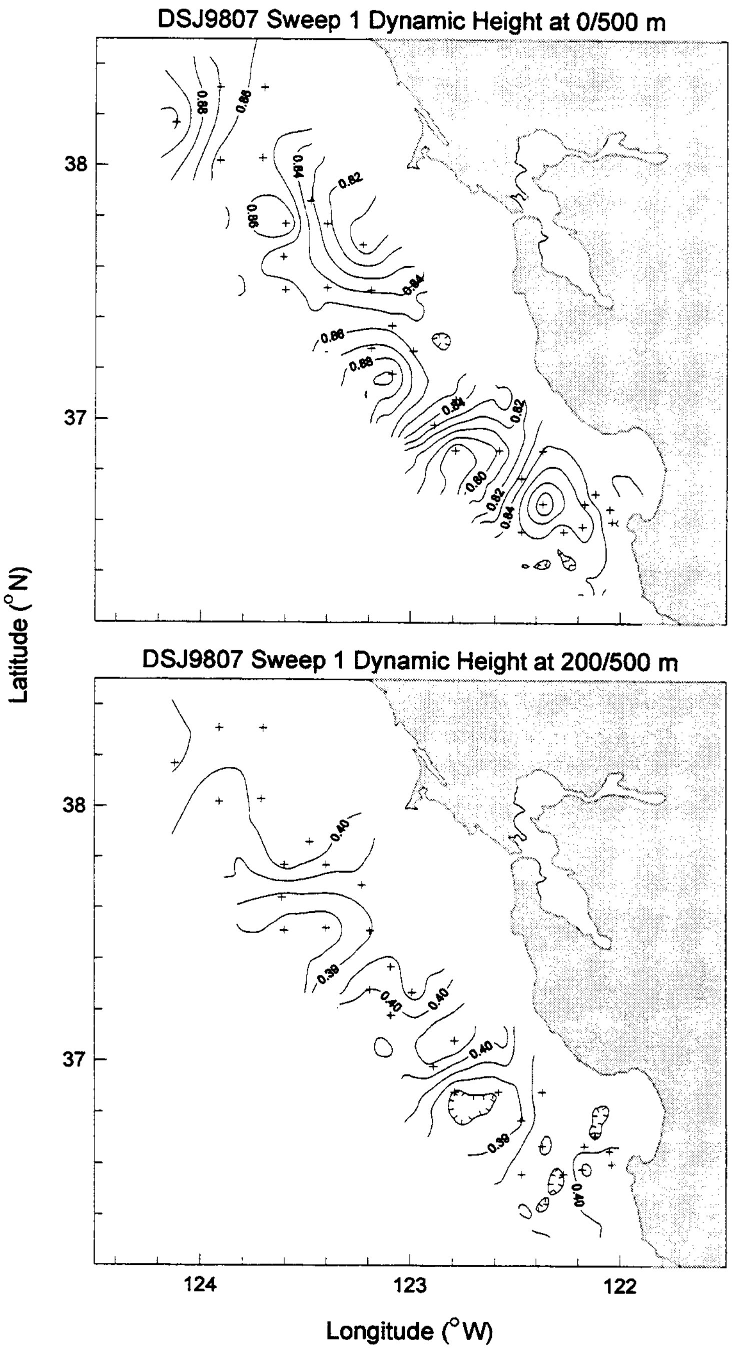
DSJ9807 Sweep 3 Pescadero
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
123.0
122.5
122.0
11
10
9
8
7
6
33.2
33.4
33.6
33.8
34.0
25.4
25.8
26.2
26.6

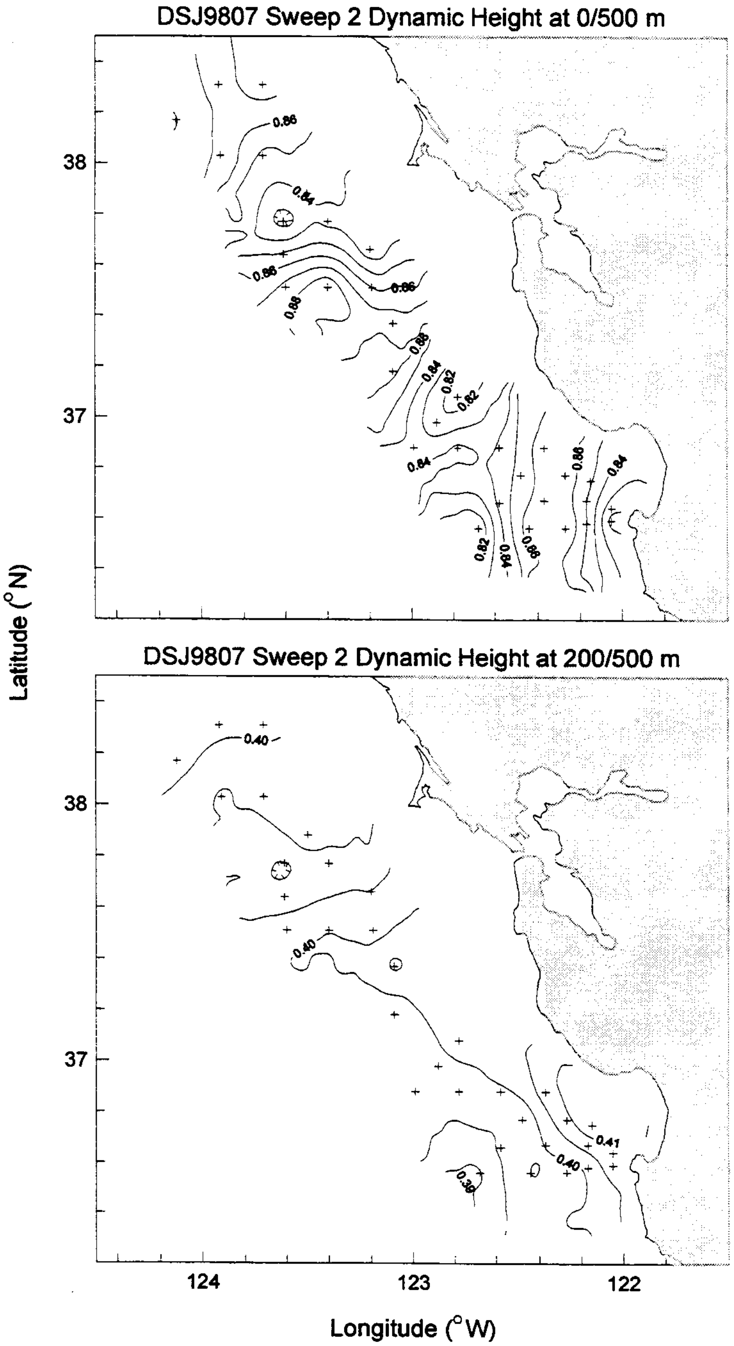


DSJ9807 Sweep 3 Farallones
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
124.0
123.5
123.0
12
11
10
9
8
7
6
33.0
33.2
33.4
33.6
33.8
34.0
25.2
25.6
26.0
26.4
26.8


DSJ9807 Sweep 3 Point Reyes
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
124.0
123.5
123.0
0
100
200
300
400
500
12
11
10
9
8
7
6
33.0
33.2
33.4
33.6
33.8
34.0
25.0
25.4
25.8
26.2
26.6

APPENDIX 8: DYNAMIC HEIGHT TOPOGRAPHY FOR DSJ9807


DSJ9807 Sweep 1 Dynamic Height at 0/500 m
0.88
0.86
0.84
0.82
0.86
0.84
0.86
0.88
0.84
0.82
0.80
0.82
0.84
DSJ9807 Sweep 1 Dynamic Height at 200/500 m
0.40
0.39
0.40
0.40
0.40
0.39
0.40
38
37
Latitude (°N)
124
123
122
Longitude (°W)


DSJ9807 Sweep 2 Dynamic Height at 0/500 m
DSJ9807 Sweep 2 Dynamic Height at 200/500 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
0.86
0.84
0.82
0.88
0.40
0.41
0.39

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