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THE PHYSICAL OCEANOGRAPHY OFF THE CENTRAL CALIFORNIA COAST DURING MAY-JUNE 2001: A SUMMARY OF CTD AND OTHER HYDROGRAPHIC DATA FROM YOUNG OF THE YEAR JUVENILE ROCKFISH SURVEYS

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NOAA-TM-NMFS-SWFSC-395

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ABSTRACT

Hydrographic conditions from mid-May through mid-June 2001 in the coastal ocean bounded by Cypress Pt. (Latitude 36°35'N) and Pt. Reyes, California (Latitude 38°10'N), and from the coast to approximately 75 km offshore, are summarized. A total of 273 standard conductivity-temperature-depth (CTD) casts were obtained during the annual young-of-the-year (YOY) juvenile rockfish survey aboard the NOAA R/V *David Starr Jordan* during cruise DSJ0103 over the course of three replicate sweeps (approximately 10 days each) of the survey region. Data products contained in this report include (1) a master list of CTD deployment locations during the survey; (2) surface wind and ocean temperatures time series from the region's four National Data Buoy Center (NDBC) buoys; (3) horizontal maps of sea surface temperatures (SST) from Advanced Very High Resolution Radiometer (AVHRR) satellite images; (4) CTD mean temperature versus mean salinity upon density at the depths of 10 m, 30 m, 50 m, 100 m, 200 m, 300 m, and 500 m; (5) horizontal maps of temperature, salinity, and density (sigma-theta [Φ_2]) at depths of 2 m, 10 m, 30 m, 100 m, 200 m, 300 m, and 500 m; (6) temperature, salinity and density along four cross-shelf vertical transects; (7) dynamic height topography (0/500 m and 200/500 m); and (8) Integrated chlorophyll (0-50 m). A temporal-spatial synopsis of oceanographic conditions within the survey region, based on these data products, is also presented. Anomalously dense water was observed during DSJ0103, especially in the upper 200 m, coincident with strong upwelling conditions, which brought deeper saltier, colder water to the surface. CTD salinities for DSJ0103 were higher, for all depths to 500 m, than all 15 previous annual YOY juvenile rockfish surveys conducted during the May-June period off central California. Significant shoaling of isopycnals and isotherms occurred near shore in the northern areas of the survey region. Overall concentrations of integrated chlorophyll from 0 to 50 m depth were highly variable from sweep to sweep, and showed significant patchiness during individual sweeps. Patchiness of chlorophyll in the survey region resembled mesoscale eddies, in the near-surface horizontal and vertical scales.

INTRODUCTION

The current oceanographic 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 & 1998), 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 Service (NMFS), Southwest Fisheries Science Center's (SWFSC), Fisheries Ecology Division has developed a recruitment index for young-of-the-year (YOY) juvenile rockfish (*Sebastes* spp.) within the region off central California. Annual YOY 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 YOY juvenile rockfish 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 and recreationally important species (e.g., widow rockfish, *Sebastes 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 YOY juvenile rockfish/tow (Adams 1995[1]).

Since a basic description of the physical environment is necessary to better understand the distribution and abundance of YOY juvenile rockfish, collection of conductivity-temperature-depth (CTD) data was initiated in 1987 as part of the NMFS SWFSC Fisheries Ecology Division's annual YOY juvenile rockfish surveys. The staff of the NMFS SWFSC Environmental Research Division and the NMFS SWFSC Fisheries Ecology Division subsequently began analyzing the CTD data to assist in this recruitment fisheries oceanography study. The ultimate goals have been 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 2001. Due to the large quantity of data analyzed and the extensive array of results presented herein, we do not attempt to provide detailed interpretations of our findings. Reports covering the juvenile rockfish surveys of 1988 (DSJ8804 and DSJ8806), 1989 (DSJ8904), 1990 (DSJ9003 and DSJ9005), 1991 (DSJ9102 and DSJ9105), 1992 (DSJ9203 and DSJ9206), 1993 (DSJ9304 and DSJ9307), 1994 (DSJ9403 and DSJ9406), 1995 (DSJ9506), 1996 (DSJ9606), 1997 (DSJ9707), 1998 (DSJ9807), 1999 (DSJ9903), and 2000 (DSJ0002) 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, Sakuma et al. 1999, Sakuma et al. 2000, Sakuma et al. 2001, Sakuma et al. 2002). A companion volume (Schwing and Ralston 1990[2]) contains individual traces of temperature, salinity, and sigma-t (Φ_t, a representation of water density) plotted against depth for each CTD cast conducted in 1989.

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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

NDBC Data

Surface data were obtained from four NOAA National Data Buoy Center (NDBC) moored buoys located within the YOY juvenile rockfish survey region. These four buoys are 46013 (Bodega Bay; 38^{o}12'N, 123^{o}18'W), 46026 (Gulf of the Farallones; 37^{o}48'N, 122^{o}42'W), 46012 (Half Moon Bay; 37^{o}24'N, 122^{o}42'W) and 46042 (Monterey Bay; 36^{o}48'N, 122^{o}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 (Baltz 1997).

Annual climatologies and variances were determined for SST and the alongshore wind component at each buoy with a biharmonic analysis of all daily mean data over most of the buoy's entire operating period. These operating periods were 1981 to 2000 for buoy 46013, 1982 to 2000 for buoy 46026, 1981 to 2000 for buoy 46012, and 1987 to 2000 for buoy 46042. The annual cycles were estimated by a least squares regression of the data to an annual and semiannual harmonic signal:

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

t = Julian Day/365
A_i and B_i = 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 (Baltz 1997).

SST Data from AVHRR Satellite Imagery

Advanced Very High Resolution Radiometer (AVHRR) products were generated by the NOAA CoastWatch Group in California. SSTs were derived from 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. In 2000, the NOAA CoastWatch Group began producing 5 night composite images, which could be scaled and downloaded directly from their website (HTTP://COASTWATCH.PFEL.NOAA.GOV/) in JPG format. These images were created using the images from the last 5 nights to obtain a median composite. The 5 night composite images were selected over the daily images, which were used in the past, as these were more comparable in temporal scale to the juvenile rockfish survey design. All images, which were clear or relatively clear of clouds/fog during the survey period were saved on a PC and stored at the NMFS SWFSC Fisheries Ecology Division as part of the oceanographic database system.

YOY Juvenile Rockfish Survey Design

Annual surveys aboard the NOAA R/V DSJ began in 1983 and have been conducted during late spring (April-June), a time when many pelagic-stage YOY juvenile rockfishes are identifiable to species, but prior to settlement to nearshore and benthic habitats. Standard 15-minute tow using a midwater trawl set to a headrope depth of 30 m, were conducted at night. Additional tows were made at other depths (i.e. 7 m and 100 m) as determined by time and bathymetry constraints. The survey summarized in this report was conducted during May and June of 2001 and designated as DSJ0103.

In 1986, the sampling design was altered to permit three consecutive "sweeps" through the area bounded by Cypress Pt. (36^{o}35'N) and Pt. Reyes (38^{o}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 in 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 repeated during each sweep of each survey. CTD cast locations that were only specific to a particular sweep during a survey 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. Additional discretionary sampling typically was focused on specific bathymetric features, such as Cordell Bank or Pioneer Canyon, or devoted to the study of oceanic features or processes that may be key to successful recruitment. CTD casts conducted during additional discretionary sampling were not included in the grid of standard CTD stations used in this report.

Collection of CTD Data and Chlorophyll Samples at Sea

CTD data from DSJ0103 presented in this report was collected with a Sea-Bird Electronics, Inc. (SBE), SEACAT-SBE-19 profiler mounted on an SBE-32 water sampler carousel, which interfaced via conducting cable to a SBE-33 deck unit[3]. This allowed for real-time data acquisition. This particular unit was rated to a depth of 600 m and contained 256K of memory and sampled at a rate of 2 Hz. 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 ^{o}C from -5 to +35 ^{o}C), conductivity (0.001 S/m from 0 to 7 S/m), and fluorometer voltage. The temperature, conductivity, and pressure sensors of the CTD profiler were calibrated annually by SBE, prior, to use at sea. The CTD fluorometers were also calibrated annually by WETLabs, Inc., prior, to use aboard the ship.

During deployment, the vessel was brought to a dead stop and the SBE-19 profiler attached to the SBE-32 carousel 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 or down to a maximum depth of 500 m, whichever was shallowest. 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 survey-specific consecutive index number, (5) the trawl station number (when appropriate), (6) latitude, (7) longitude, (8) bucket temperature (temperature [^{o}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 portable salinometer), and (10) bottom depth in meters. In addition, during the upcast, water samples from the chlorophyll maximum layer and two other discreet depths were collected at least twice every 24 hours (using the Niskin bottles attached to the SBE-32 carousel) for later use in calibrating the WETStar fluorometer data. 200 ml of the collected seawater from each Niskin bottle was immediately filtered through a Whatman GF/F 25 mm glass microfibre filter. The filters were frozen and kept in the dark for later analysis back at the NMFS SWFSC Fisheries Ecology Division. Locations were obtained using the ship's GPS, recorded on the data sheets, and eventually entered into data files.

If the CTD was operated in stand-alone mode (i.e. not in real-time data acquisition mode via the SBE Model 32 carousel/model 33 deck unit), then the data collected from a short series of CTD 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 ship.

An additional source of hydrographic data was the vessel's SBE, thermosalinometer (TS), 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 PC for further processing, analysis, and comparison with, and verification of, CTD observations. Positions for the thermosalinometer unit, while underway, were based on the ship's GPS.

[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.

CTD Data Processing

Uploaded hexadecimal CTD data files were converted to ASCII files using programs supplied by SBE, in their SEASOFT software suite[3]. All files were batch-processed through the SEASOFT's data processing modules DATCNV, FILTER, ALIGNCTD, LOOPEDIT, BINAVG, and DERIVE (refer to footnote 3 and past Technical Memorandums, e.g., Sakuma et al. 1995b, for more information) and output as ASCII files. All data were averaged into 2 m 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 obvious calibration problems (Appendix 5).

Processed hydrographic data (temperature and salinity) were summarized by selected depths for the entire survey (Appendix 6), in relation to density. The seawater density for the temperature versus salinity plots was calculated following Unesco (1983). Mean temperatures (^{o}C) and mean salinities (psu) from the CTD casts are plotted upon density (sigma-t) contours at depths of 10 m, 30 m, 50 m, 100 m, 200 m, 300 m, 400 m, and 500 m. Density contours are in sigma-t instead of sigma-theta for the mean temperatures and mean salinities plots in order to show the non-linear relationship that density has with seawater depth due to pressure effects.

Processed hydrographic data were also summarized by sweep, in a series of horizontal maps and vertical sections. Although additional CTD casts were completed during DSJ0103, 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 7). 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 DSJ0103 were spatially standardized. It should be noted that the Farallones transect line does not follow a straight course, which may lead to some distortion of the vertical section contours near the shore. All contouring of CTD data for horizontal maps and vertical sections was done using SURFER FOR WINDOWS graphics software[4], 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 data were edited to provide a nearly continuous sampling track for each sweep of the survey. 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,

$$TS' = \forall + \exists(TS_u)$$

TS' = adjusted TS value (either temperature or salinity)
TS_u = the unadjusted value
$\forall$ and $\exists$ = the intercept and slope parameters of the regression of the 2 m CTD data.

TS data were subsequently contoured using SURFER FOR WINDOWS[4].

Dynamic height was calculated for stations occupied during the survey 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 DSJ0103 were output from the DERIVE module of SEASOFT's SBE Data Processing[3] and these data were gridded in SURFER FOR WINDOWS[4]. A 0.01

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[4]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.

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 YOY juvenile rockfish surveys necessitates the extrapolation of isopycnals into the shore, a procedure that is subject to great uncertainty. In addition, studies (Berryman 1989; Tisch 1990) suggest that geostrophic velocities calculated for stations spaced closer than the internal Rossby radius (approximately 10-20 km) frequently feature alternating current bands of reversed flow, which are thought to be associated with inertial currents.

Chlorophyll Sample Processing

Within 30 days after the survey completion the glass filters containing the Niskin water bottle samples were processed with acetone and acidified for analysis with a Turner Designs, Inc. Model 10AU Fluorometer. Prior to reading the samples in the fluorometer, 8ml of 100% acetone was placed in 13mm cuvettes which contained the filtered samples and these were wrapped in aluminum foil to exclude any light and were refrigerated overnight. The next day the cuvettes were allowed to warm up to room temperature and the Turner 10AU Fluorometer was calibrated with chlorophyll standards from Turner Designs, Inc. that were validated prior to calibration and then zeroed with 100% acetone. The standard was validated spectrophotometrically. Dilutions of additional 8ml of acetone were necessary for samples with high chlorophyll *a* concentrations. Once each sample was read and recorded, it was then acidified using 3 drops of 10% hydrochloric acid (HCL), which removed all the chlorophyll *a* leaving only the phaeopigments. Chlorophyll *a* concentrations were derived using the following:

$$\text{Chlorophyll } a = ((A_{max} - A_{750nm}) / E \times l)$$

A_{max} = absorption maximum (664nm)
A_{750nm} = absorbance at 750 nm to correct for light scattering
E = extinction coefficient for chl a in 90% acetone at 664 Nm (87.67 L $g^{-1}cm^{-1}$)
l = cuvette path length (cm)

From the calibration Tau and Fs were derived. Tau equaled chlorophyll *a* before acidification divided by chlorophyll *a* after acid. These values were used in the following equations for the determination of chlorophyll *a* and phaeopigments in filtered samples.

$$\text{Chlorophyll } a = (Tau / (Tau-1)) \times (R_b - R_a) \times R_s \times (Vol_{ex}/Vol_{filt})$$

$$\text{Phaeopigments} = (Tau / (Tau-1)) \times [(Tau \times R_a) - R_b]\ F_s \times (Vol_{ex}/Vol_{filt})$$

Tau = acidification coefficient (Rb/Ra) for pure Chlorophyll a (usually 2.2)
R_b = reading before acidification
R_a = reading after acidification
F_s = instrument response factor from fluorometer calibration
Vol_{ex} = extracted volume
Vol_{filt} = sample volume

Once chlorophyll *a* concentrations were determined for all the filtered samples, chlorophyll concentration calibrations were determined for the CTD WETStar fluorometer voltage based on the chlorophyll *a* concentrations that corresponded to the synchronistic CTD WETStar fluorometer voltages (i.e. fluorometer voltages recorded at the same time the Niskin Bottles were tripped).

The basic model used to determine chlorophyll concentrations from fluorometer voltages:

$$\log_e(C') = Y_i + \delta_j \log_e(Z) + \gamma \log_e(V') + \varepsilon_{ijk}$$

C' = (Chlorophyll *a* + 0.025 [:g/Θ) (to ensure positive values)
Y_i = the cruise/year effect { i = 2001}
$*_j$ = a diel effect { $_j$ = day or night}
Z = the depth of the sample [m]
(= the nonlinear coefficient relating chlorophyll *a* and millivolts
V' = Voltage - 0.1025 (to ensure a zero-intercept)
ε_{ijk} = a normal error term ~⌉(0, Φ^2).

The initial model was significant for all variables, with a total model $r^2 = 0.8078$. There were, however, four extreme outliers that exerted considerable leverage on the parameter estimates. These values also caused the distribution of residuals to be non-normal (W=0.9324, P < 0.0001). Consequently, the four data points were excluded from the analysis and the model refit to the trimmed data set.

All effects in the new model were highly significant (P < 0.0001) with an $r^2 = 0.8722$. Specific parameter estimates were as follows:

Y_{2001} = 2.722493
$*_D$ = -0.187728
$*_N$ = -0.193035
(= 0.835312
Φ^2 = 0.311550

The predictive equations according to the back-transformation of the model was:

$$C' = Z^{\delta_j} (V')^{\gamma} e^{Y_i + 0.5\sigma^2} - 0.025$$

This equation was applied to all fluorometer voltage recordings from all the DSJ0103 CTD casts to determine the chlorophyll *a* concentrations within the CTD cast profiles.
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RESULTS

Data Products

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

Appendix 1: List of CTD Deployments and Locations from Cruise DSJ0103

The station list includes, from left to right, CTD cast number, date, local time, latitude and longitude (degrees, minutes), and station bottom depth.

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

The locations of the standard CTD stations for DSJ0103 along with the locations of the NDBC buoys, the place names, and the bathymetry of the survey areas are shown.

Appendix 3: NDBC Time Series

Time series of daily-averaged SST and alongshore wind are presented for January-June 2001 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 wind plots represents the direction of the alongshore wind relative to north, which was determined from a principal component analysis.

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 DSJ0103. Each image represents a median 5 night composite obtained directly form the NOAA CoastWatch web site. The temperature color spectrum ranges from 7.5-17.5^{o}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

Comparisons between CTD, TS, and bucket temperatures and CTD and TS salinities are shown. The solid lines represent the lines of equality in order to show how the different data varied from each other. The regression statistics for comparisons were as follows:

$T_{CTD} = T_{TS} \times 0.995 - 0.357$ $r^2 = 0.99$

$T_{CTD} = T_{B} \times 0.991 - 0.112$ $r^2 = 0.98$

$T_{TS} = T_{B} \times 0.975 + 0.491$ $r^2 = 0.98$

$S_{CTD} = S_{TS} \times 0.909 + 3.385$ $r^2 = 0.95$

$S_{CTD} = S_{B} \times 0.806 + 6.551$ $r^2 = 0.85$

$S_{TS} = S_{B} \times 0.858 + 4.443$ $r^2 = 0.84$

T_{CTD} = CTD temperature at 2 m
T_{TS} = TS temperature
T_B = Bucket temperature
S_{CTD} = CTD salinity at 2 m
S_{TS} = TS salinity
S_B = Bucket salinity

Appendix 6: CTD Mean Temperature versus Mean Salinity

Temperature versus salinity over density contours at 8 discrete depths (10 m, 30 m, 50 m, 100 m, 200 m, 300 m, 400 m, and 500 m) are shown for 3 different periods; (1) means at the discrete depths from all CTD casts from DSJ0103, (2) means at the discrete depths from all CTD casts taken during surveys from 1987-2001 (a 15-year average), and (3) means at the discrete depths from all CTD casts of DSJ9206. DSJ9206 was conducted in May/June of 1992, during an El Niño period. The plot of DSJ0103 (summer of 2001) represents a total of 272 CTD casts, while DSJ9206 represents a total of 399 CTD casts. The 15-year mean (1987-2001) represents a total of 4680 CTD casts. For the 15-year mean, the values at 300 m and 400 m were from the years 1990-2001, the values at 500 m were from the years 1991-2001. Temperatures were measured directly by the SBE Seacat model 19 CTD. Salinities were calculated from the CTD's conductivity recordings by the SBE data processing software. The density contour background was generated by a MATLAB software program, using the seawater Equation of State (UNESCO 1983). The density intervals are 0.2 kg/m^3.

Appendix 7: Horizontal Maps of TS and CTD

a) Maps of TS temperature and salinity

Maps of surface temperature (^oC) and salinity (psu) obtained from the ship's TS unit are presented for each sweep of the survey. The TS maps are located in front of the corresponding horizontal map for the CTD at 2 m. The contour intervals are 0.5 ^oC for temperature and 0.1 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 (^oC), salinity (psu), and density (sigma-theta [Φ_2]) (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^oC, 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^oC, 0.02, and 0.02 kg/m^3.

Appendix 8: Vertical Sections

Vertical sections of temperature, salinity and density are presented for four cross-shelf transects off Pt. Reyes, the Farallones, Pescadero, and Davenport. 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^oC for temperature, 0.1 for salinity, and 0.2 kg/m^3 for density.

Appendix 9: Dynamic Height Topography

Horizontal maps of dynamic height (0/500 m and 200/500 m) are presented for the three sweeps during the survey. 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.

Appendix 10: Integrated Chlorophyll *a*

Horizontal maps of integrated chlorophyll *a* (from the surface to 50 m depth) are presented for the three sweeps of the survey. Contour intervals are 10 micrograms/liter of chlorophyll *a*.

Synopsis of Meteorological and Hydrographic Conditions

Based on the NDBC time series, cooler than normal buoy SSTs were established during southward or equatorward (upwelling-favorable) wind conditions two weeks prior to the 2001 survey. This was followed by unseasonably strong poleward winds from the south, and warmer than normal SSTs at the beginning of sweep 1. The remainder of sweep 1 saw upwelling favorable equatorward winds. Sweeps 2 and 3 were nearly identical to sweep 1 in this pattern of wind variability with a relaxation event and strong poleward winds at the beginning of the sweep followed by equatorward winds during the majority of the sweep. Equatorward winds during most of sweep 3 were especially strong. Buoy SSTs followed the same variability patterns, with cooler temperatures associated with equatorward winds and warmer temperatures associated with poleward winds. Sweep 3 saw the strongest and most persistent upwelling conditions and anomalously cool buoy SSTs, during the survey's period.

The plot of mean temperature versus mean salinity illustrates the general seawater density conditions in temperature and salinity space for the central California region during May and June. In relation to the 15-year temperature and salinity climatology (1987-2001), density was at least .2 kg/m^3 higher at all depths from 10m to 50m, and salinities were higher than the climatology's mean values at all measured depths. Temperatures at all depths in 2001 were very close to the 15-year mean temperatures. DSJ0103 had the highest mean salinity values in the upper 200m of all the surveys conducted since 1987 and anomalously dense water in the upper 200 m. This was due to the strong upwelling that occurred during the survey, which brought deeper dense (saltier, colder) water to the surface, and covered large portions of the continental shelf. The relatively dense seawater from DSJ0103 is in strong contrast to DSJ9206, which occurred during an El Niño period with abnormally warm/fresh seawater occupying the upper 150 m of the water column, especially from 10 m to 50 m. The distance along density contours for the 10 m depth temperature and salinity between the 2001 survey and the 1992 survey is striking, with the water being nearly 1 kg/m^3 denser in 2001.

Contour plots of temperature and salinity from TS recordings showed the presence of a small cool water eddy centered approximately 10 miles off Pt. Reyes during sweeps 1 and 2. Sweep 3 produced a much cooler temperature pattern in the northern half of the survey area, especially north of Pt. Reyes, which had a strong upwelling signature on the horizontal sea surface scale, with higher salinities, within 30 miles of the shore, along with a developing filament just west of Pt. Reyes. A fresh (less saline) circulation was apparent during sweep 3 centered approximately 40 miles west of Pescadero. Eastern moving meanders from the California Current containing fresher, warmer water were apparent along the western edge of the survey area during all sweeps.

Contour plots of density from CTD casts during sweep 1 show a distinct division between offshore (less dense) and inshore (more dense) water from the surface to at least 30 m depth, except for a fresher eddy located close to Monterey Bay. During sweep 2, denser upwelled water began to dominate the areas north of the Gulf of the Farallones and off Pescadero. Sweep 3 showed a significant north-south gradient between colder, saltier, recently upwelled water to the north and less dense water occupying the southern portion of the survey region.

Vertical sections at 4 transects of the survey region for temperature, salinity, and density illustrate a fairly well stratified ocean in the southern half, during sweep 1, with denser water near the surface around the Farallon Islands, and a distinct cool, dense, small-scale eddy off Pt. Reyes. During sweep 2, the southern half of the survey area remained evenly stratified, whereas the isotherms and isopycnals at the Farallones and Pt. Reyes show more shoaling behavior nearshore. Dramatic shoaling of cold, dense water occurred within the northern two transects during sweep 3, apparently due to strong upwelling. An upwelling filament also appeared in the vertical section during sweep 3 and extended westward from 60-70 nm off Pt. Reyes.

Dynamic height topography shows much variability in geostrophic current direction at the surface during all 3 sweeps. Geostrophic flow patterns at the surface during sweeps 1 and 2 were generally more offshore to inshore except around the Farallon Island region, whereas sweep 3 showed more eddy-like and meander circulations in nearly all the regions south of Pt. Reyes. At the 200 m depth, the northerly moving California Undercurrent is visible near and along the continental slope, south of Pt. Reyes, during all 3 sweeps. Geostrophic flow at 200 m, as indicated by the distance between dynamic height pressure gradients, shows the California Undercurrent's velocity to be highest during sweep 3, between Monterey and Half Moon Bay. The higher velocities of the California Undercurrent at 200 m depth during sweep 3 probably result from geostrophic equilibrium on the mesoscale, causing a balancing adjustment against the strong upwelling/filament behavior in the waters above the California Undercurrent.

Contour plots of chlorophyll *a* integrated from the sea surface to 50 m depth shows much variability in overall concentrations from sweep to sweep, as well as significant patchiness during individual sweeps. Sweep 1 saw a chlorophyll *a* concentration centered off the western boundary of Monterey Bay, with a horizontal size and location that is similar to the Monterey Bay eddy (Baltz, 1997). Another concentrated pool of chlorophyll *a* during sweep 1 was centered approximately 20 miles west of Half Moon Bay, and was similar in size and location of the Pioneer eddy (Baltz, 1997). Entrainment of phytoplankton within mesoscale eddies may account for the contoured shape of these chlorophyll *a* concentrations. Chlorophyll *a* levels north of the Golden Gate entrance to San Francisco Bay were lower and more dispersed than the areas south, at least during the first sweep. During sweep 2, a significant eddy-shaped region of high chlorophyll *a* was centered 10 miles northwest of Pt. Reyes, similar in size and location to the Bodega eddy (Baltz, 1997). Chlorophyll *a* levels decreased south of Pescadero during sweep 2, and the eddy-shaped feature off Monterey Bay disappeared completely. During sweep 3, chlorophyll *a* levels decreased dramatically and became much less patchy throughout the survey's region, in comparisons to sweeps 1 and 2. Strong upwelling, during sweep 3, mixed, dispersed, and pushed phytoplankton offshore and out of the survey's region, resulting in much lower levels of chlorophyll a within the survey's area. Newly upwelled water is normally low in chlorophyll *a*, even though the colder, saltier, nutrient-rich water is conducive to phytoplankton growth. The relatively high overall chlorophyll *a* levels during the survey correspond to similar elevated chlorophyll *a* levels recorded during the 2001 CalCOFI survey conducted just before, and south, of this survey's area (Schwing et al., 2002a).

2001 was a La Niña year on the large scale for the California Current System (CCS) (Bograd et al., 2000; Durazo et al., 2001; Schwing et al., 2002). A pool of cooler than normal upper ocean water covered most of the CCS, including the central California coastal region, coincident with the time period of DSJ0103. This pool of cool water corresponded to a negative phase of the Pacific Decadal Oscillation (PDO) (Mantua et al. 1997) and has been present since 1998 with summer averages of the PDO being negative over the last four years. The recent behavior of the PDO strongly indicates that the transition from an extremely strong El Niño Southern Oscillation (ENSO) in 1997-1998 may signal a shift to a new oceanic regime in the northeast Pacific. These cooler conditions associated with a possible regime shift may benefit YOY juvenile rockfish survival due to increased productivity and zooplankton biomass within the CCS and on the continental shelf of the California coast (Schwing et al., 2002). Although not as strong as the record upwelling levels of 1999 (Schwing and Moore, 2000; Schwing et al., 2000; Sakuma et al., 2001), conditions in 2001 appeared to be much more favorable for biological production than in the most recent El Niño event of 1997-98 (Schwing et al., 2002; Schwing et al., 2002a). Other than the record 1999 upwelling, based on the upwelling indices produced by NMFS SWFSC Environmental Research Division, 2001 had the highest mean summer upwelling index (Schwing et al., 1996) since

1981. The period following the 1997-1998 ENSO has been the highest 4-year mean on record for upwelling indices, extending back to 1946 (Schwing et al. 2002).

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APPENDIX 1: LIST OF CTD DEPLOYMENTS AND LOCATIONS FROM CRUISE DSJ0103

CAST #	DATE & TIME	LATITUDE	LONGITUDE	BOTTOM DEPTH(M)
1	5/11/2001 19:50	36 53	121 56.09	36
2	5/11/2001 20:25	36 50.72	121 59.01	88
3	5/12/2001 00:30	36 46.39	121 52.70	121
4	5/12/2001 01:18	36 44.48	121 58.63	325
5	5/12/2001 03:40	36 42.14	121 55.76	94
6	5/12/2001 06:17	36 39.26	121 58.04	88
7	5/12/2001 07:33	36 39.94	122 10.08	1278
8	5/12/2001 08:51	36 46.22	122 16.09	853
9	5/12/2001 10:15	36 40.00	122 22.30	1737
10	5/12/2001 11:34	36 46.21	122 28.38	2100
11	5/12/2001 13:05	36 39.94	122 34.79	2300
12	5/12/2001 14:37	36 40.08	122 47.07	2745
13	5/12/2001 15:56	36 33.79	122 40.86	2859
14	5/12/2001 17:20	36 33.61	122 28.62	2831
15	5/12/2001 16:50	36 33.72	122 16.44	2625
16	5/12/2001 20:28	36 34.68	122 11.00	2330
17	5/13/2001 01:27	36 35.87	122 02.61	920
18	5/13/2001 02:15	36 38.59	122 02.57	760
19	5/13/2001 05:41	36 45.77	122 09.92	1040
20	5/13/2001 06:55	36 52.48	122 10.00	102
21	5/13/2001 08:11	36 52.64	122 22.46	825
22	5/13/2001 09:42	36 52.70	122 34.76	1800
23	5/13/2001 11:10	36 52.60	122 47.09	2286
24	5/13/2001 12:38	36 52.56	122 59.38	2699
25	5/13/2001 14:03	36 59.00	122 53.40	1372
26	5/13/2001 15:24	37 04.94	122 47.12	652
27	5/13/2001 16:56	37 05.03	122 34.78	115
28	5/13/2001 18:12	36 59.73	122 13.66	59
29	5/13/2001 20:15	36 58.89	122 17.63	86
30	5/13/2001 22:45	36 58.97	122 22.75	126
31	5/13/2001 23:25	36 59.06	122 25.61	580
32	5/14/2001 02:15	37 00.35	122 37.04	378
33	5/14/2001 03:20	36 59.15	122 45.50	1250
34	5/14/2001 05:29	36 53.38	122 45.08	1875
35	5/14/2001 08:15	37 10.75	122 28.32	69
36	5/14/2001 09:30	37 10.85	122 40.82	113
37	5/14/2001 10:45	37 10.71	122 53.12	432
38	5/14/2001 12:16	37 10.78	123 06.25	869
39	5/14/2001 13:36	37 16.41	123 11.71	1190
40	5/14/2001 15:02	37 22.19	123 05.44	813
41	5/14/2001 14:34	37 22.23	122 53.03	200
42	5/14/2001 17:49	37 22.33	122 40.83	86
43	5/14/2001 19:00	37 22.30	122 28.79	33
44	5/14/2001 20:00	37 16.48	122 34.01	85
45	5/14/2001 22:40	37 15.75	122 39.04	96
46	5/14/2001 23:45	37 15.89	122 48.90	186
47	5/15/2001 02:05	37 17.19	123 00.19	609
48	5/15/2001 03:00	37 20.70	123 01.58	860
49	5/15/2001 05:38	37 24.19	122 53.04	332
50	5/15/2001 06:56	37 30.90	122 59.29	209
51	5/15/2001 08:21	37 30.76	123 11.70	1280

52	5/15/2001 09:55	37 30.86	123 24.12	2370
53	5/15/2001 11:30	37 30.76	123 36.45	3200
54	5/15/2001 12:48	37 38.43	123 36.37	3340
55	5/15/2001 14:04	37 46.15	123 36.36	2700
56	5/15/2001 15:45	37 46.06	123 23.87	1510
57	5/15/2001 17:18	37 46.15	123 11.65	115
58	5/15/2001 20:10	37 39.42	123 02.45	106
59	5/15/2001 23:00	37 39.36	123 12.94	1140
60	5/16/2001 00:15	37 43.96	123 07.91	103
61	5/16/2001 03:15	37 52.83	123 19.40	96
62	5/16/2001 04:25	37 53.31	123 30.26	1313
63	5/16/2001 06:44	38 01.39	123 30.25	160
64	5/16/2001 08:05	38 01.55	123 43.45	2353
65	5/16/2001 09:36	38 01.62	123 54.80	2475
66	5/16/2001 11:31	38 10.07	124 07.08	3650
67	5/16/2001 13:29	38 18.47	123 54.76	2835
68	5/16/2001 15:06	38 18.62	123 42.37	1460
69	5/16/2001 16:40	38 18.35	123 30.21	260
70	5/16/2001 18:01	38 18.60	123 17.62	105
71	5/16/2001 20:00	38 10.10	123 17.70	125
72	5/16/2001 23:15	38 09.97	123 10.17	91
73	5/17/2001 00:05	38 11.16	123 06.99	81
74	5/17/2001 02:28	38 10.26	123 01.03	62
75	5/17/2001 04:25	38 01.60	123 05.59	62
76	5/17/2001 06:04	38 01.52	123 17.78	110
77	5/17/2001 20:15	37 48.30	122 53.70	59
78	5/17/2001 23:10	37 42.05	122 55.29	54
79	5/18/2001 01:50	37 55.90	122 53.25	49
80	5/18/2001 20:35	36 50.96	121 59.84	82
81	5/18/2001 23:10	36 45.69	121 51.70	70
82	5/18/2001 23:55	36 44.32	121 57.96	119
83	5/19/2001 01:55	36 42.81	121 54.08	84
84	5/19/2001 02:30	36 39.56	121 56.33	80
85	5/19/2001 05:00	36 38.56	121 51.24	26
86	5/19/2001 08:27	36 40.15	122 10.32	1130
87	5/19/2001 09:51	36 46.16	122 16.09	825
88	5/19/2001 11:18	36 40.20	122 22.40	1350
89	5/19/2001 12:39	36 48.32	122 28.34	2250
90	5/19/2001 14:06	36 40.00	122 34.96	2380
91	5/19/2001 15:46	36 39.91	122 46.75	2745
92	5/19/2001 17:07	36 33.88	122 40.79	2850
93	5/19/2001 18:39	36 33.69	122 28.29	2724
94	5/19/2001 20:37	36 34.88	122 10.16	2286
95	5/20/2001 01:09	36 35.39	122 01.50	451
96	5/20/2001 02:04	36 38.75	122 03.03	870
97	5/20/2001 05:08	36 46.77	122 09.71	1028
98	5/20/2001 06:10	36 52.65	122 09.99	99
99	5/20/2001 07:26	36 52.67	122 22.15	885
100	5/20/2001 09:03	36 52.42	122 34.30	1600
101	5/20/2001 10:36	36 52.41	122 46.79	2285
102	5/20/2001 12:15	36 52.68	122 59.65	2700
103	5/20/2001 13:41	36 58.92	122 53.01	1370

104	5/20/2001 15:00	37 04.84	122 46.96	700
105	5/20/2001 16:34	37 04.96	122 34.65	114
106	5/20/2001 17:57	37 05.00	122 22.53	60
107	5/20/2001 20:34	36 58.75	122 16.83	84
108	5/20/2001 23:31	36 59.63	122 23.59	120
109	5/21/2001 00:02	36 58.59	122 24.51	166
110	5/21/2001 02:21	36 58.63	122 36.09	493
111	5/21/2001 03:39	36 58.92	122 44.50	985
112	5/21/2001 06:39	37 10.62	122 28.33	70
113	5/21/2001 07:56	37 10.65	122 40.91	115
114	5/21/2001 09:11	37 10.66	122 53.03	433
115	5/21/2001 10:59	37 10.70	123 05.30	860
116	5/21/2001 12:10	37 16.54	123 11.25	1190
117	5/21/2001 13:27	37 22.21	123 05.29	816
118	5/21/2001 15:00	37 22.29	122 53.03	200
119	5/21/2001 16:15	37 22.33	122 40.66	86
120	5/21/2001 17:25	37 22.25	122 28.41	30
121	5/21/2001 20:34	37 17.00	122 34.50	87
122	5/21/2001 23:16	37 17.00	122 39.86	98
123	5/22/2001 00:16	37 16.07	122 48.30	170
124	5/22/2001 02:44	37 17.40	123 00.33	623
125	5/22/2001 03:34	37 20.81	123 01.66	900
126	5/22/2001 05:33	37 26.01	123 01.67	552
127	5/22/2001 06:34	37 30.79	122 59.79	228
128	5/22/2001 07:54	37 31.02	123 11.84	1274
129	5/22/2001 09:44	37 30.96	123 24.08	2375
130	5/22/2001 11:14	37 30.77	123 36.45	3110
131	5/22/2001 12:32	37 38.47	123 36.32	3335
132	5/22/2001 13:45	37 46.13	123 36.24	2700
133	5/22/2001 15:25	37 46.27	123 24.04	1510
134	5/22/2001 16:59	37 46.18	123 11.66	114
135	5/22/2001 20:35	37 39.30	123 02.01	105
136	5/22/2001 23:27	37 40.45	123 12.86	1280
137	5/23/2001 00:35	37 44.53	123 08.38	104
138	5/23/2001 03:29	37 52.62	123 20.98	112
139	5/23/2001 05:10	37 53.73	123 31.16	1238
140	5/23/2001 06:28	38 01.53	123 30.24	157
141	5/23/2001 07:56	38 01.83	123 42.40	2560
142	5/23/2001 09:25	38 01.75	123 54.73	3475
143	5/23/2001 11:13	38 10.08	124 07.08	3650
144	5/23/2001 13:00	38 18.66	123 54.66	2835
145	5/23/2001 14:29	38 18.58	123 42.42	1460
146	5/23/2001 16:08	38 18.42	123 30.09	253
147	5/23/2001 17:34	38 18.46	123 17.95	108
148	5/23/2001 20:40	38 10.56	123 22.50	194
149	5/24/2001 01:00	38 09.66	123 15.74	115
150	5/24/2001 01:47	38 10.69	123 10.92	95
151	5/24/2001 03:47	38 09.01	123 04.07	71
152	5/24/2001 05:13	38 10.01	123 00.36	56
153	5/24/2001 06:21	38 01.41	123 05.45	60
154	5/24/2001 07:48	38 01.57	123 17.71	119
155	5/24/2001 20:38	37 36.43	122 50.75	73

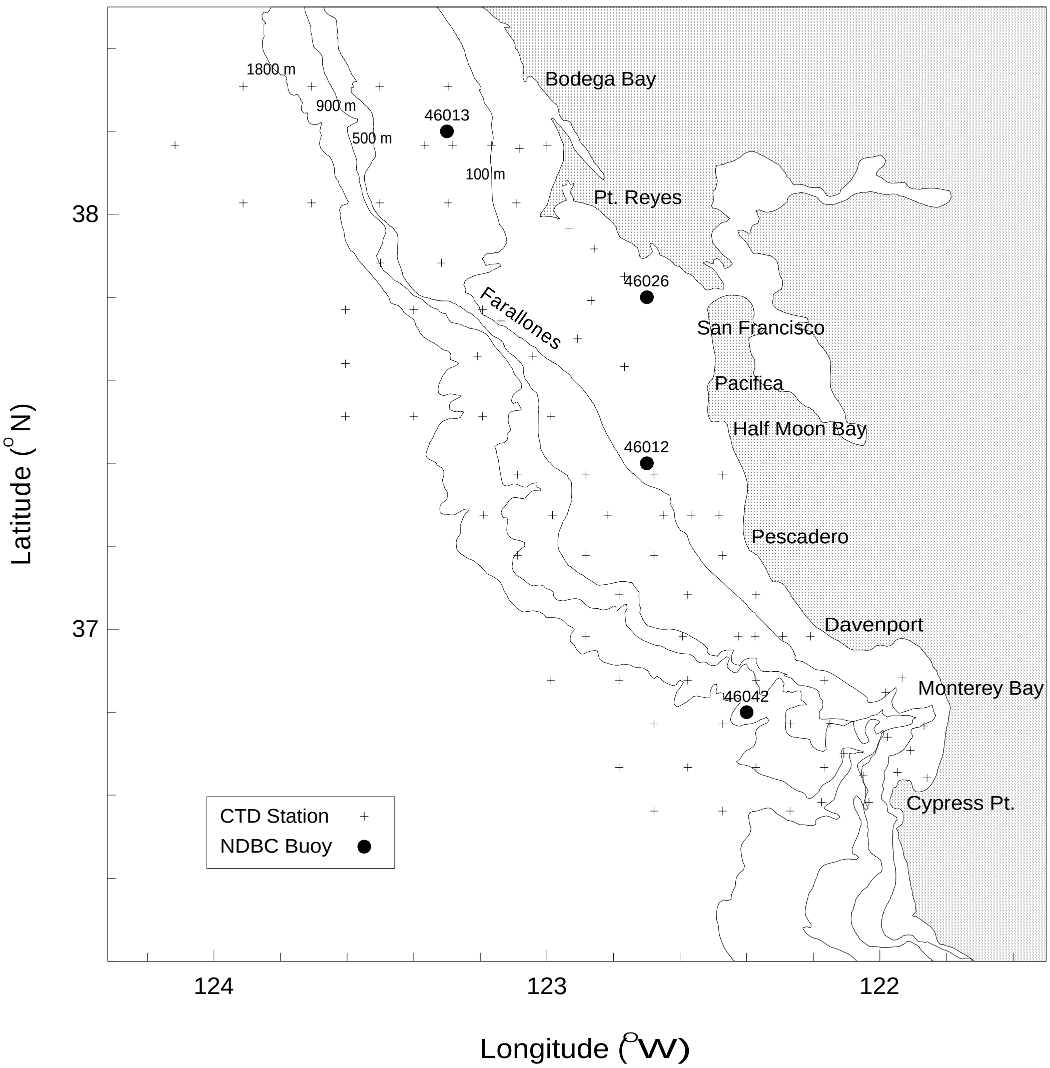
156	5/24/2001 23:19	37 41.94	122 54.91	57
157	5/25/2001 00:23	37 48.12	122 52.74	57
158	5/25/2001 05:58	38 07.07	123 28.87	296
159	5/25/2001 07:33	38 16.04	123 34.74	688
160	5/25/2001 09:20	38 25.08	123 40.62	737
161	5/25/2001 11:03	38 34.19	123 45.98	933
162	5/25/2001 12:51	38 43.20	123 53.12	555
163	5/25/2001 14:41	38 52.68	123 55.54	260
164	5/25/2001 16:15	38 42.95	123 59.28	1943
165	5/25/2001 17:50	38 33.64	124 03.16	2588
166	5/25/2001 19:28	38 24.39	124 07.66	3679
167	5/25/2001 20:59	38 15.37	124 13.45	3668
168	5/25/2001 23:58	38 05.14	124 17.84	3852
169	5/26/2001 01:33	37 57.22	124 23.69	3840
170	5/26/2001 04:50	38 02.18	124 13.45	3485
171	5/26/2001 06:31	38 09.29	124 03.70	3780
172	5/26/2001 08:27	38 16.21	123 52.40	2820
173	5/26/2001 10:05	38 21.29	123 42.67	1275
174	5/26/2001 11:47	38 26.64	123 32.20	180
175	5/26/2001 13:14	38 32.09	123 21.36	83
176	5/26/2001 14:41	38 32.18	123 34.04	147
177	5/26/2001 16:10	38 32.29	123 46.71	1314
178	5/26/2001 17:53	38 32.28	123 59.62	2849
179	5/26/2001 19:36	38 32.11	124 12.29	3323
180	5/26/2001 23:52	38 31.96	124 24.00	3620
181	5/27/2001 01:33	38 32.44	124 38.01	3756
182	5/27/2001 04:20	38 27.54	124 25.62	3674
183	5/27/2001 05:44	38 24.54	124 14.50	3811
184	5/27/2001 07:22	38 20.35	124 02.79	3524
185	5/27/2001 08:57	38 24.92	123 52.65	1929
186	5/27/2001 11:20	38 11.63	123 40.49	1856
187	5/27/2001 13:03	38 07.11	123 29.08	297
188	5/30/2001 19:06	36 52.93	122 55.90	37
189	5/30/2001 20:55	36 50.83	121 59.69	83
190	5/30/2001 23:17	36 45.95	121 51.50	73
191	5/31/2001 00:07	36 44.41	121 57.37	106
192	5/31/2001 02:01	36 42.30	121 53.70	80
193	5/31/2001 02:39	36 38.83	121 52.67	60
194	5/31/2001 05:12	36 39.61	121 56.58	84
195	5/31/2001 06:35	36 40.05	122 10.01	1130
196	5/31/2001 08:01	36 46.27	122 16.01	825
197	5/31/2001 09:20	36 39.94	122 22.42	1740
198	5/31/2001 10:52	36 46.31	122 28.41	2105
199	5/31/2001 12:13	36 40.12	122 34.66	2357
200	5/31/2001 13:29	36 46.27	122 40.65	2150
201	5/31/2001 14:50	36 40.07	122 46.87	2745
202	5/31/2001 16:57	36 33.67	122 40.49	2655
203	5/31/2001 18:25	36 33.75	122 28.38	2730
204	5/31/2001 19:55	36 33.72	122 16.32	2562
205	5/31/2001 20:50	36 35.16	122 11.26	2330
206	6/01/2001 00:55	36 34.12	122 01.41	1092
207	6/01/2001 02:03	36 38.42	122 02.28	910

208	6/01/2001 05:29	36 47.18	122 09.45	685
209	6/01/2001 06:35	36 52.43	122 09.33	97
210	6/01/2001 07:54	36 52.63	122 22.41	825
211	6/01/2001 09:24	36 52.62	122 34.54	1600
212	6/01/2001 10:51	36 52.64	122 47.05	2285
213	6/01/2001 12:27	36 52.59	122 59.15	2700
214	6/01/2001 13:53	36 58.92	122 53.12	1370
215	6/01/2001 15:15	37 04.92	122 47.03	650
216	6/01/2001 16:55	37 04.97	122 34.65	114
217	6/01/2001 18:15	37 04.96	122 22.30	60
218	6/01/2001 21:00	36 59.75	122 18.46	86
219	6/01/2001 23:05	36 58.25	122 22.32	139
220	6/01/2001 23:55	36 59.61	122 25.98	151
221	6/02/2001 02:31	36 58.08	122 35.08	529
222	6/02/2001 04:50	36 58.52	122 45.12	1000
223	6/02/2001 07:39	37 10.70	122 28.42	71
224	6/02/2001 09:06	37 10.62	122 40.58	114
225	6/02/2001 10:42	37 10.79	122 52.95	429
226	6/02/2001 12:42	37 10.71	123 05.21	870
227	6/02/2001 15:23	37 22.17	123 05.25	825
228	6/02/2001 18:41	37 22.27	122 52.92	194
229	6/02/2001 21:08	37 22.27	122 40.58	88
230	6/02/2001 23:15	37 22.21	122 28.37	30
231	6/03/2001 00:20	37 17.40	122 35.08	85
232	6/04/2001 08:35	37 22.36	122 28.37	30
233	6/04/2001 10:00	37 22.33	122 40.62	86
234	6/04/2001 11:25	37 22.33	122 52.70	190
235	6/04/2001 12:51	37 22.23	123 05.20	810
236	6/04/2001 15:06	37 16.53	123 11.63	1190
237	6/04/2001 16:30	37 10.54	123 05.40	855
238	6/04/2001 18:10	37 10.69	122 53.19	420
239	6/04/2001 19:45	37 10.64	122 40.79	114
240	6/04/2001 21:01	37 17.01	122 39.62	97
241	6/05/2001 00:04	37 15.82	122 48.48	181
242	6/05/2001 01:35	37 16.94	122 59.62	559
243	6/05/2001 04:40	37 20.09	123 00.49	763
244	6/05/2001 06:49	37 30.72	122 59.20	205
245	6/05/2001 08:19	37 30.83	123 11.57	1280
246	6/05/2001 10:00	37 30.75	123 24.01	2375
247	6/05/2001 11:31	37 30.81	123 36.28	3110
248	6/05/2001 12:51	37 38.25	123 36.25	3335
249	6/05/2001 14:14	37 46.14	123 36.29	2700
250	6/05/2001 15:45	37 46.16	123 24.08	1410
251	6/05/2001 17:16	37 46.18	123 11.66	113
252	6/05/2001 21:09	37 40.26	123 03.59	103
253	6/05/2001 23:45	37 38.62	123 11.96	1280
254	6/06/2001 01:08	37 45.22	123 08.96	82
255	6/06/2001 05:30	37 50.85	123 20.98	124
256	6/06/2001 07:03	38 01.59	123 17.86	119
257	6/06/2001 08:21	38 01.61	123 05.50	62
258	6/06/2001 21:21	38 10.80	123 01.20	63
259	6/06/2001 23:48	38 08.69	123 03.79	71

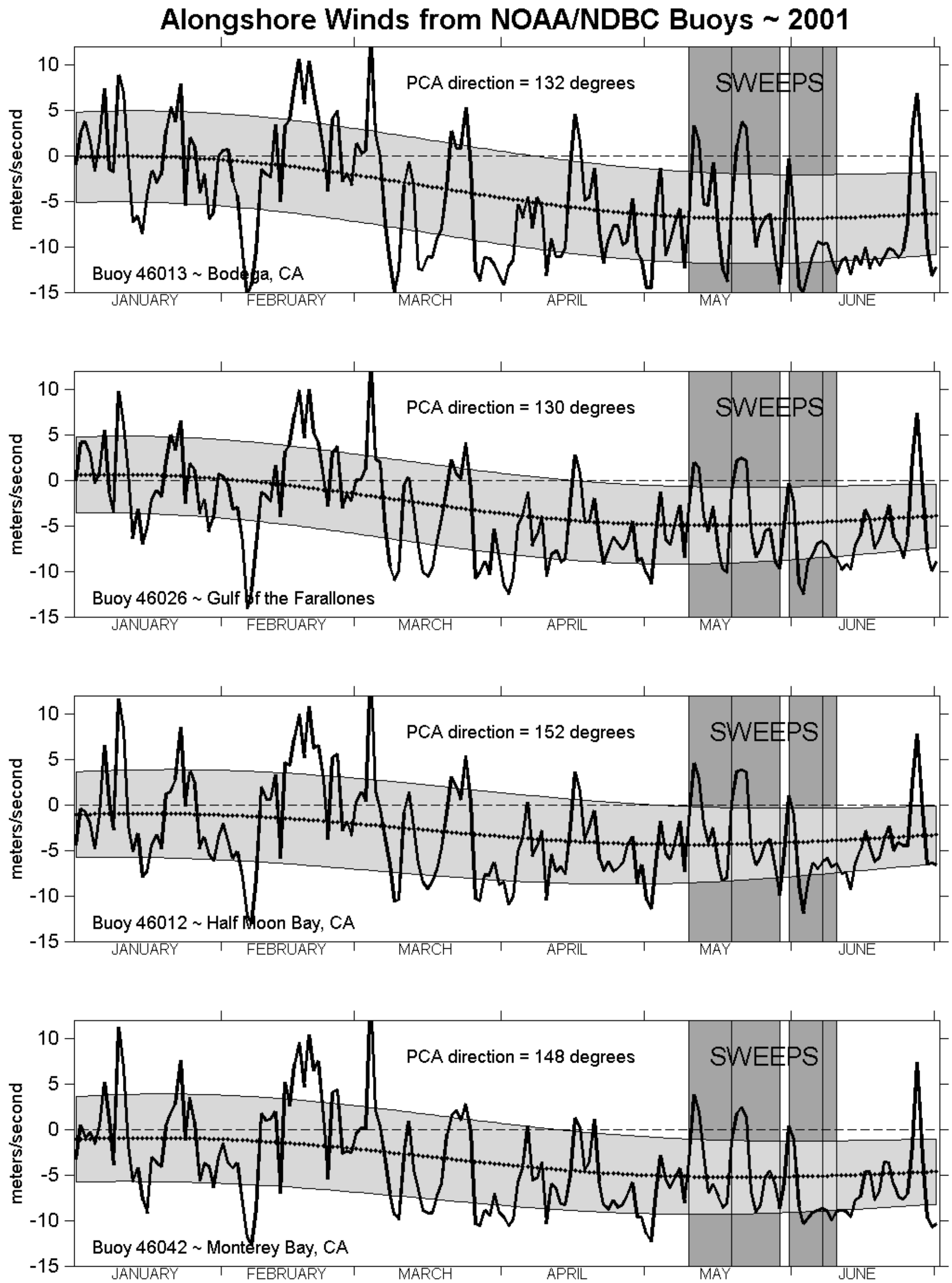
260	6/07/2001 00:57	38 10.41	123 10.50	93
261	6/07/2001 03:41	38 08.98	123 16.28	117
262	6/07/2001 05:19	38 09.01	123 21.12	161
263	6/07/2001 06:45	38 18.39	123 17.83	108
264	6/07/2001 08:10	38 18.40	123 30.04	260
265	6/07/2001 09:38	38 18.35	123 42.33	1460
266	6/07/2001 11:11	38 18.40	123 54.73	2385
267	6/07/2001 13:08	38 10.12	124 06.83	3650
268	6/07/2001 15:02	38 01.62	123 54.76	3475
269	6/07/2001 16:38	38 01.50	123 42.54	2560
270	6/07/2001 18:15	38 01.60	123 30.25	147
271	6/07/2001 23:32	37 48.00	122 52.65	57
272	6/08/2001 01:18	37 41.80	122 54.50	57
273	6/08/2001 02:13	37 36.21	122 50.58	73

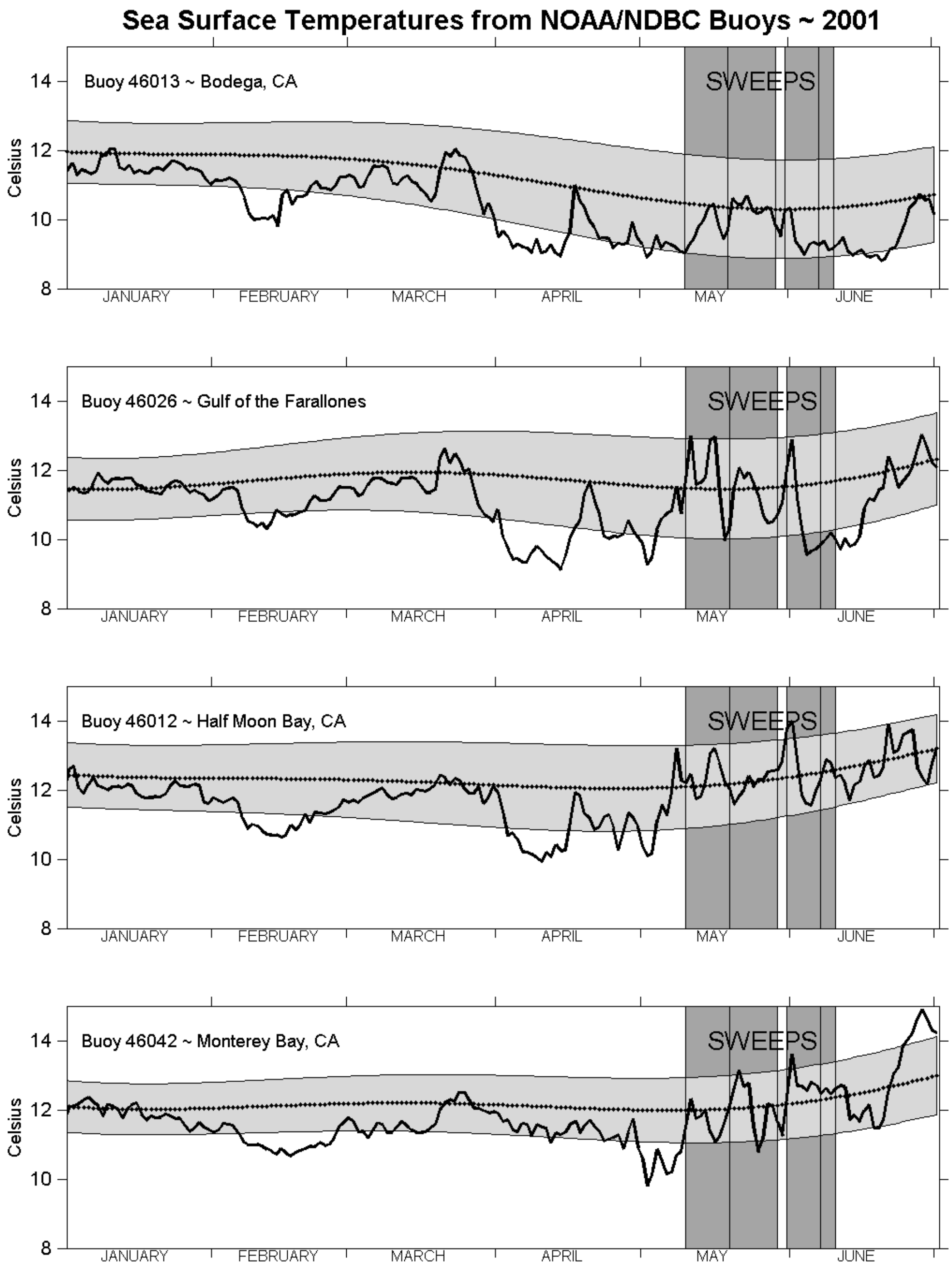
APPENDIX 2: CTD STATIONS AND BATHYMETRIC CHART OF SURVEY REGION WITH LOCATIONS OF THE NDBC BUOYS

Standard CTD Station Locations



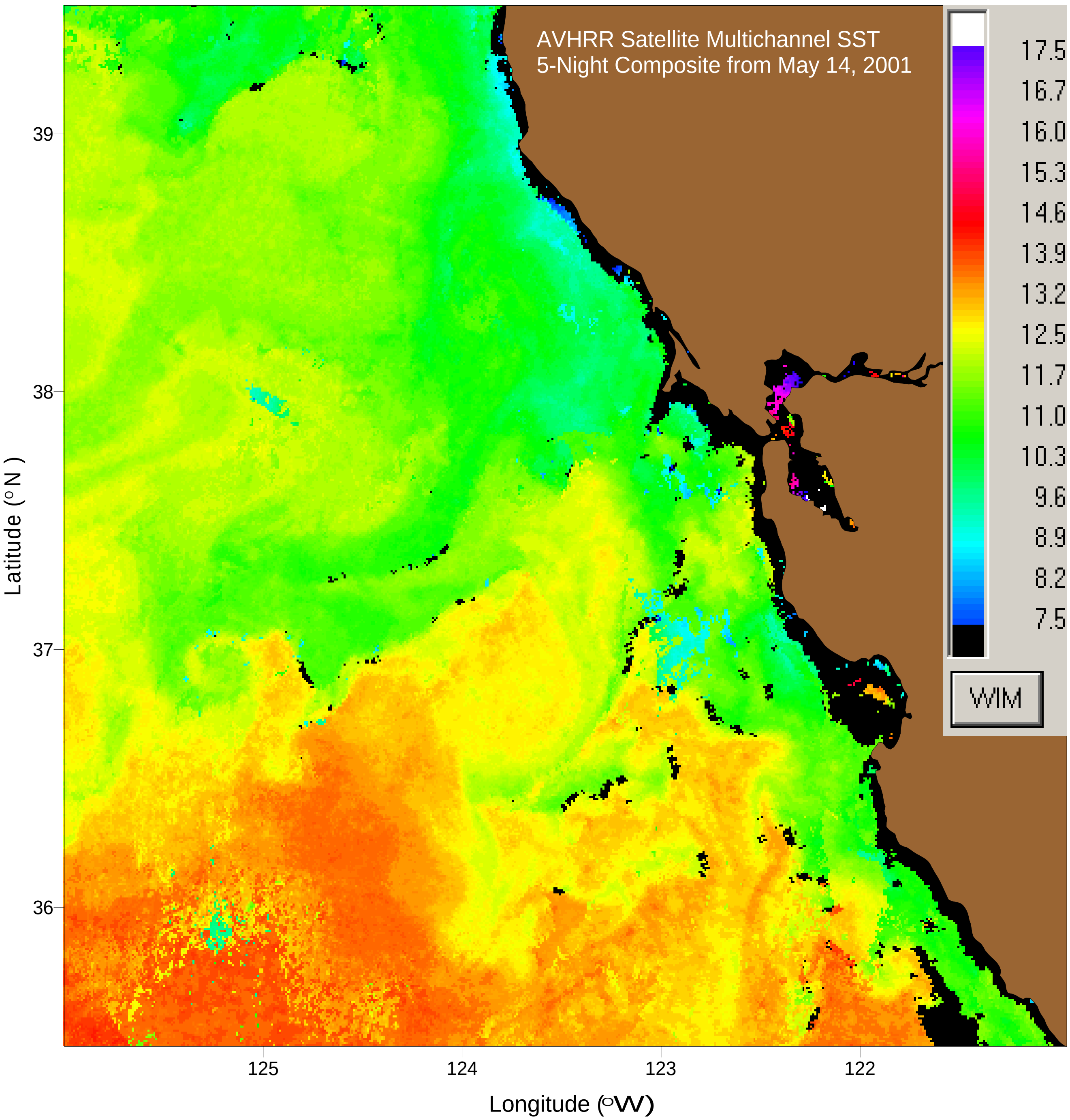
APPENDIX 3: NDBC TIME SERIES

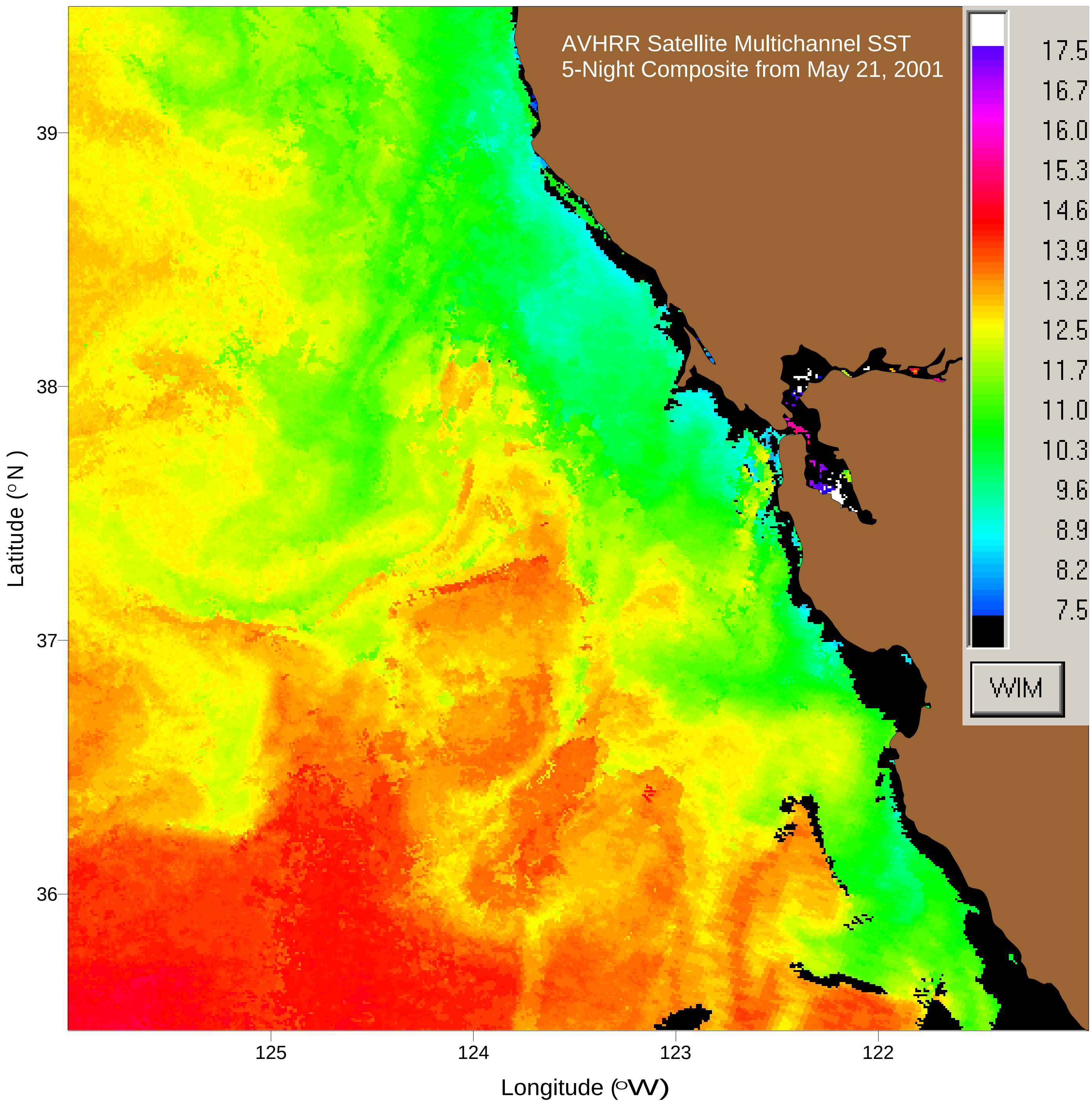

Alongshore Winds from NOAA/NDBC Buoys ~ 2001
PCA direction = 132 degrees
SWEEPS
Buoy 46013 ~ Bodega, CA
PCA direction = 130 degrees
SWEEPS
Buoy 46026 ~ Gulf of the Farallones
PCA direction = 152 degrees
SWEEPS
Buoy 46012 ~ Half Moon Bay, CA
PCA direction = 148 degrees
SWEEPS
Buoy 46042 ~ Monterey Bay, CA
meters/second
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE

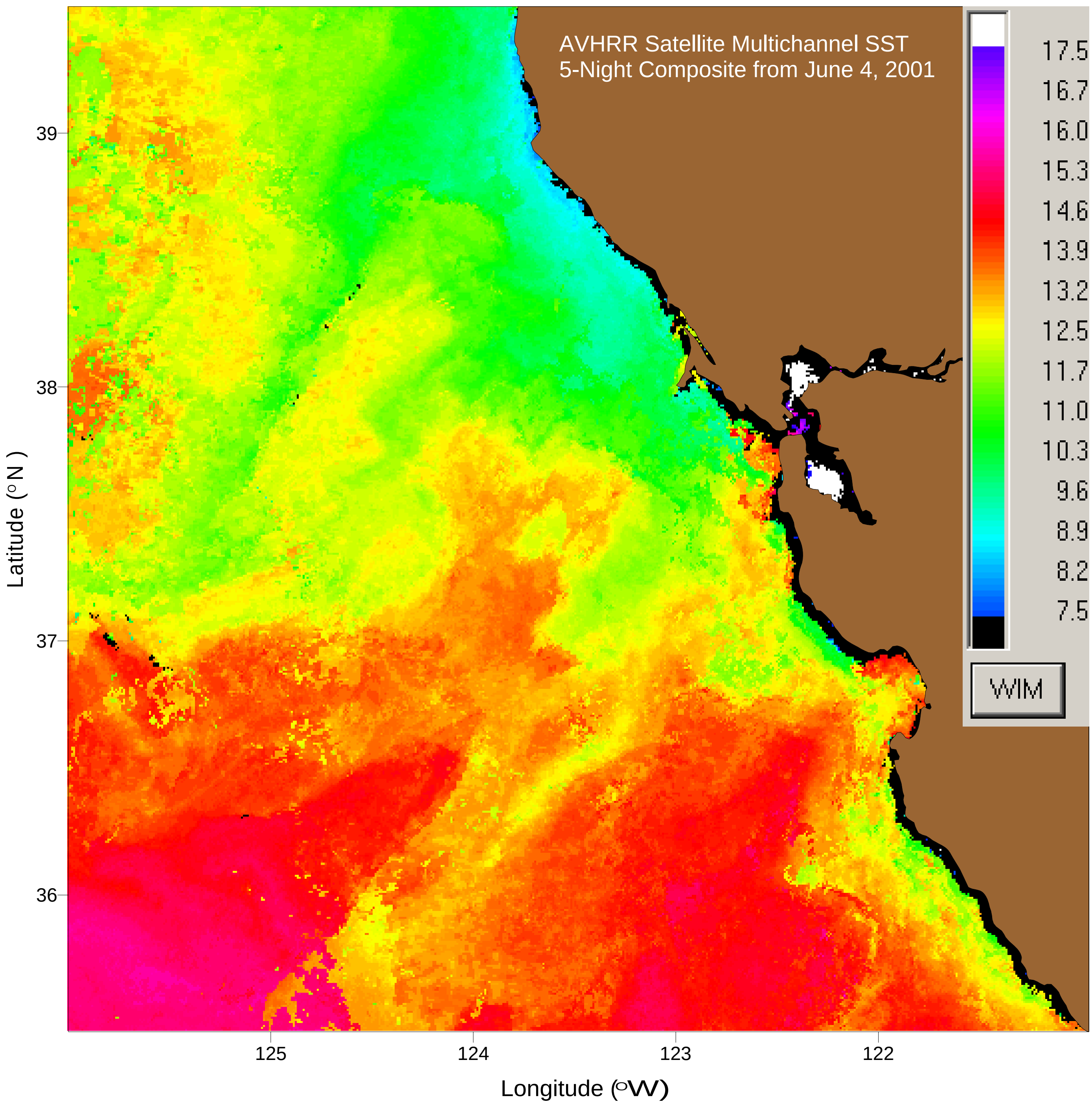


Sea Surface Temperatures from NOAA/NDBC Buoys ~ 2001
Buoy 46013 ~ Bodega, CA
Buoy 46026 ~ Gulf of the Farallones
Buoy 46012 ~ Half Moon Bay, CA
Buoy 46042 ~ Monterey Bay, CA
SWEEPS
Celsius
14
12
10
8
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE

APPENDIX 4: AVHRR SATELLITE IMAGES OF MULTICHANNEL SST

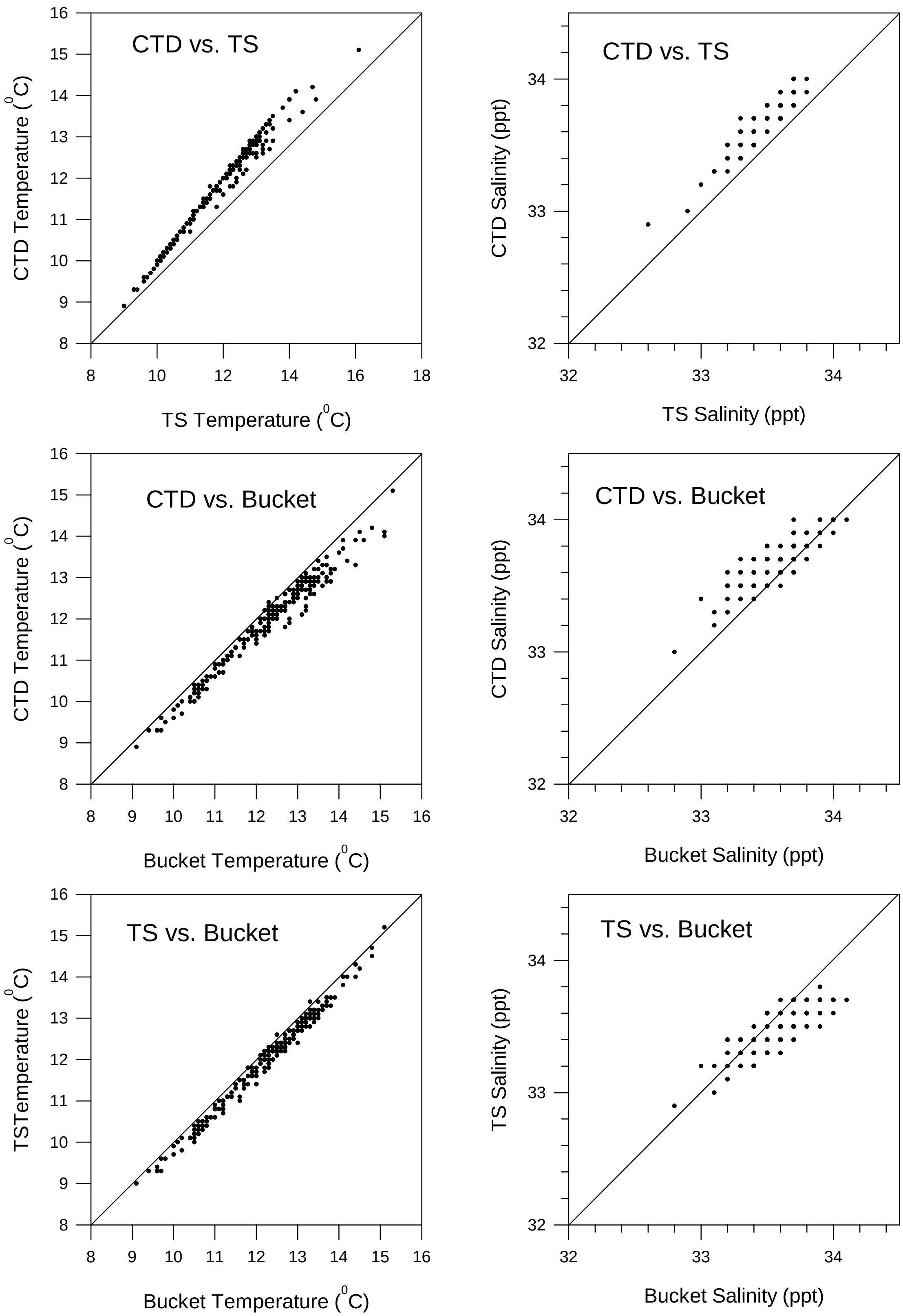

AVHRR Satellite Multichannel SST
5-Night Composite from May 14, 2001
17.5
16.7
16.0
15.3
14.6
13.9
13.2
12.5
11.7
11.0
10.3
9.6
8.9
8.2
7.5
WIM
39
38
37
36
Latitude (°N)
125
124
123
122
Longitude (°W)


AVHRR Satellite Multichannel SST
5-Night Composite from May 21, 2001
17.5
16.7
16.0
15.3
14.6
13.9
13.2
12.5
11.7
11.0
10.3
9.6
8.9
8.2
7.5
WIM
39
38
37
36
Latitude (°N)
125
124
123
122
Longitude (°W)

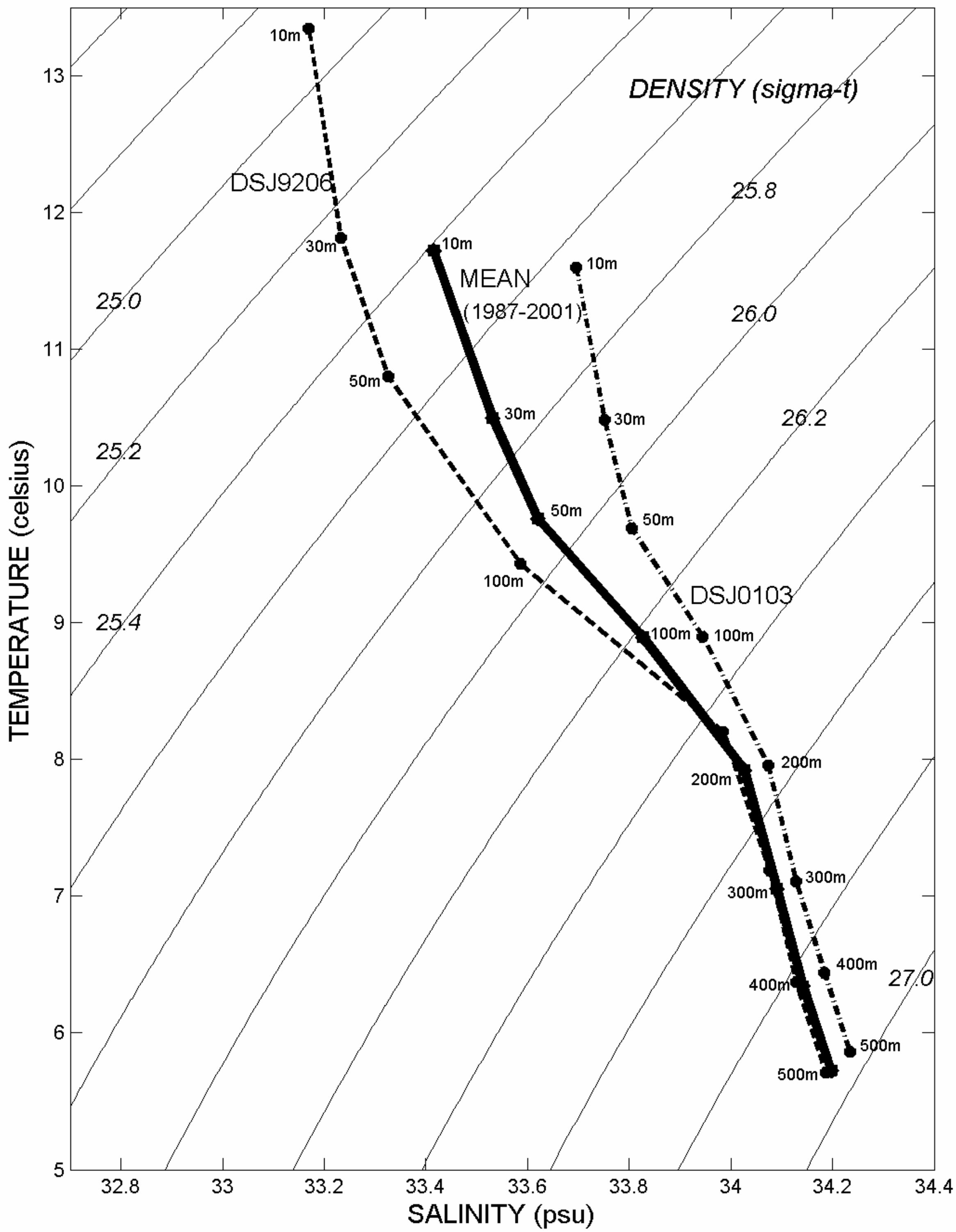

AVHRR Satellite Multichannel SST
5-Night Composite from June 4, 2001
17.5
16.7
16.0
15.3
14.6
13.9
13.2
12.5
11.7
11.0
10.3
9.6
8.9
8.2
7.5
WIM
39
38
37
36
Latitude (°N)
125
124
123
122
Longitude (°W)

APPENDIX 5: REGRESSION COMPARISONS OF CTD, TS, AND BUCKET FOR DSJ0103

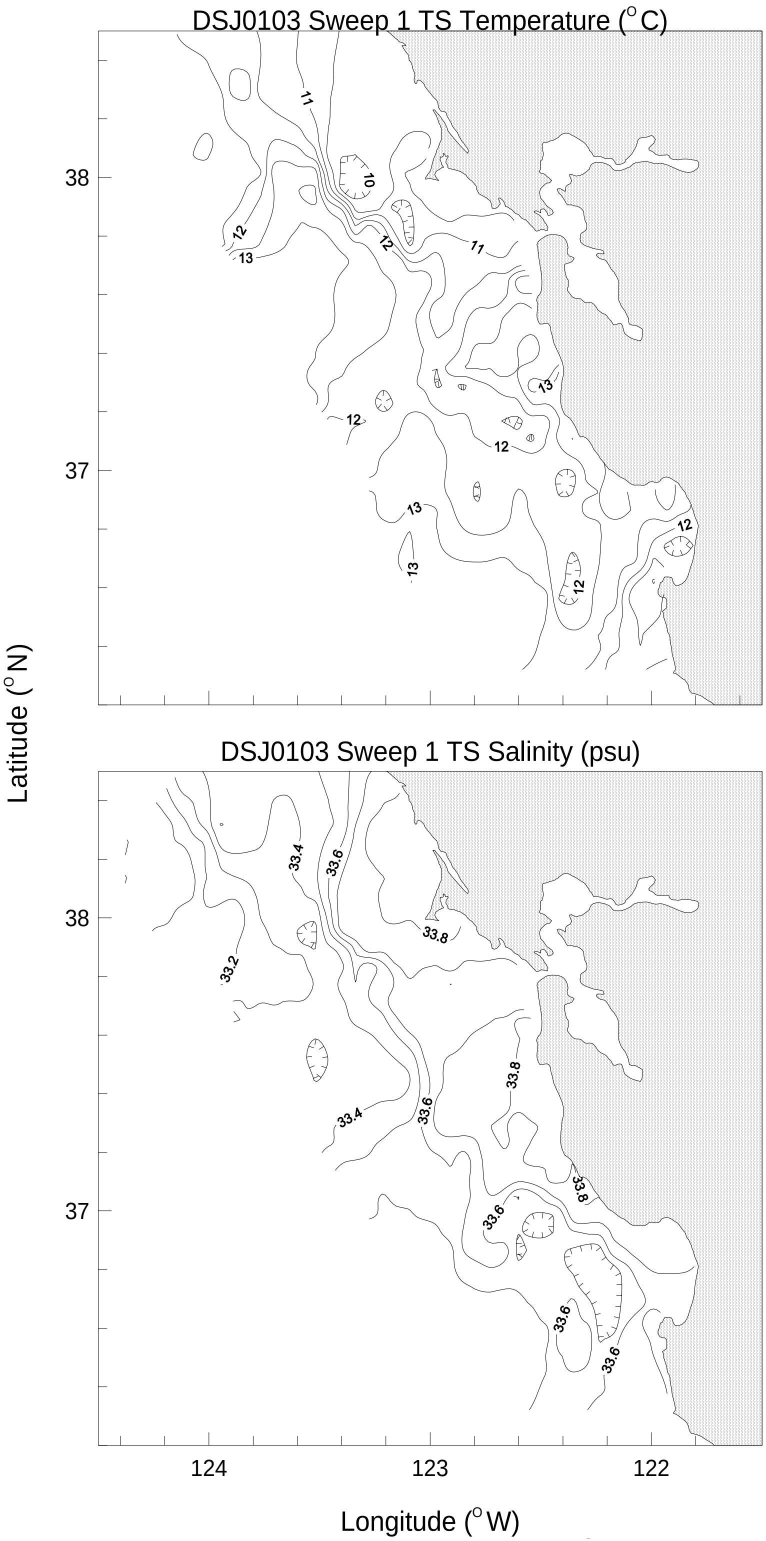
DSJ0103


CTD vs. TS
CTD Temperature (⁰C)
TS Temperature (⁰C)
CTD vs. TS
CTD Salinity (ppt)
TS Salinity (ppt)
CTD vs. Bucket
CTD Temperature (⁰C)
Bucket Temperature (⁰C)
CTD vs. Bucket
CTD Salinity (ppt)
Bucket Salinity (ppt)
TS vs. Bucket
TSTemperature (⁰C)
Bucket Temperature (⁰C)
TS vs. Bucket
TS Salinity (ppt)
Bucket Salinity (ppt)

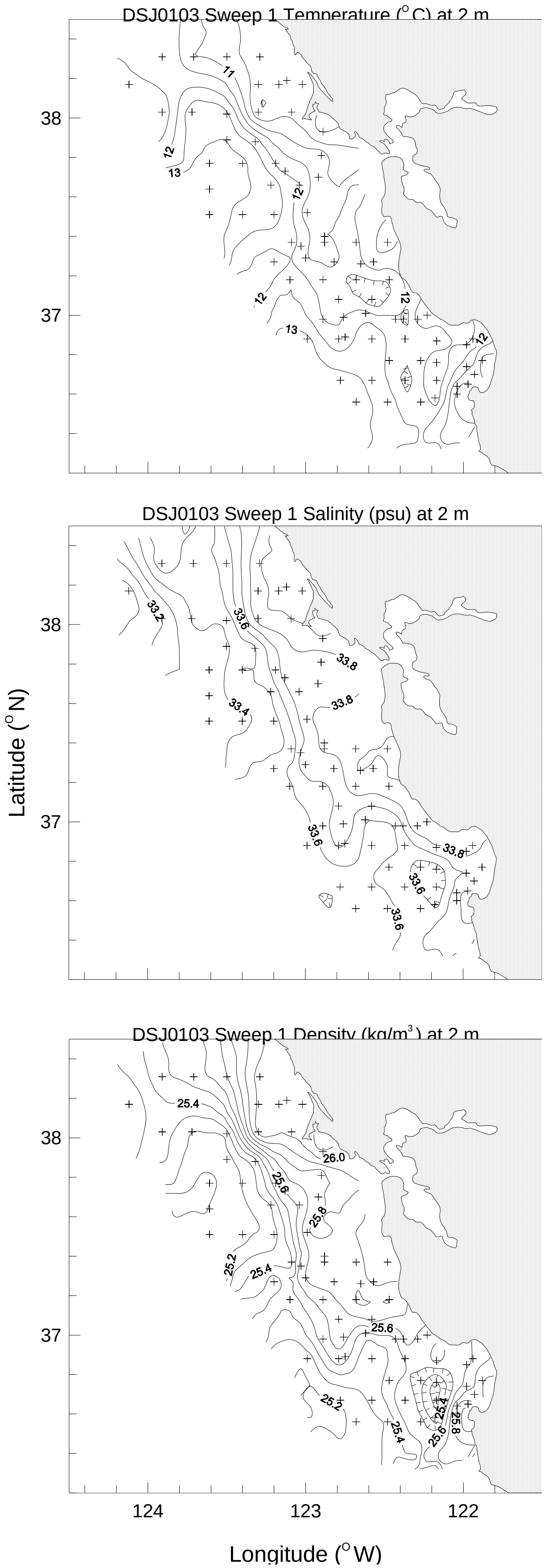
APPENDIX 6: CTD MEAN TEMPERATURE VS. MEAN SALINITY PLOTS

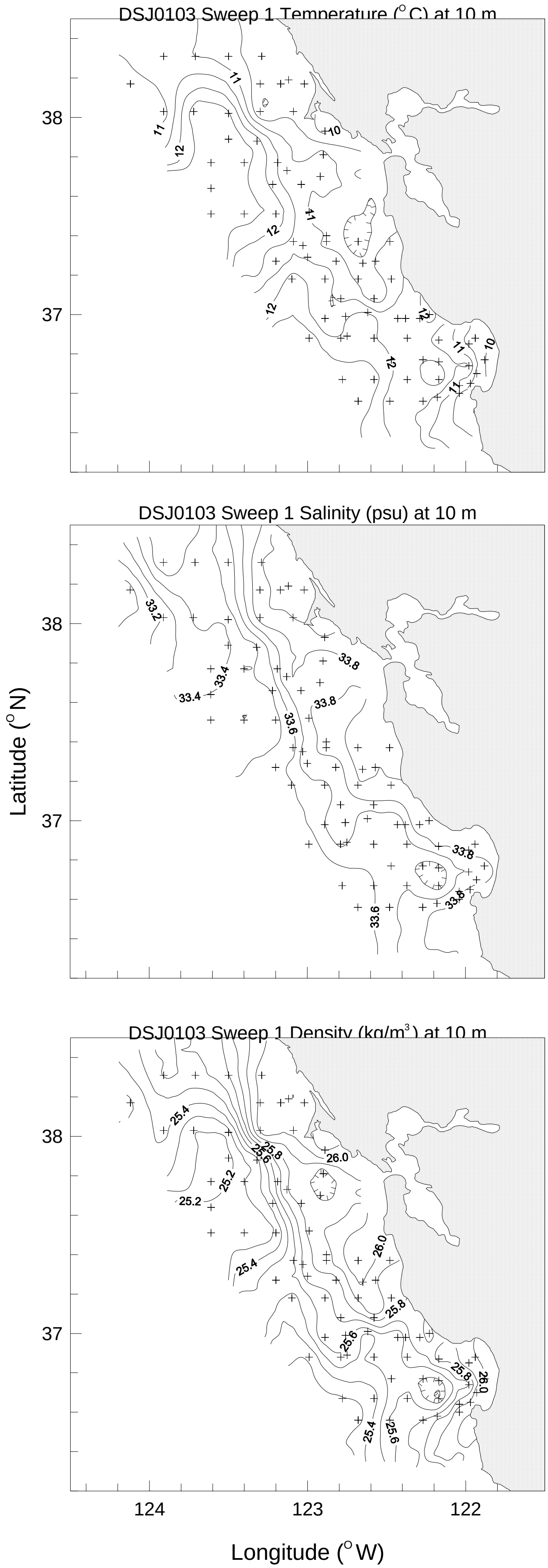

DENSITY (sigma-t)
25.0
25.2
25.4
25.8
26.0
26.2
27.0
DSJ9206
MEAN
(1987-2001)
DSJ0103
10m
30m
50m
100m
200m
300m
400m
500m
TEMPERATURE (celsius)
SALINITY (psu)
13
12
11
10
9
8
7
6
5
32.8
33
33.2
33.4
33.6
33.8
34
34.2
34.4

APPENDIX 7.1: HORIZONTAL MAPS OF TS AND CTD FOR DSJ0103, SWEEP 1

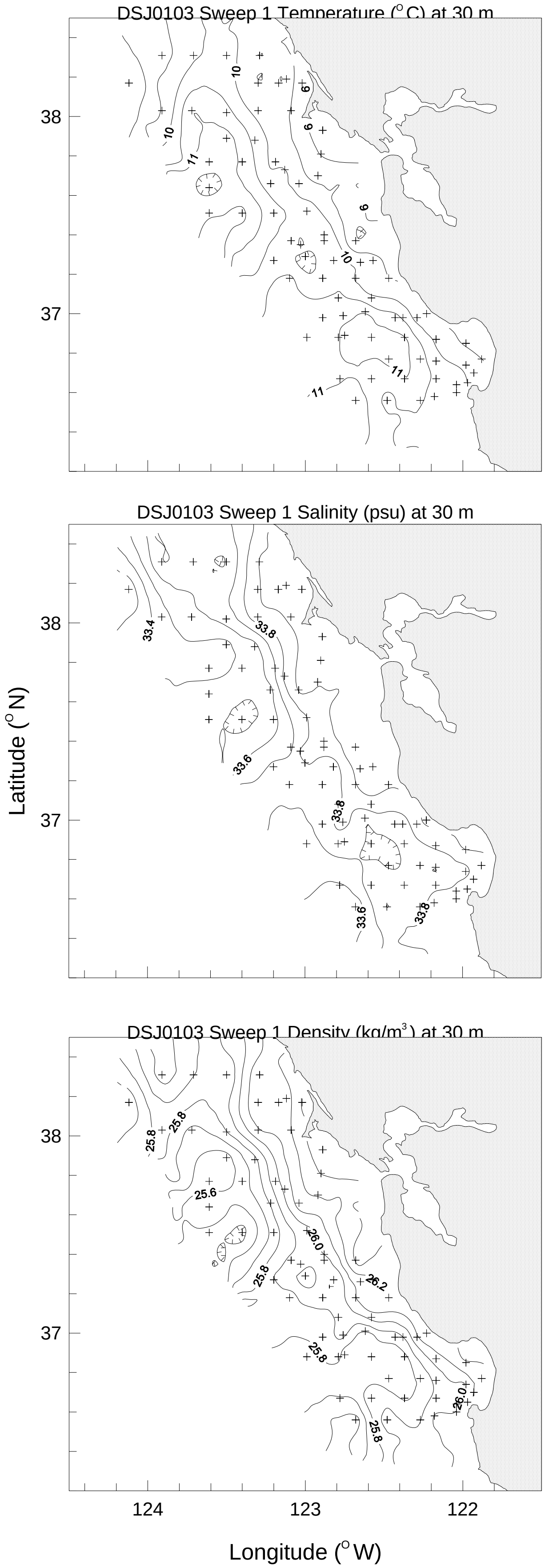


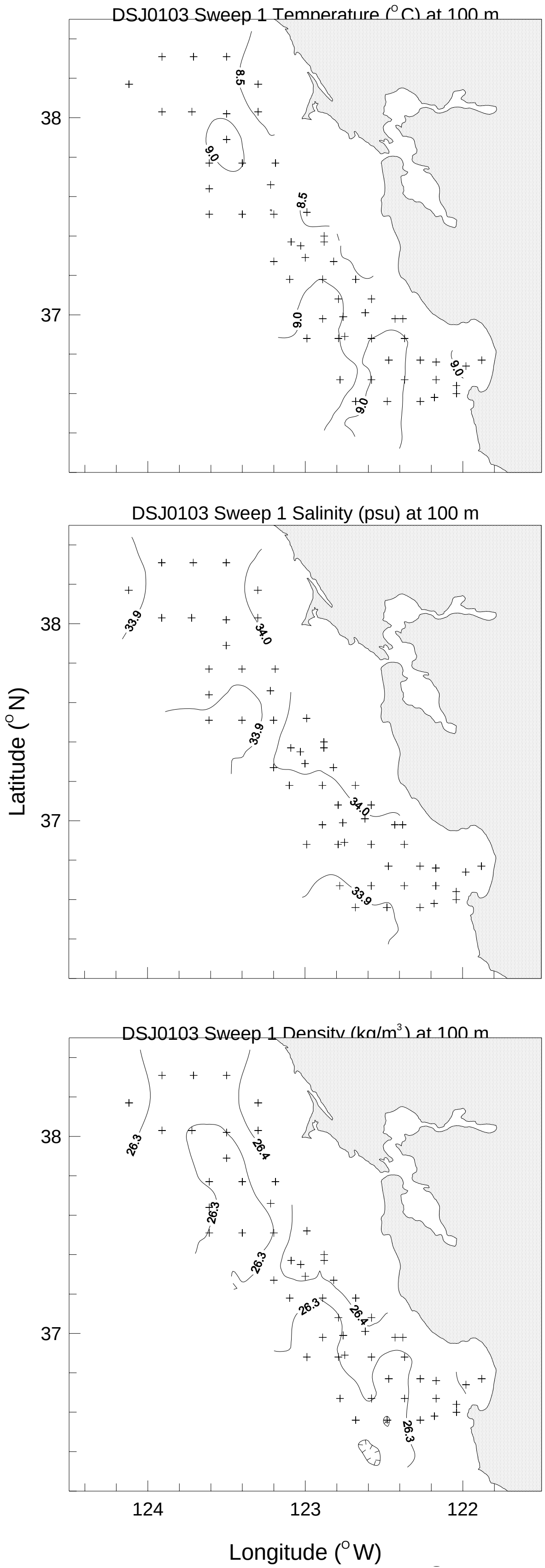
DSJ0103 Sweep 1 TS Temperature (°C)
DSJ0103 Sweep 1 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
10
11
12
13
33.2
33.4
33.6
33.8


DSJ0103 Sweep 1 Temperature (°C) at 2 m
11
12
13
38
37
DSJ0103 Sweep 1 Salinity (psu) at 2 m
33.2
33.6
33.8
33.4
Latitude (°N)
DSJ0103 Sweep 1 Density (kg/m³) at 2 m
25.4
26.0
25.6
25.8
25.2
124
123
122
Longitude (°W)

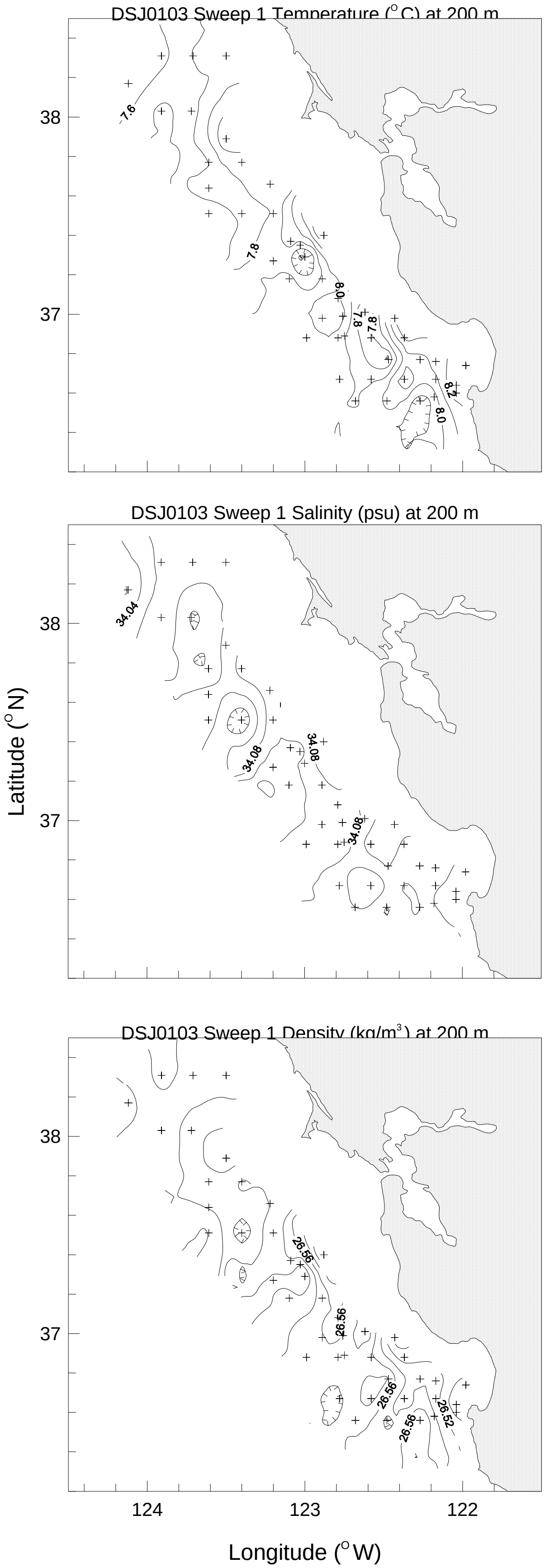


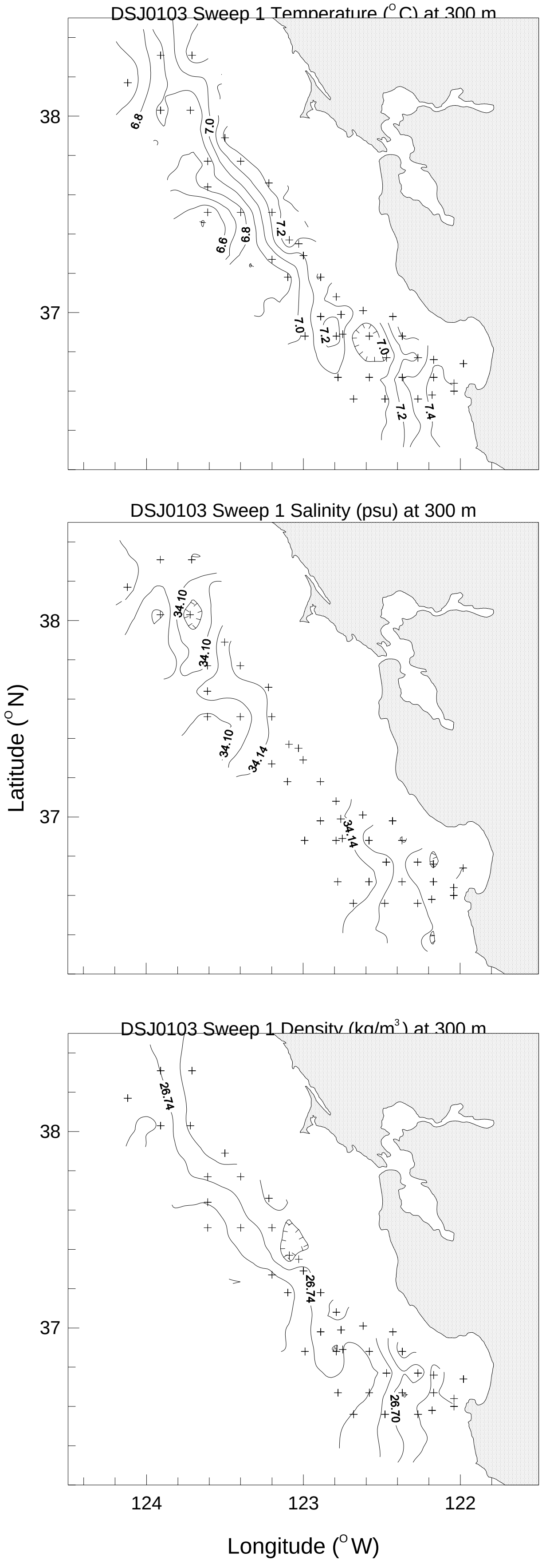
DSJ0103 Sweep 1 Temperature (°C) at 10 m
DSJ0103 Sweep 1 Salinity (psu) at 10 m
DSJ0103 Sweep 1 Density (kg/m³) at 10 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122

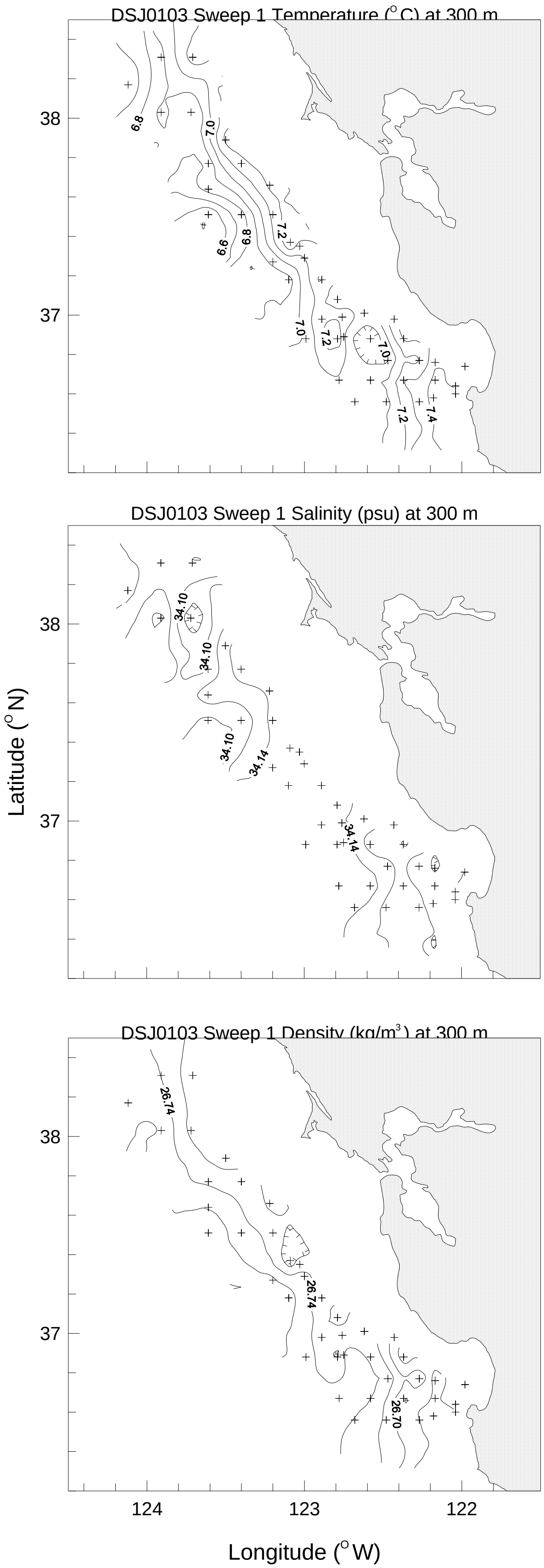

DSJ0103 Sweep 1 Temperature (°C) at 30 m
10
9
11
DSJ0103 Sweep 1 Salinity (psu) at 30 m
33.4
33.8
33.6
DSJ0103 Sweep 1 Density (kg/m³) at 30 m
25.8
25.6
26.0
26.2
38
37
Latitude (°N)
124
123
122
Longitude (°W)



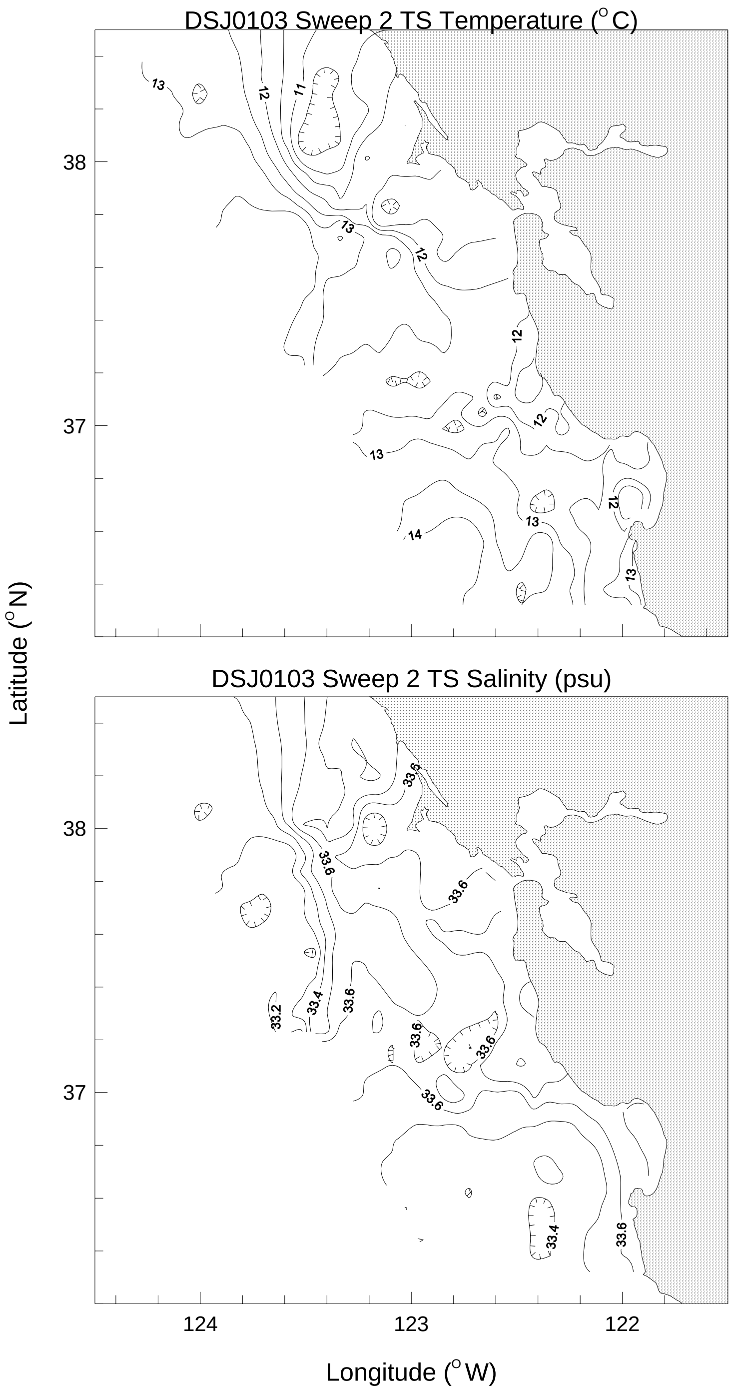
DSJ0103 Sweep 1 Temperature (°C) at 100 m
DSJ0103 Sweep 1 Salinity (psu) at 100 m
DSJ0103 Sweep 1 Density (kg/m³) at 100 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
8.5
9.0
33.9
34.0
26.3
26.4

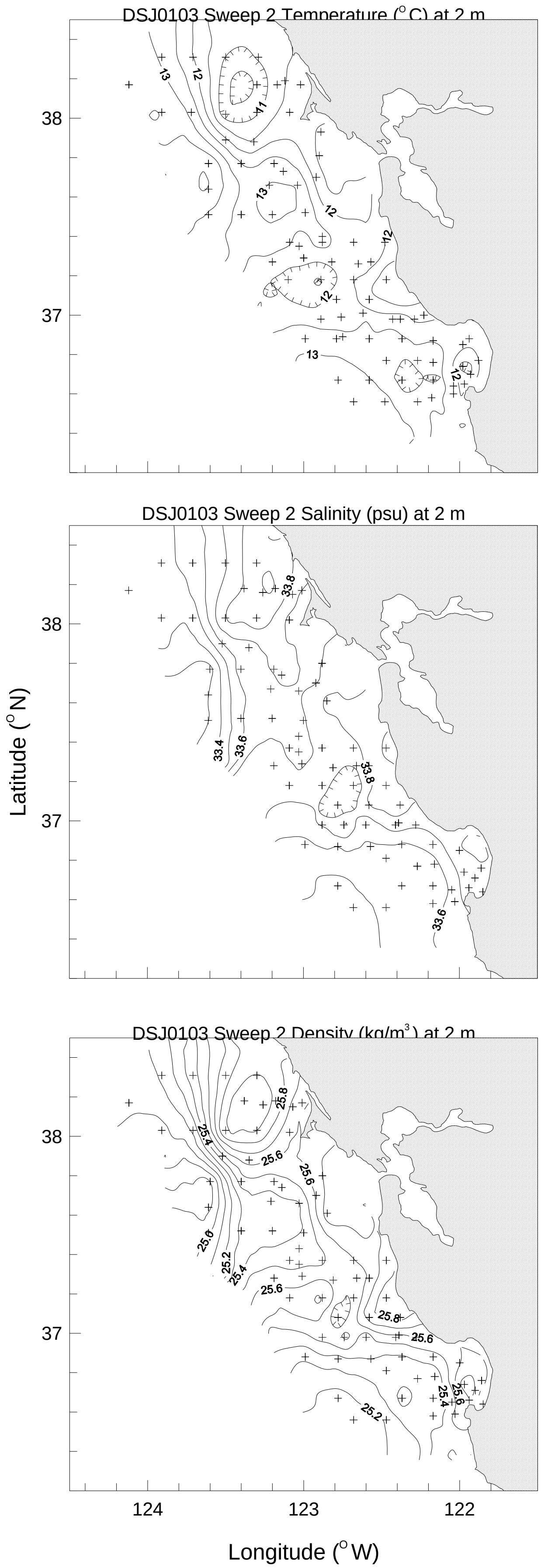

DSJ0103 Sweep 1 Temperature (°C) at 200 m
DSJ0103 Sweep 1 Salinity (psu) at 200 m
DSJ0103 Sweep 1 Density (kg/m³) at 200 m
7.6
7.8
8.0
8.2
34.04
34.08
26.56
26.52
38
37
124
123
122
Latitude (°N)
Longitude (°W)

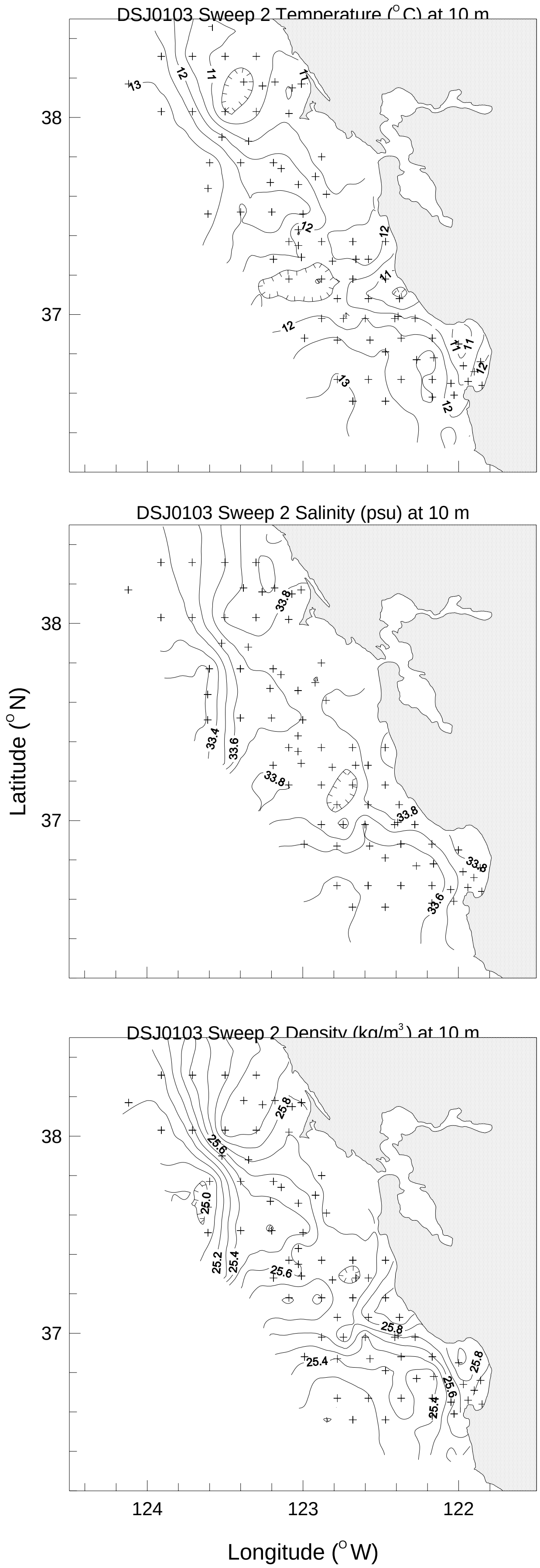

DSJ0103 Sweep 1 Temperature (°C) at 300 m
6.8
7.0
7.2
6.6
6.8
7.0
7.2
7.0
7.2
7.4
DSJ0103 Sweep 1 Salinity (psu) at 300 m
34.10
34.10
34.10
34.14
34.14
DSJ0103 Sweep 1 Density (kg/m³) at 300 m
26.74
26.74
26.70
38
37
Latitude (°N)
124
123
122
Longitude (°W)

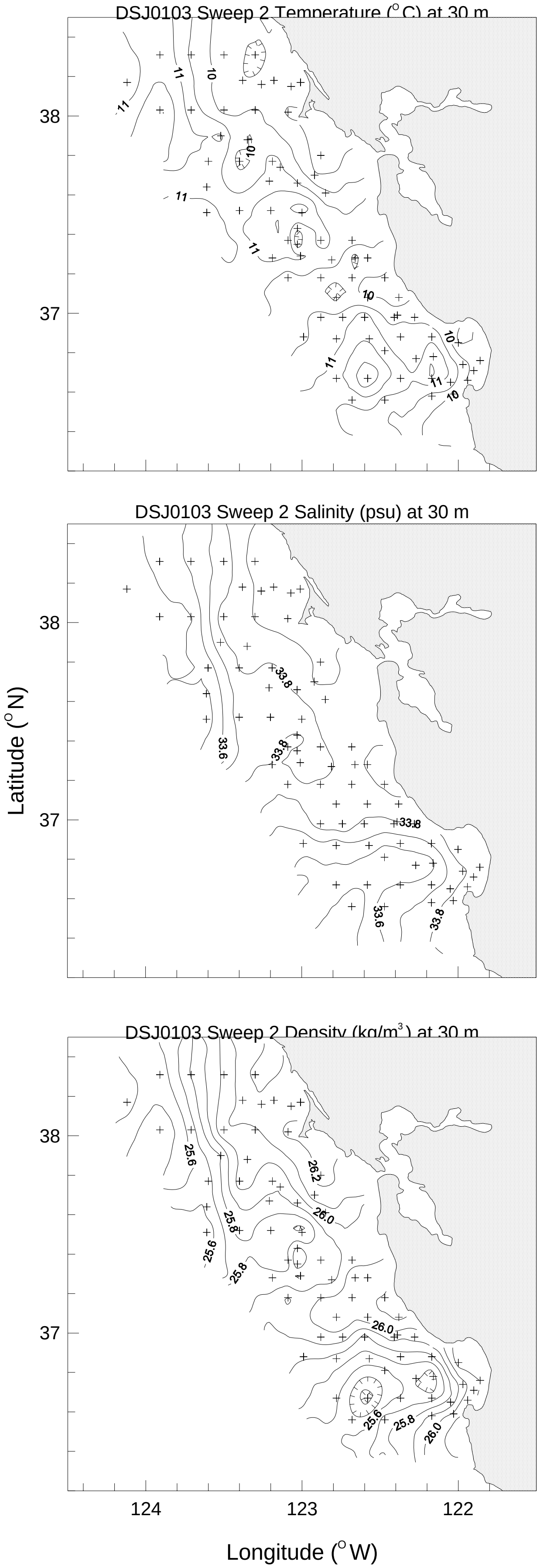

DSJ0103 Sweep 1 Temperature (°C) at 300 m
DSJ0103 Sweep 1 Salinity (psu) at 300 m
DSJ0103 Sweep 1 Density (kg/m³) at 300 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
6.6
6.8
7.0
7.2
7.4
34.10
34.14
26.74
26.70

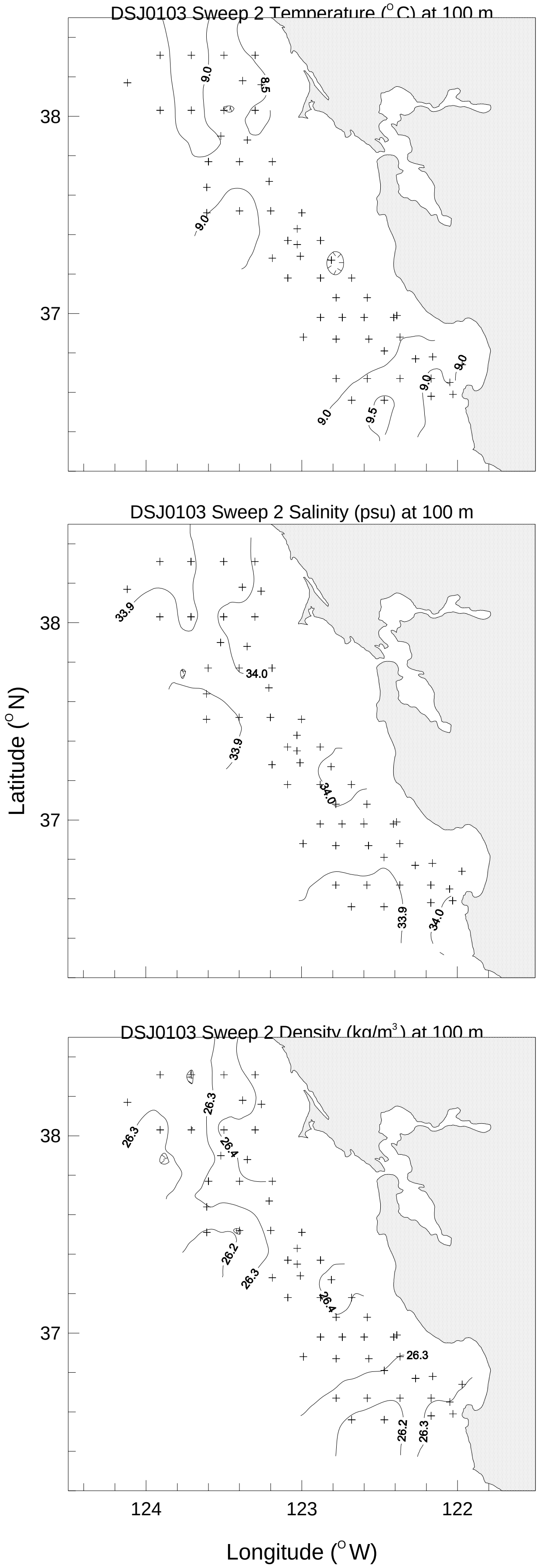
APPENDIX 7.2: HORIZONTAL MAPS OF TS AND CTD FOR DSJ0103, SWEEP 2

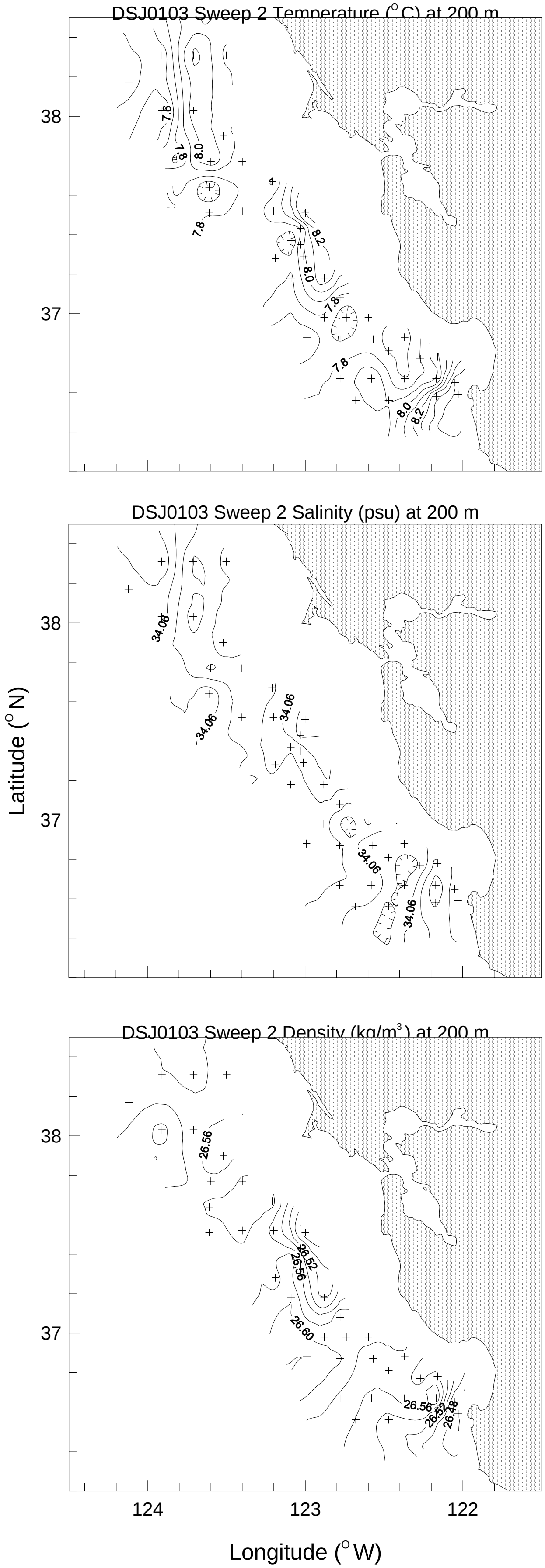

DSJ0103 Sweep 2 TS Temperature (°C)
DSJ0103 Sweep 2 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
11
12
13
14
33.2
33.4
33.6

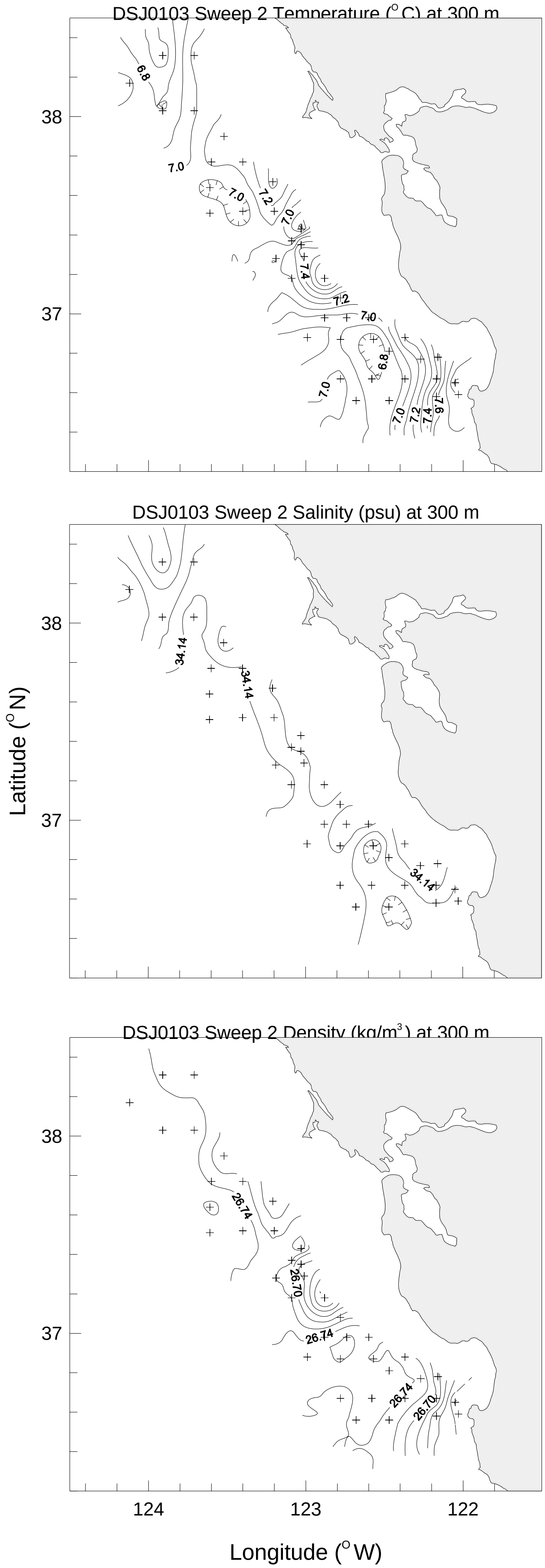

DSJ0103 Sweep 2 Temperature (°C) at 2 m
DSJ0103 Sweep 2 Salinity (psu) at 2 m
DSJ0103 Sweep 2 Density (kg/m³) at 2 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
13
12
11
33.4
33.6
33.8
25.0
25.2
25.4
25.6
25.8

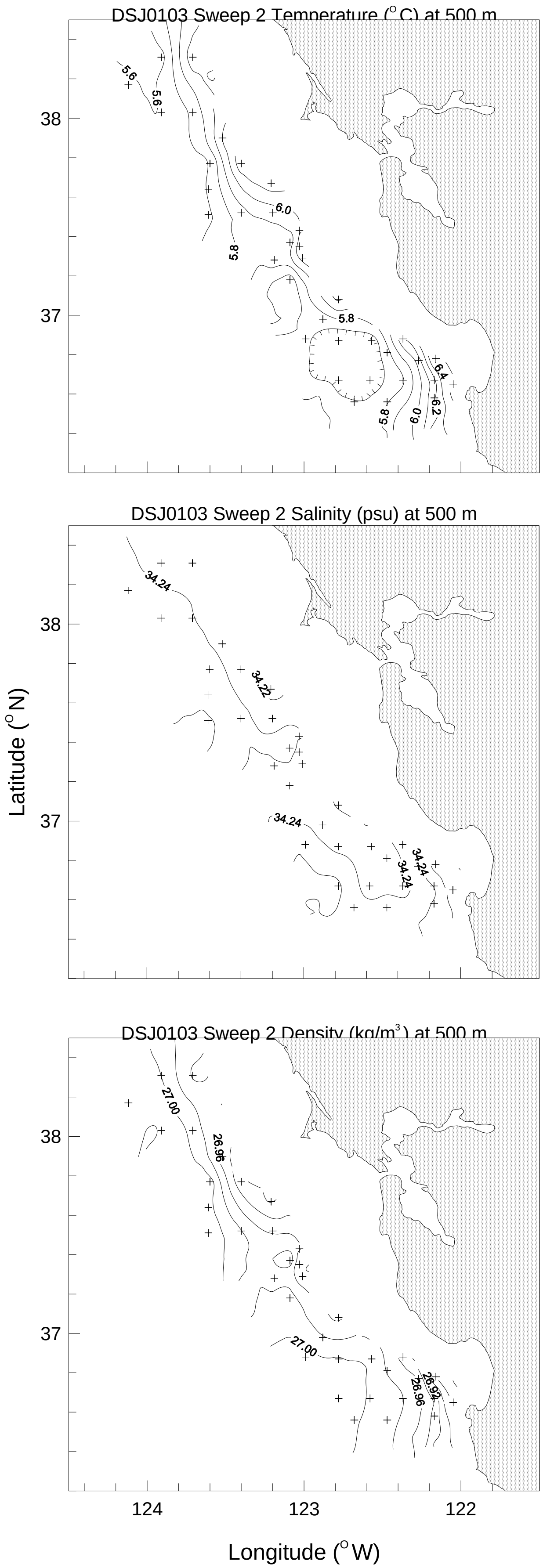

DSJ0103 Sweep 2 Temperature (°C) at 10 m
DSJ0103 Sweep 2 Salinity (psu) at 10 m
DSJ0103 Sweep 2 Density (kg/m³) at 10 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)


DSJ0103 Sweep 2 Temperature (°C) at 30 m
DSJ0103 Sweep 2 Salinity (psu) at 30 m
DSJ0103 Sweep 2 Density (kg/m³) at 30 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
11
10
33.6
33.8
25.6
25.8
26.0
26.2

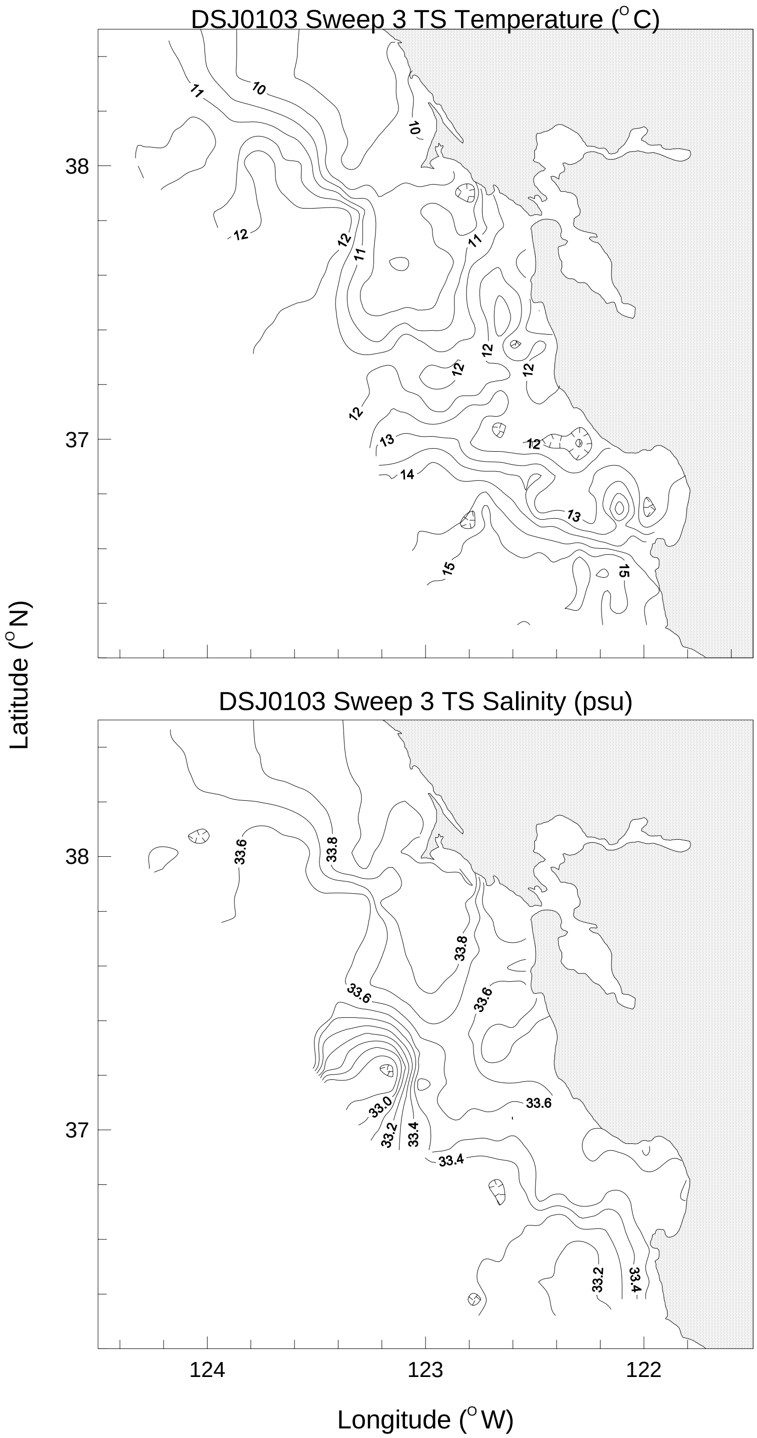

DSJ0103 Sweep 2 Temperature (°C) at 100 m
9.0
8.5
9.0
9.0
9.0
9.5
9.0
9.0
DSJ0103 Sweep 2 Salinity (psu) at 100 m
33.9
34.0
33.9
34.0
33.9
34.0
DSJ0103 Sweep 2 Density (kg/m³) at 100 m
26.3
26.3
26.4
26.2
26.3
26.4
26.3
26.2
26.3
38
37
Latitude (°N)
124
123
122
Longitude (°W)

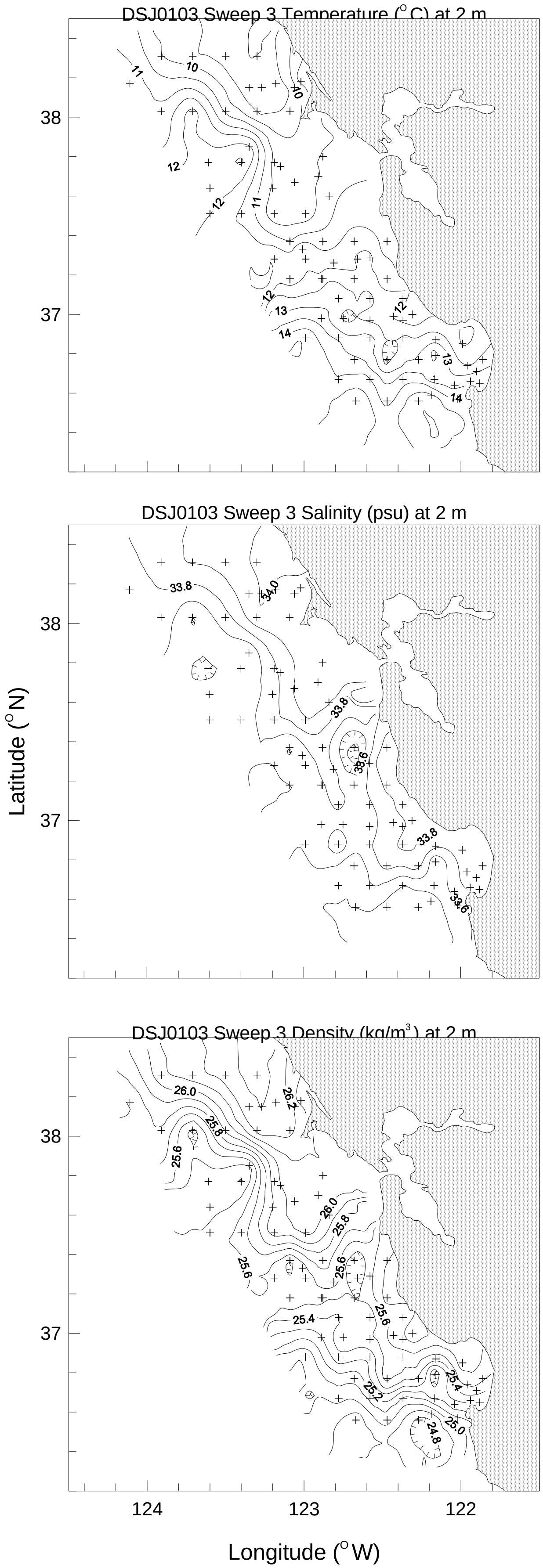

DSJ0103 Sweep 2 Temperature (°C) at 200 m
DSJ0103 Sweep 2 Salinity (psu) at 200 m
DSJ0103 Sweep 2 Density (kg/m³) at 200 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122

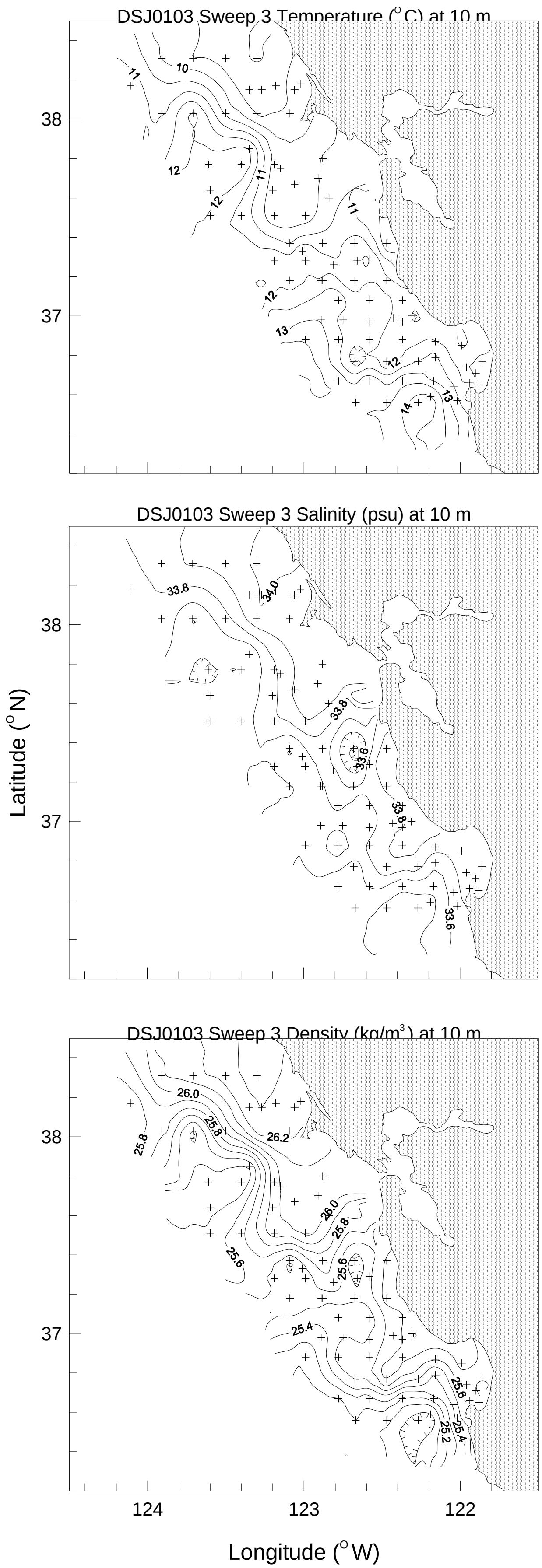

DSJ0103 Sweep 2 Temperature (°C) at 300 m
DSJ0103 Sweep 2 Salinity (psu) at 300 m
DSJ0103 Sweep 2 Density (kg/m³) at 300 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
6.8
7.0
7.2
7.4
7.6
34.14
26.74
26.70

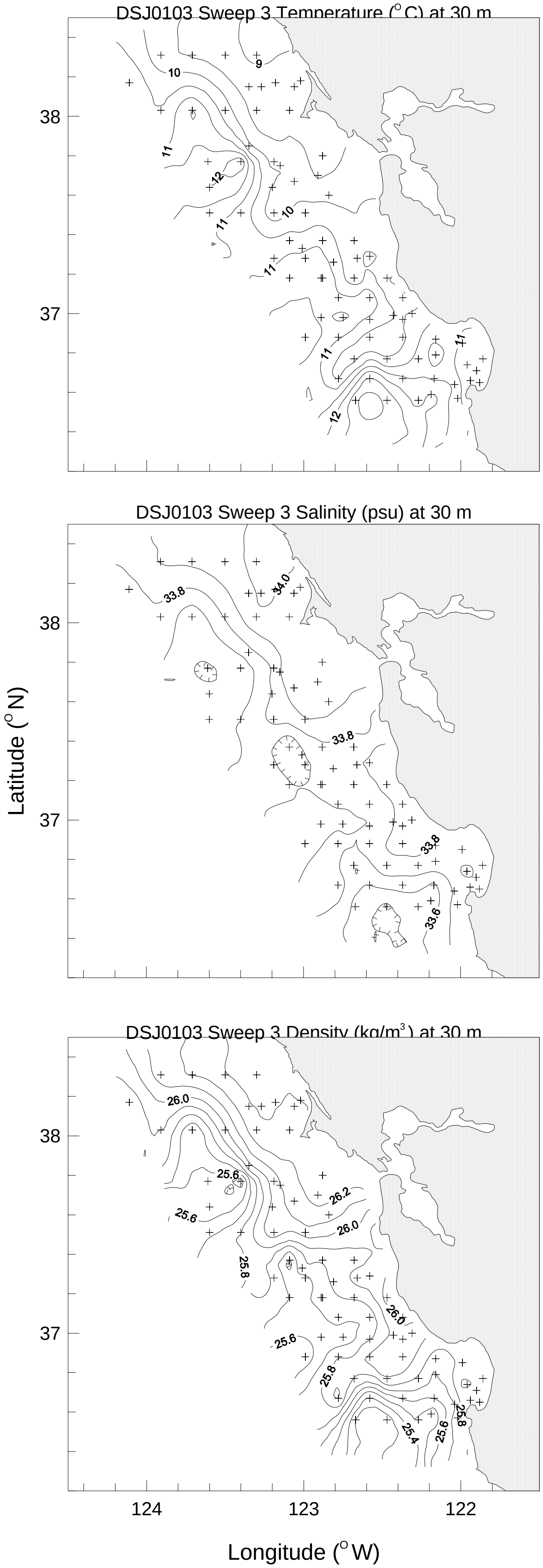

DSJ0103 Sweep 2 Temperature (°C) at 500 m
5.6
5.6
6.0
5.8
5.8
6.4
5.8
6.0
6.2
DSJ0103 Sweep 2 Salinity (psu) at 500 m
34.24
34.22
34.24
34.24
34.24
DSJ0103 Sweep 2 Density (kg/m³) at 500 m
27.00
26.96
27.00
26.92
26.96
38
37
Latitude (°N)
124
123
122
Longitude (°W)

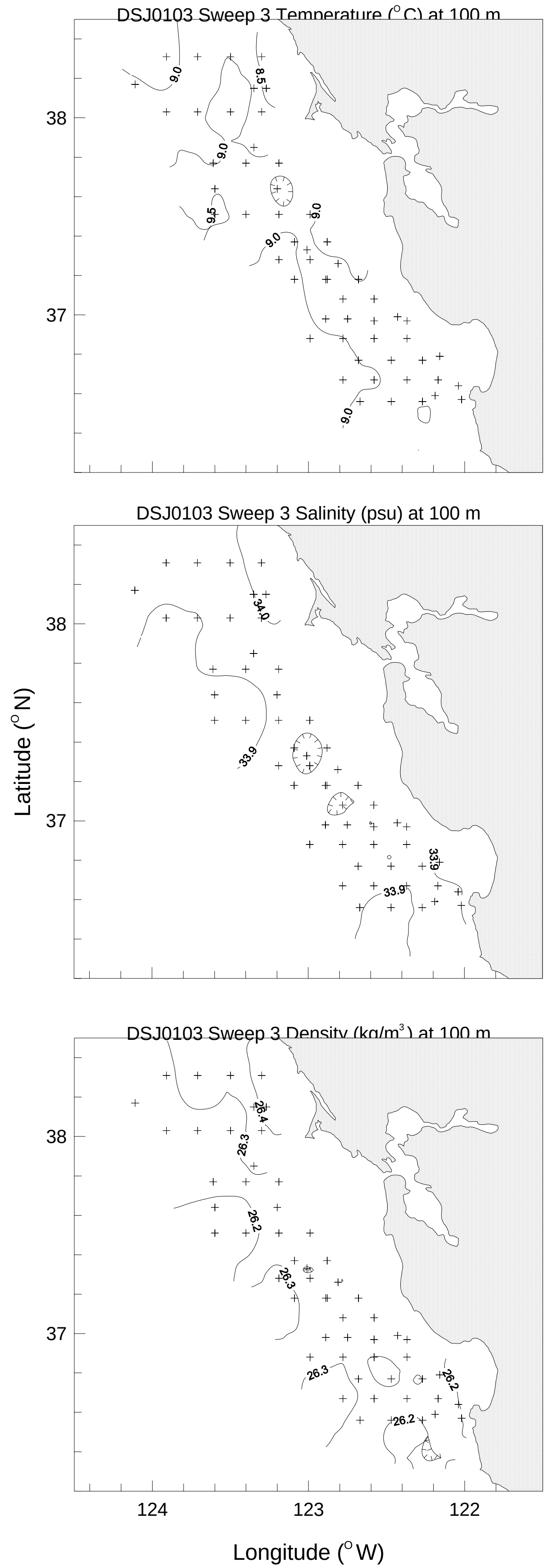
APPENDIX 7.3: HORIZONTAL MAPS OF CTD AND TS FOR DSJ0103, SWEEP 3

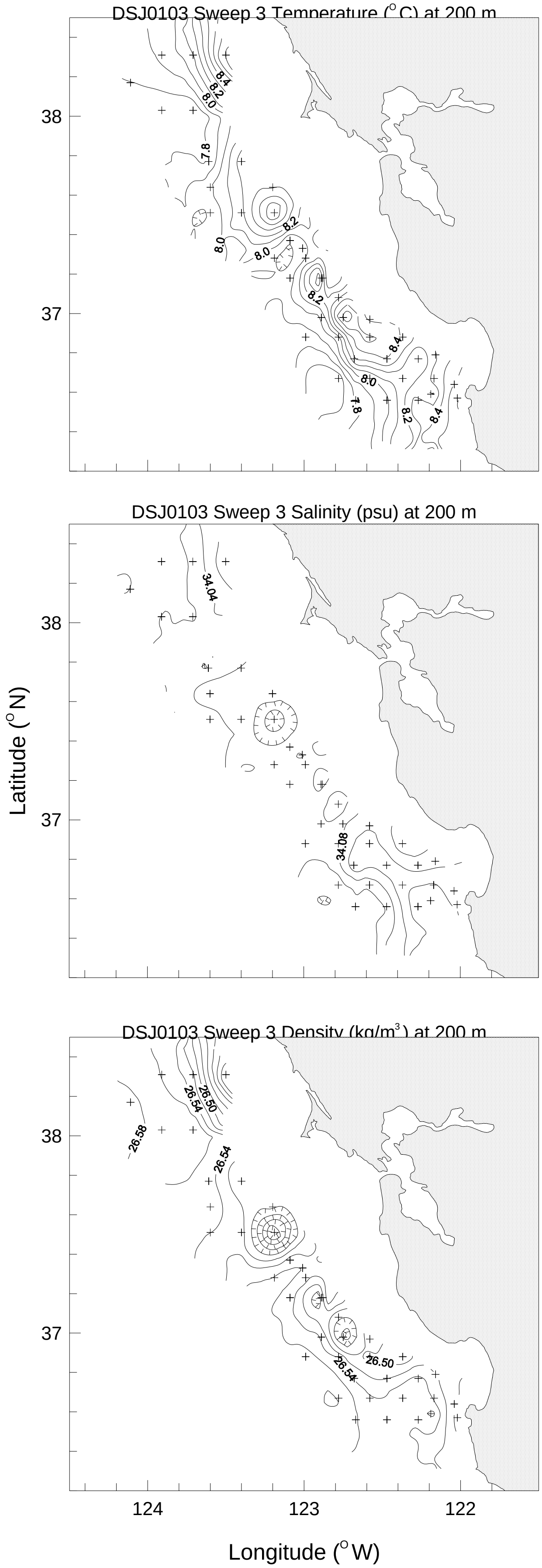

DSJ0103 Sweep 3 TS Temperature (°C)
DSJ0103 Sweep 3 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
10
11
12
13
14
15
33.0
33.2
33.4
33.6
33.8

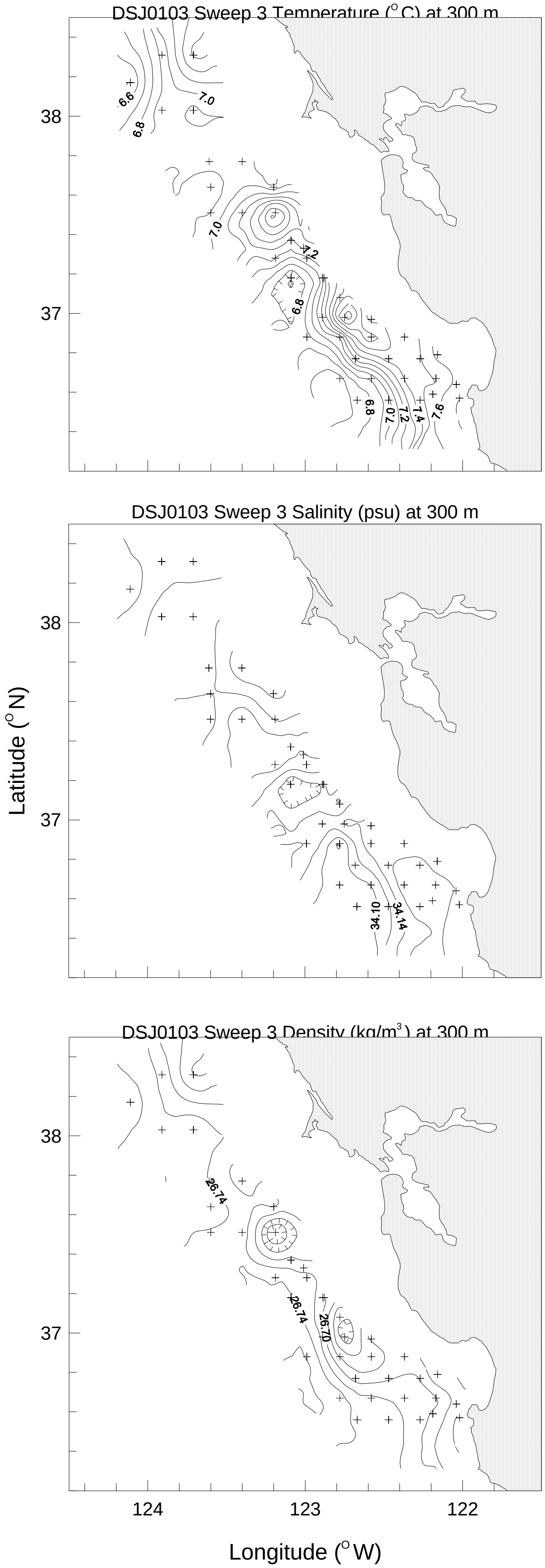

DSJ0103 Sweep 3 Temperature (°C) at 2 m
DSJ0103 Sweep 3 Salinity (psu) at 2 m
DSJ0103 Sweep 3 Density (kg/m³) at 2 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)
10
11
12
13
14
33.8
34.0
33.6
26.0
26.2
25.8
25.6
25.4
25.2
25.0
24.8

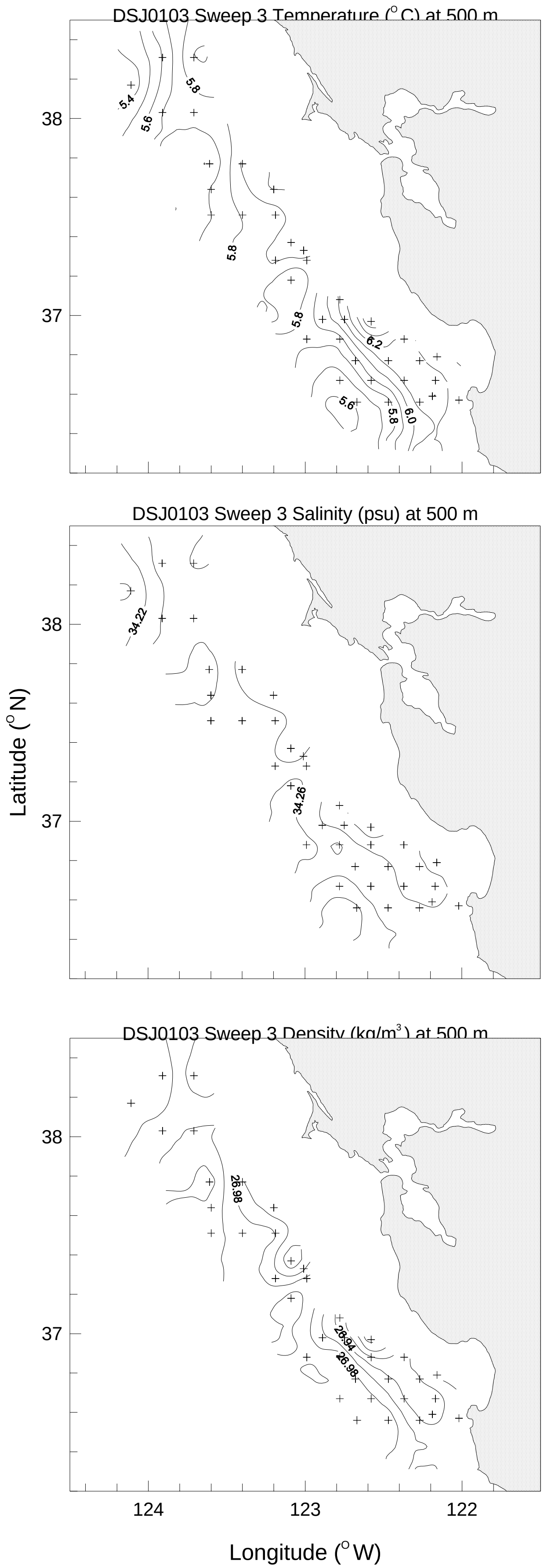

DSJ0103 Sweep 3 Temperature (°C) at 10 m
DSJ0103 Sweep 3 Salinity (psu) at 10 m
DSJ0103 Sweep 3 Density (kg/m³) at 10 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122


DSJ0103 Sweep 3 Temperature (°C) at 30 m
9
10
11
12
DSJ0103 Sweep 3 Salinity (psu) at 30 m
34.0
33.8
33.6
DSJ0103 Sweep 3 Density (kg/m³) at 30 m
26.0
26.2
25.8
25.6
25.4
38
37
Latitude (°N)
124
123
122
Longitude (°W)

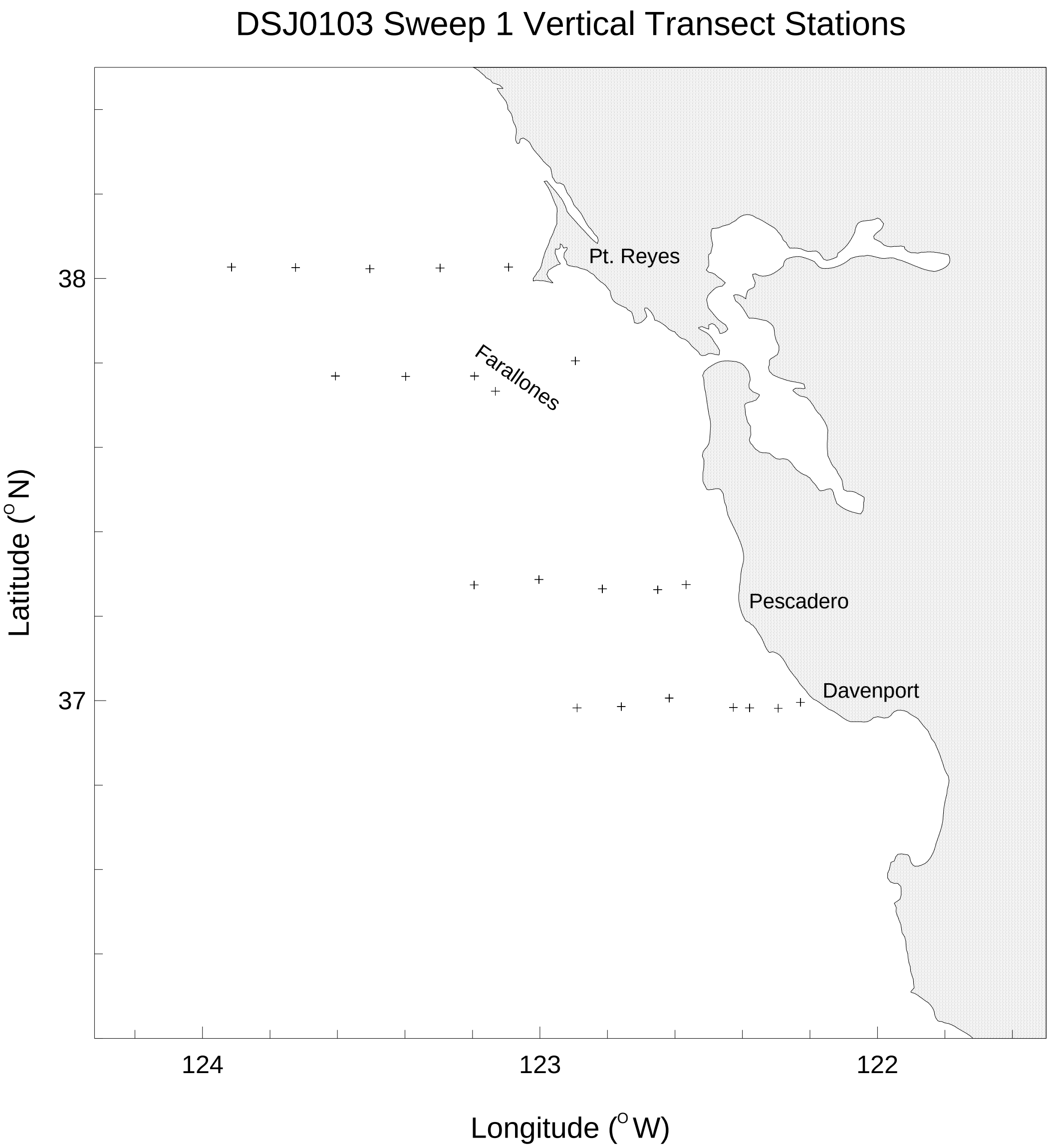

DSJ0103 Sweep 3 Temperature (°C) at 100 m
38
37
9.0
8.5
9.5
DSJ0103 Sweep 3 Salinity (psu) at 100 m
Latitude (°N)
34.0
33.9
DSJ0103 Sweep 3 Density (kg/m³) at 100 m
26.4
26.3
26.2
124
123
122
Longitude (°W)

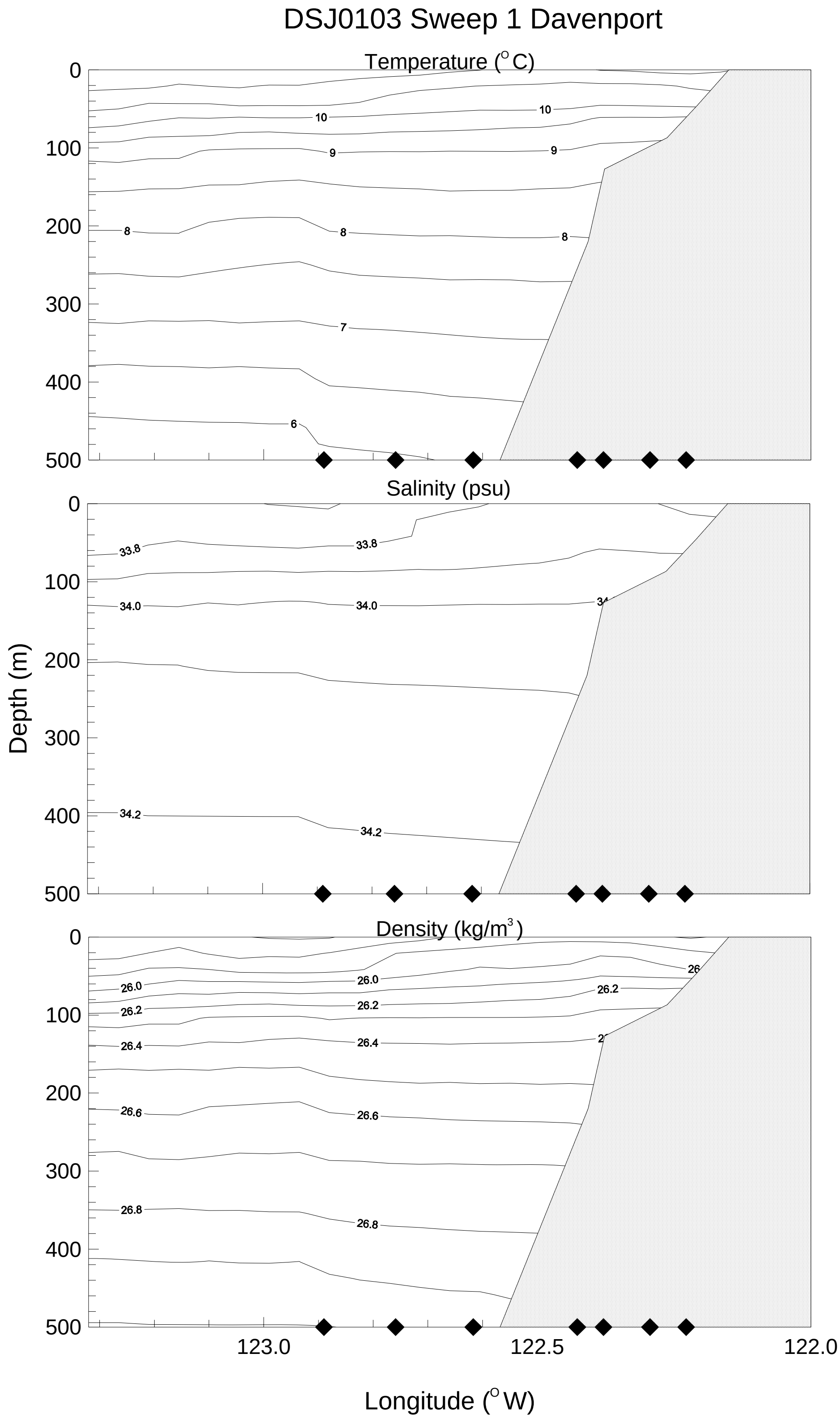

DSJ0103 Sweep 3 Temperature (°C) at 200 m
DSJ0103 Sweep 3 Salinity (psu) at 200 m
DSJ0103 Sweep 3 Density (kg/m³) at 200 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
8.4
8.2
8.0
7.8
34.04
34.08
26.50
26.54
26.58


DSJ0103 Sweep 3 Temperature (°C) at 300 m
DSJ0103 Sweep 3 Salinity (psu) at 300 m
DSJ0103 Sweep 3 Density (kg/m³) at 300 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
6.6
6.8
7.0
7.2
7.4
7.6
34.10
34.14
26.74
26.70

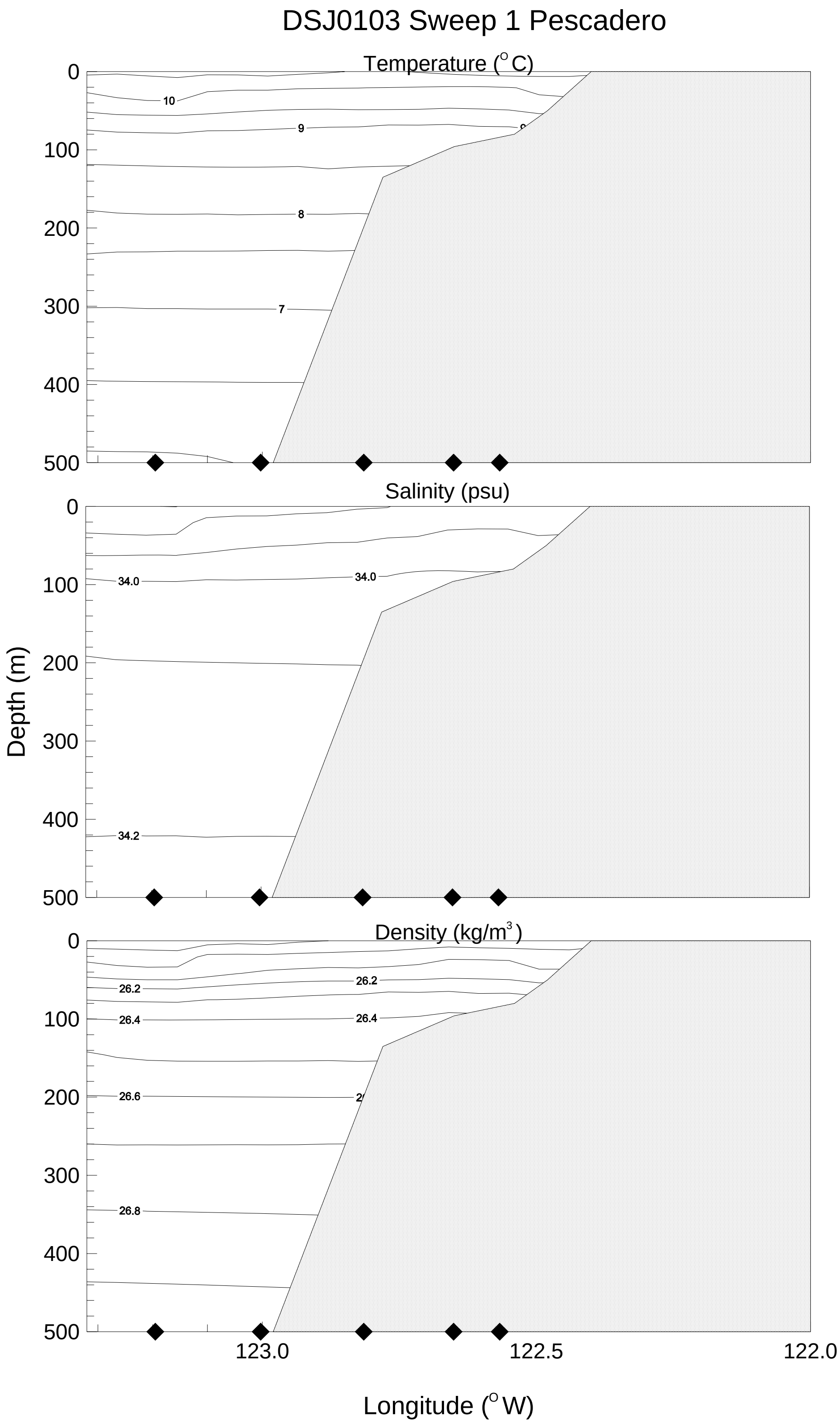

DSJ0103 Sweep 3 Temperature (°C) at 500 m
5.4
5.6
5.8
5.8
5.8
6.2
5.6
5.8
6.0
DSJ0103 Sweep 3 Salinity (psu) at 500 m
34.22
34.26
DSJ0103 Sweep 3 Density (kg/m³) at 500 m
26.98
26.94
26.98
38
37
Latitude (°N)
124
123
122
Longitude (°W)

APPENDIX 8: VERTICAL SECTIONS FOR DSJ0103

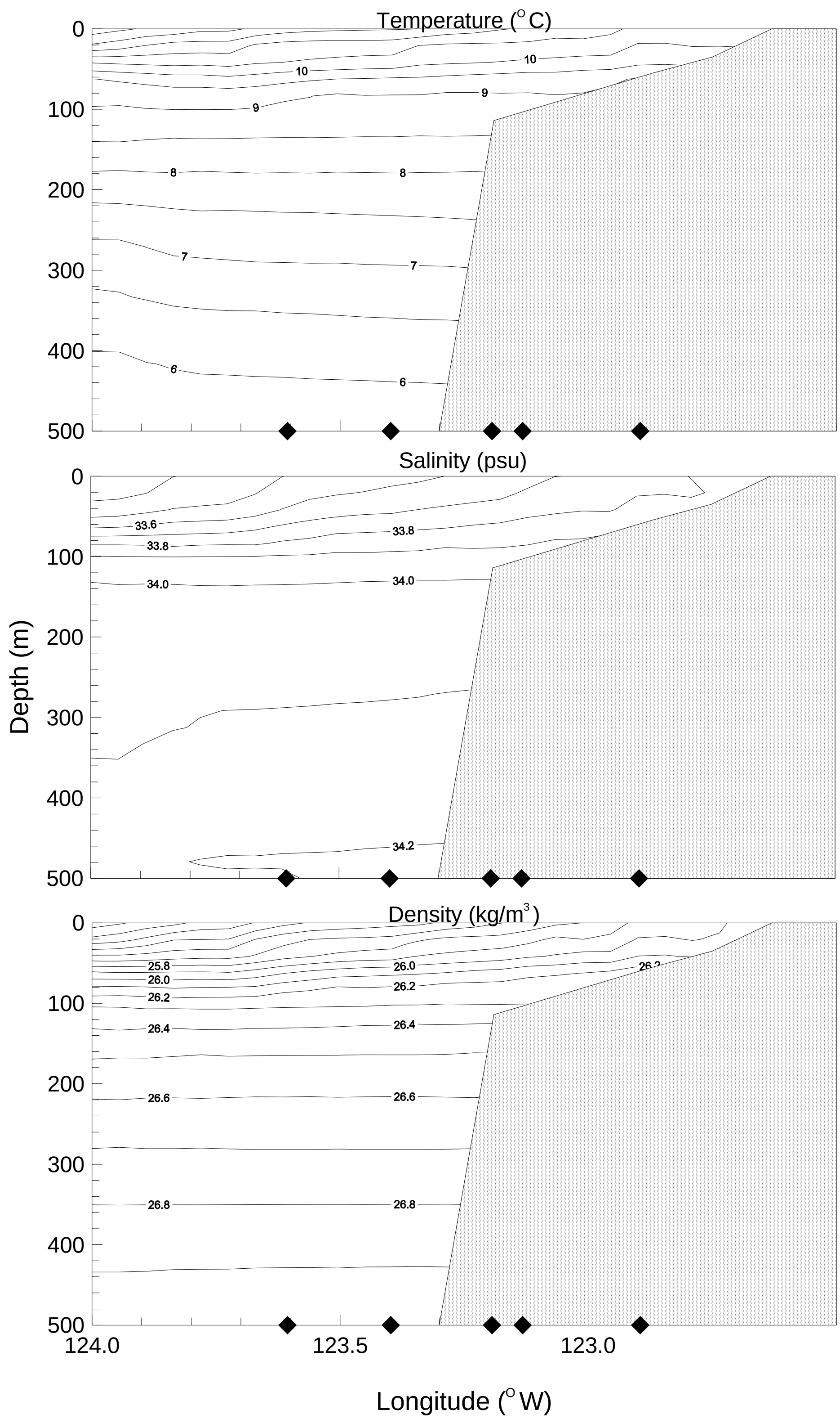

DSJ0103 Sweep 1 Vertical Transect Stations
Pt. Reyes
Farallones
Pescadero
Davenport
38
37
Latitude (°N)
124
123
122
Longitude (°W)



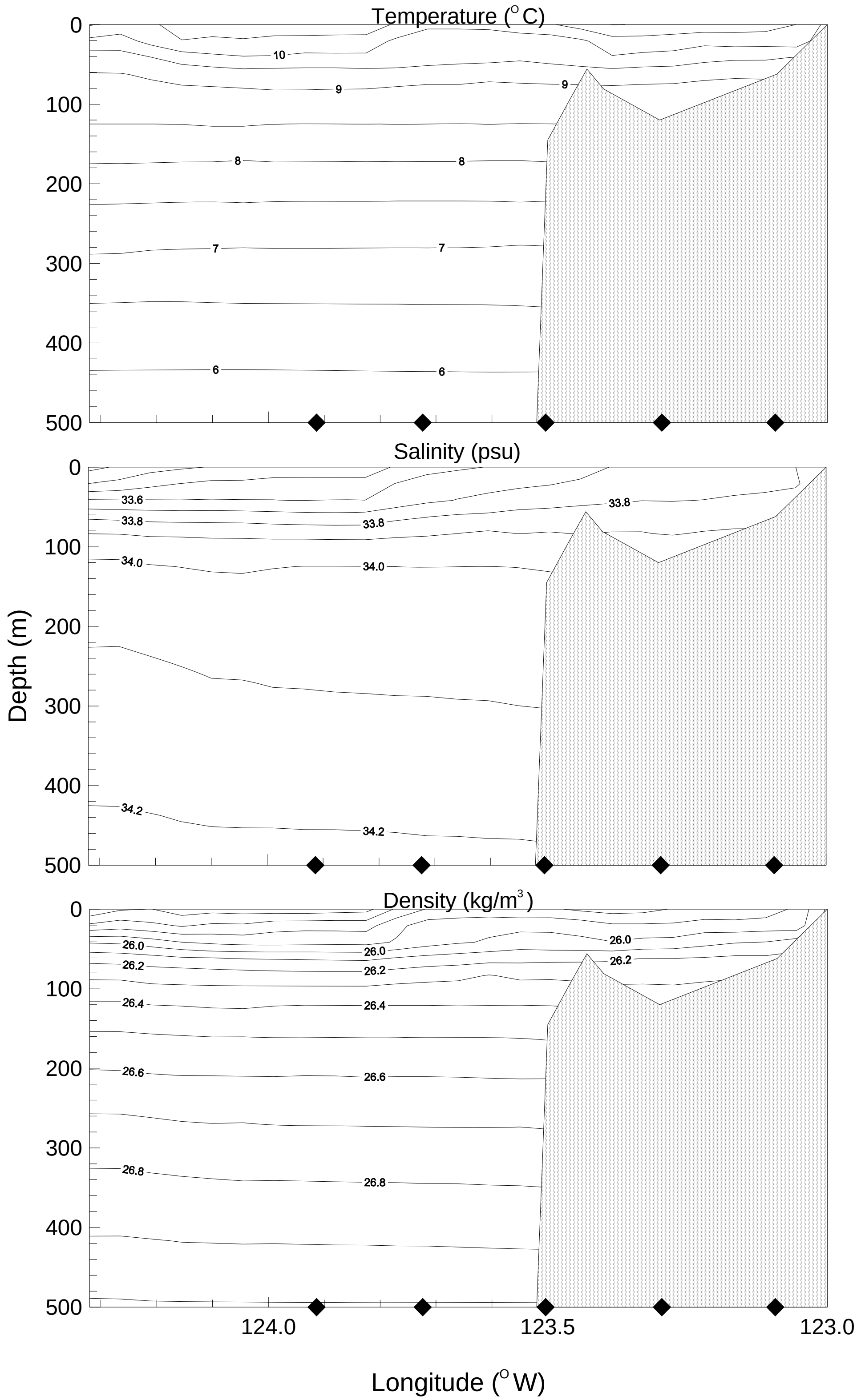
DSJ0103 Sweep 1 Davenport
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
123.0
122.5
122.0
10
9
8
7
6
33.8
34.0
34.2
26.0
26.2
26.4
26.6
26.8


DSJ0103 Sweep 1 Pescadero
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
10
9
8
7
34.0
34.2
26.2
26.4
26.6
26.8
123.0
122.5
122.0

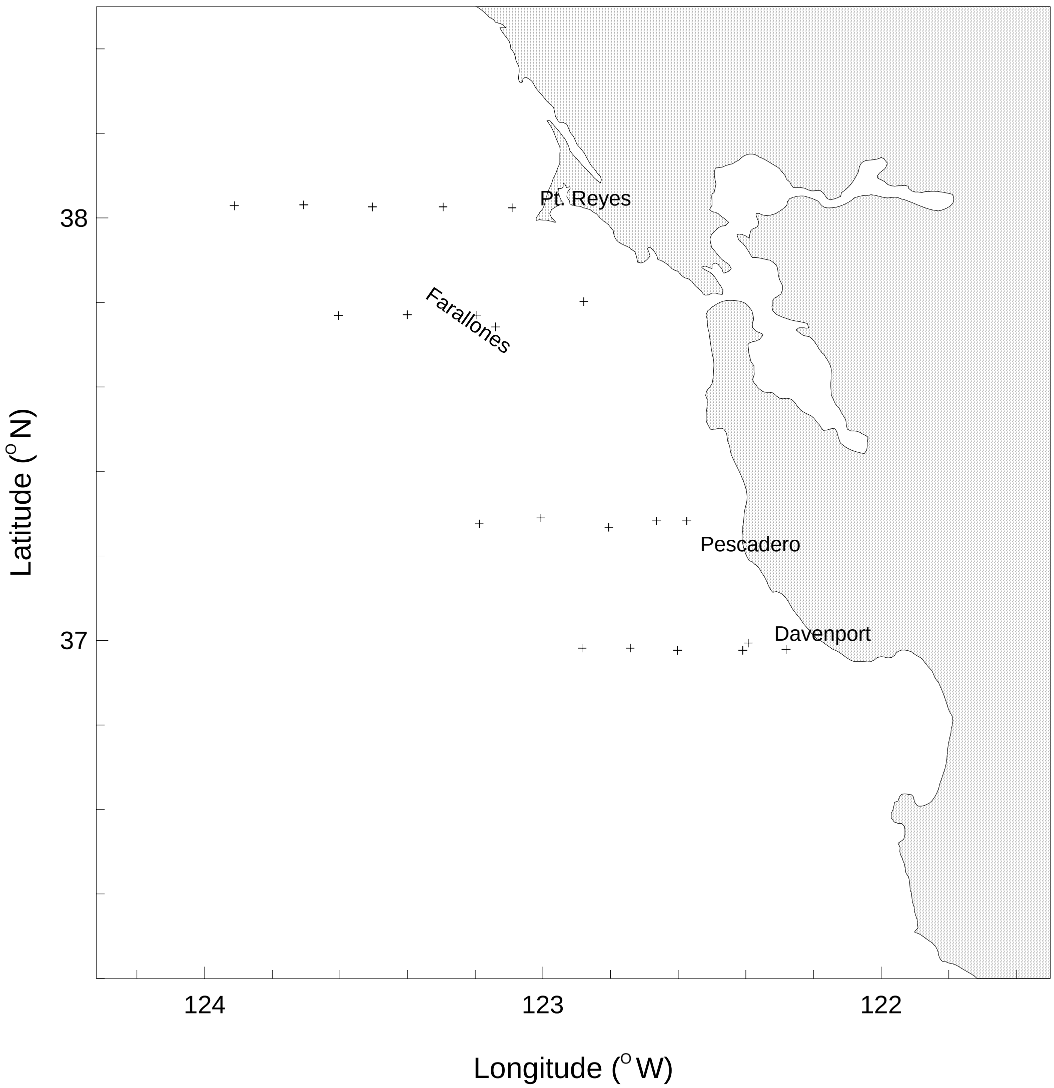
DSJ0103 Sweep 1 Farallones



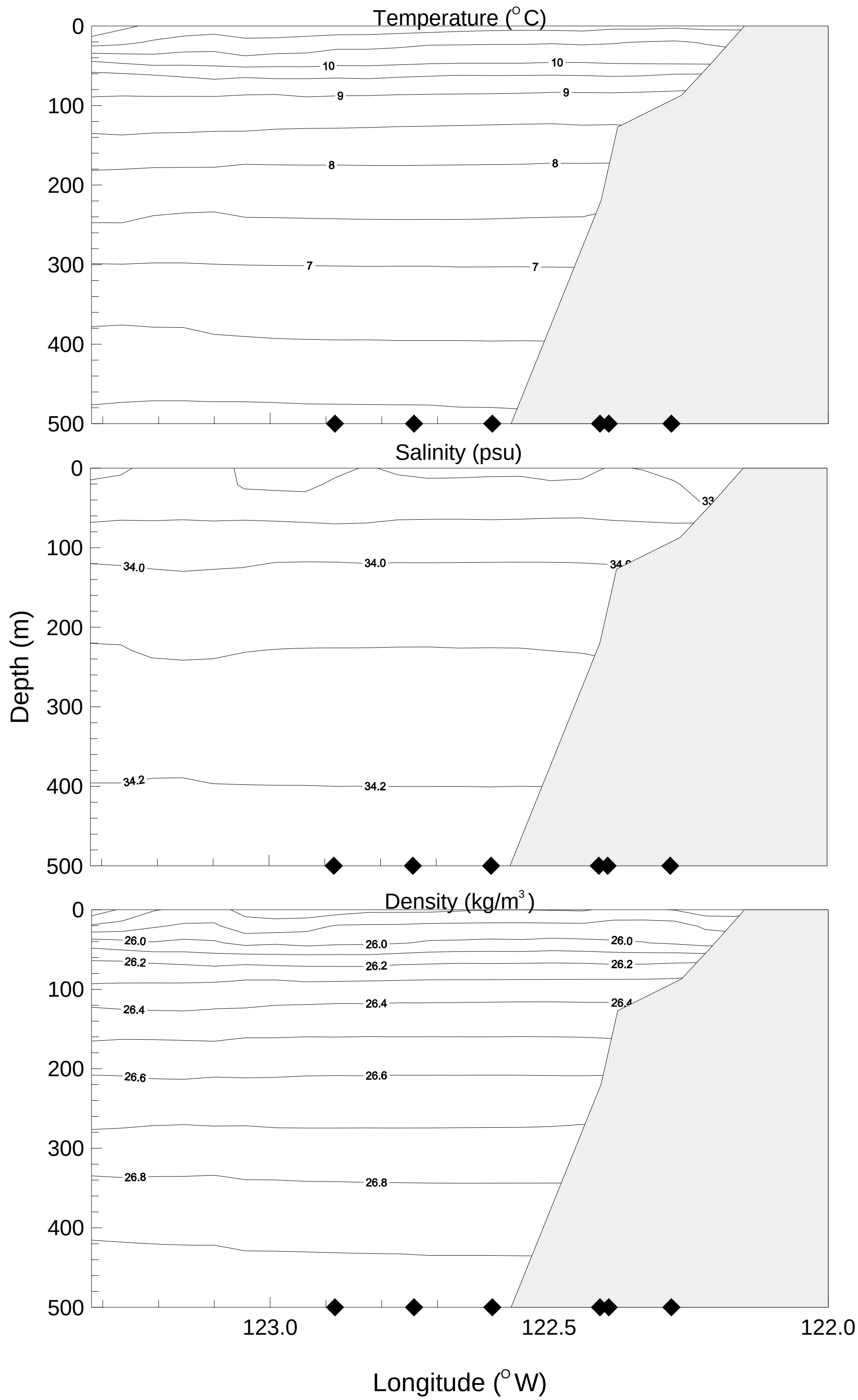
DSJ0103 Sweep 1 Point Reyes

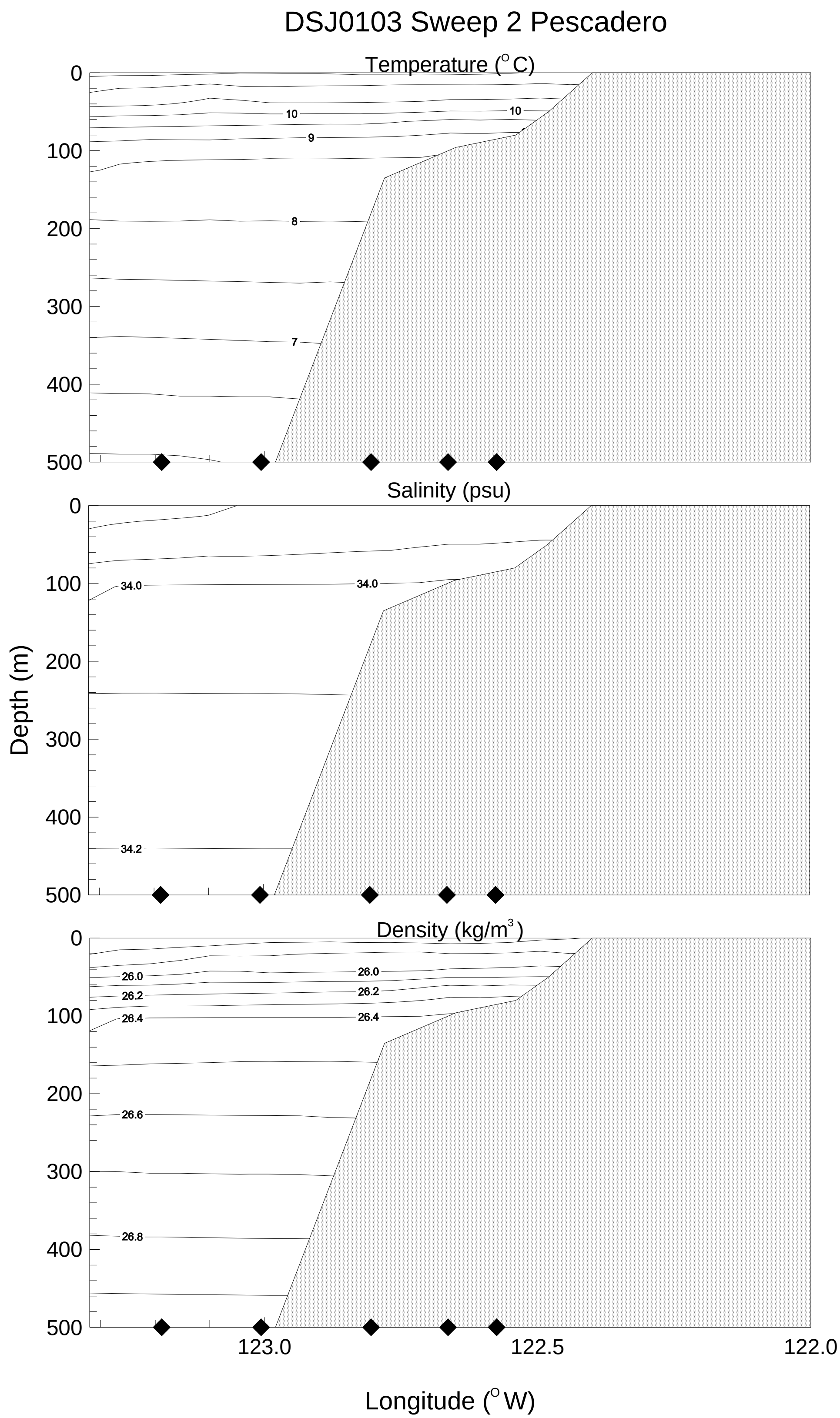


DSJ0103 Sweep 2 Vertical Transect Stations

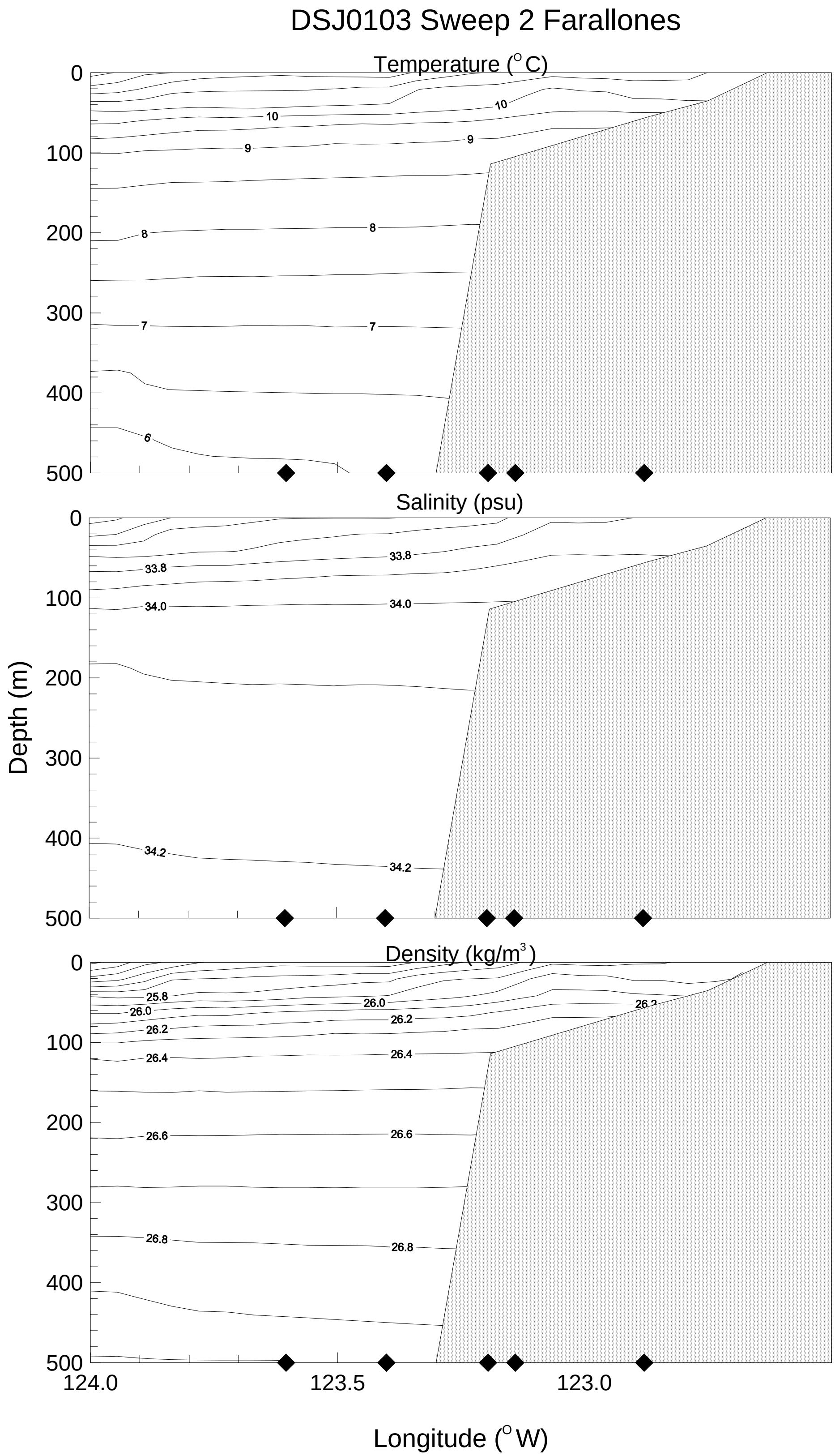


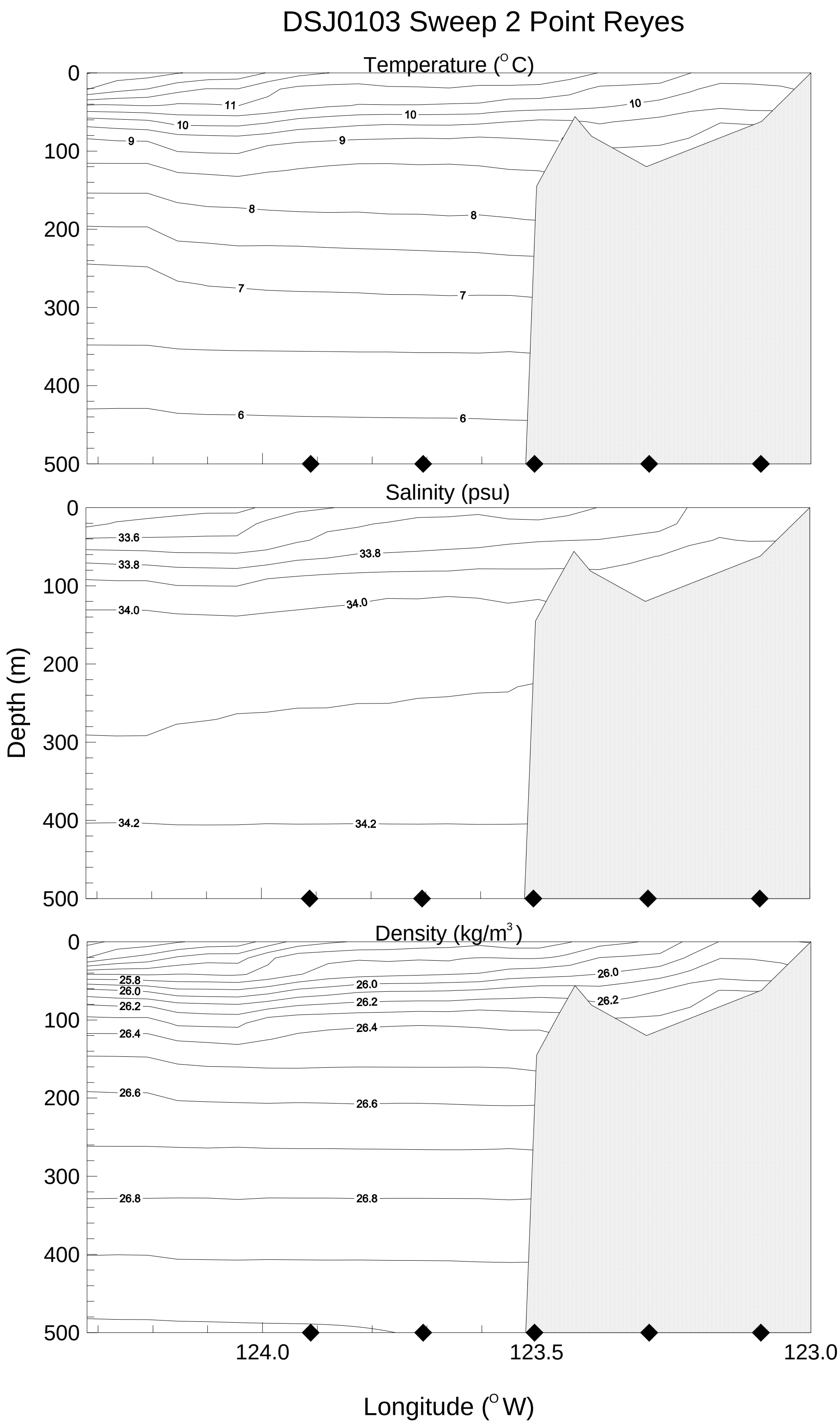
DSJ0103 Sweep 2 Davenport



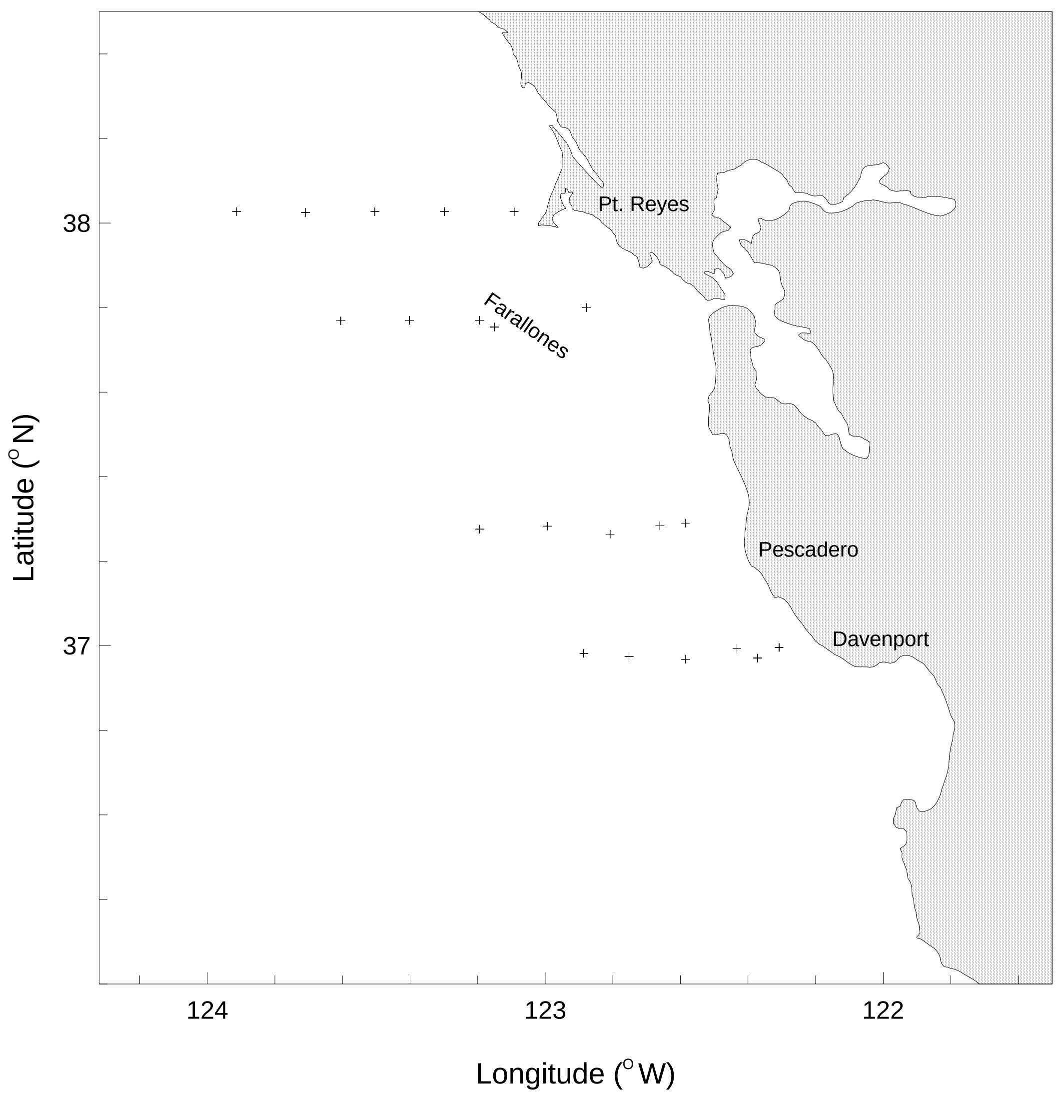


DSJ0103 Sweep 2 Pescadero
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
123.0
122.5
122.0
10
9
8
7
34.0
34.2
26.0
26.2
26.4
26.6
26.8

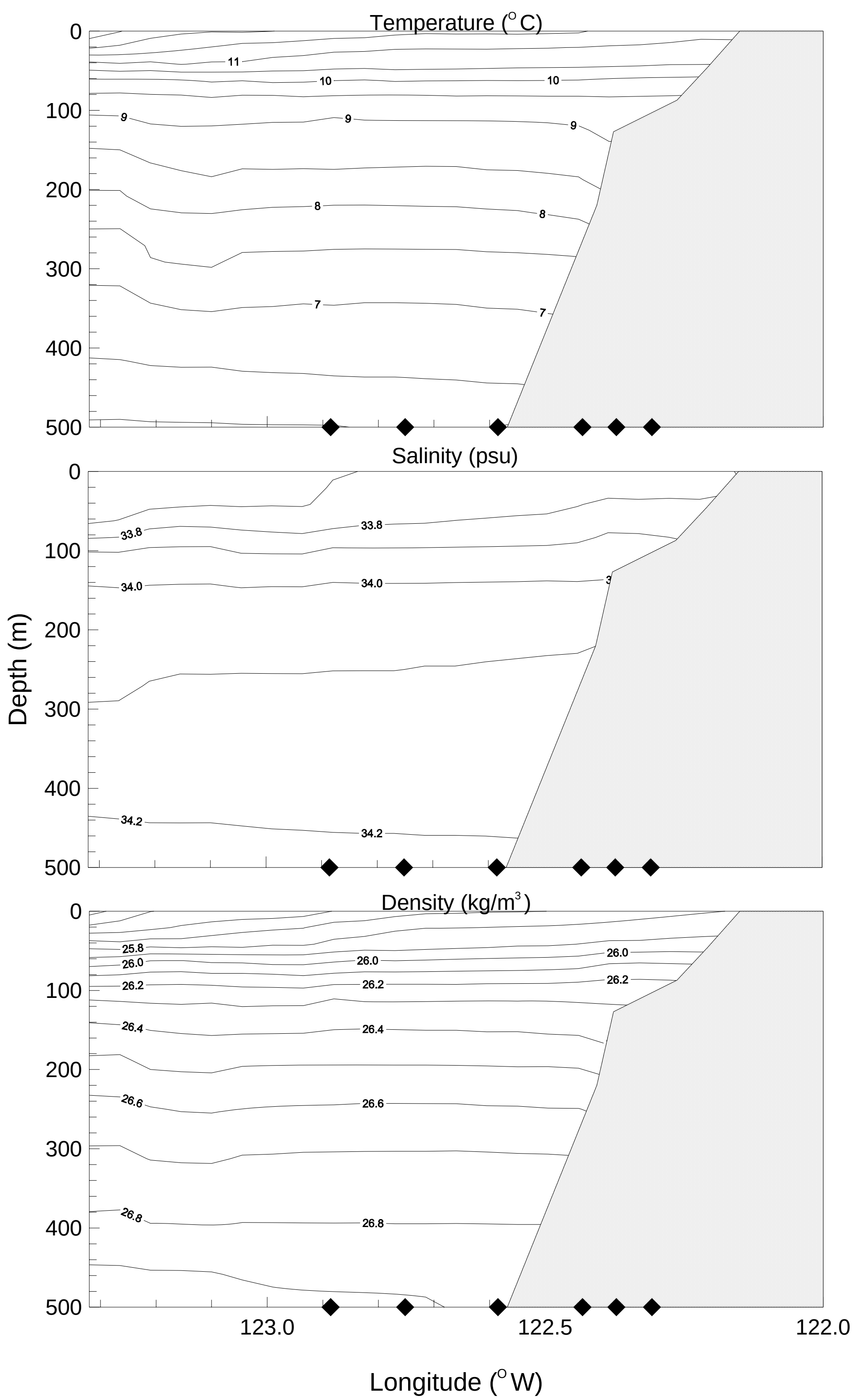

DSJ0103 Sweep 2 Farallones
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
10
9
8
7
6
33.8
34.0
34.2
25.8
26.0
26.2
26.4
26.6
26.8
124.0
123.5
123.0

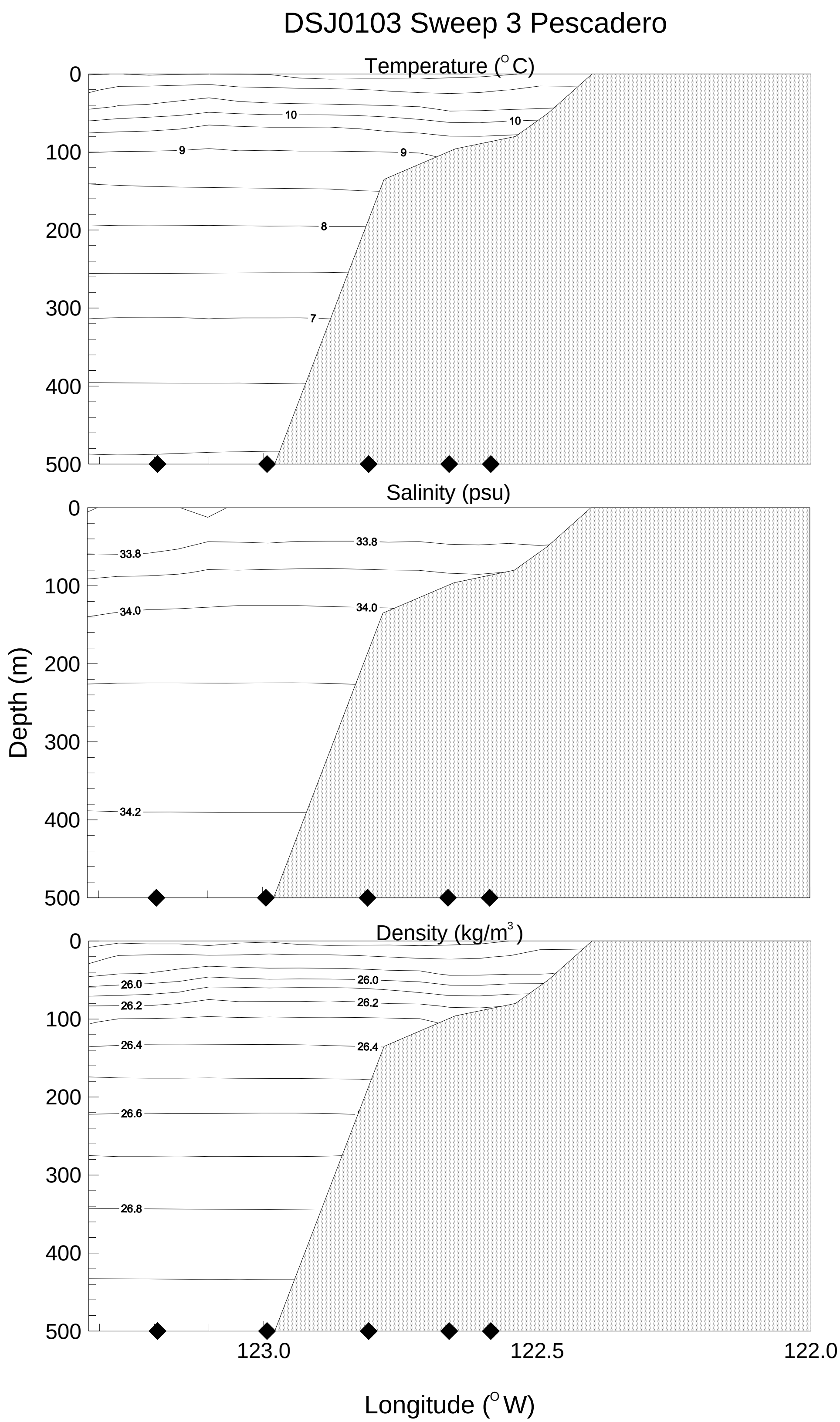

DSJ0103 Sweep 2 Point Reyes
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
124.0
123.5
123.0
0
100
200
300
400
500
11
10
9
8
7
6
33.6
33.8
34.0
34.2
25.8
26.0
26.2
26.4
26.6
26.8

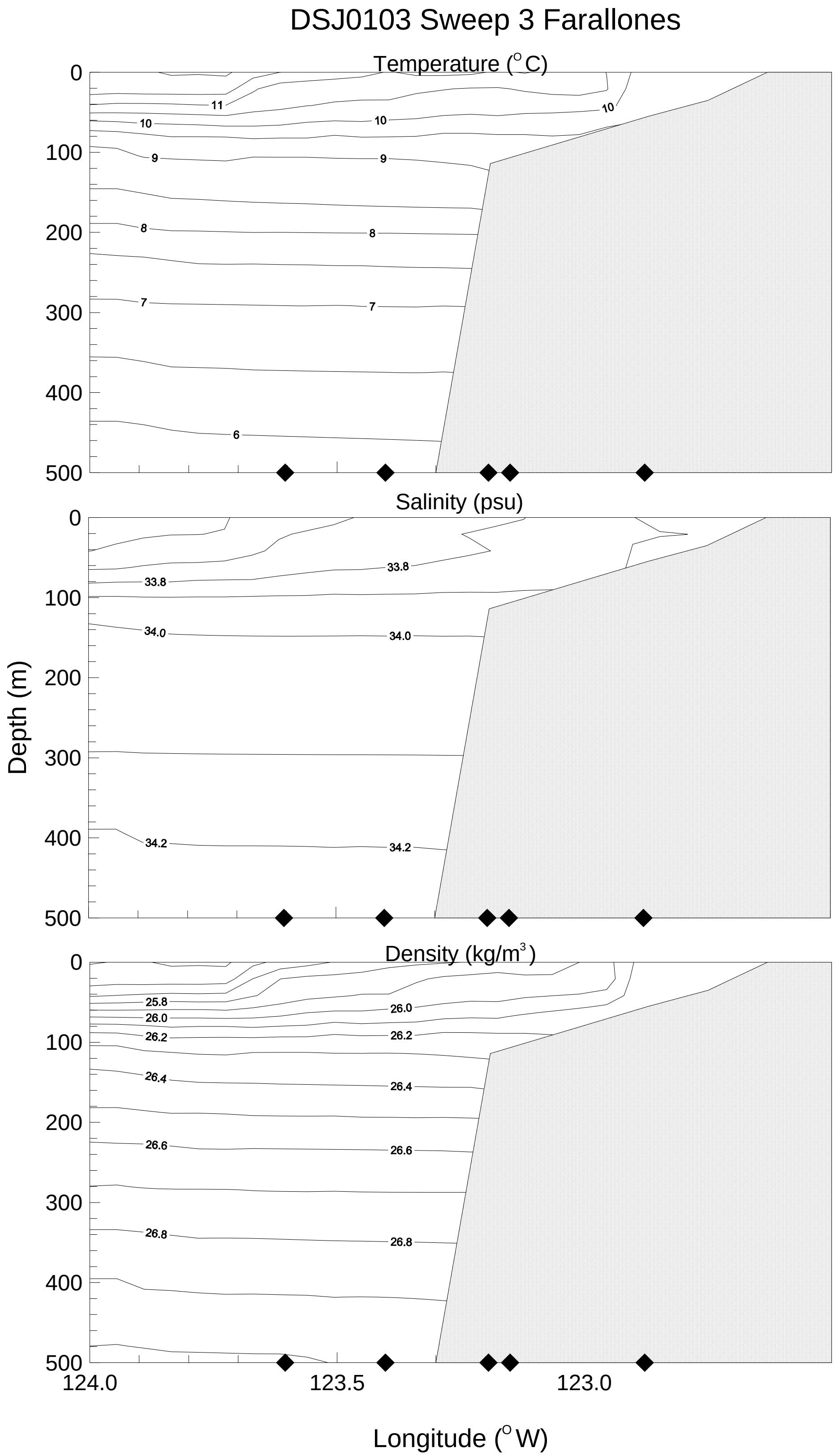
DSJ0103 Sweep 3 Vertical Transect Stations

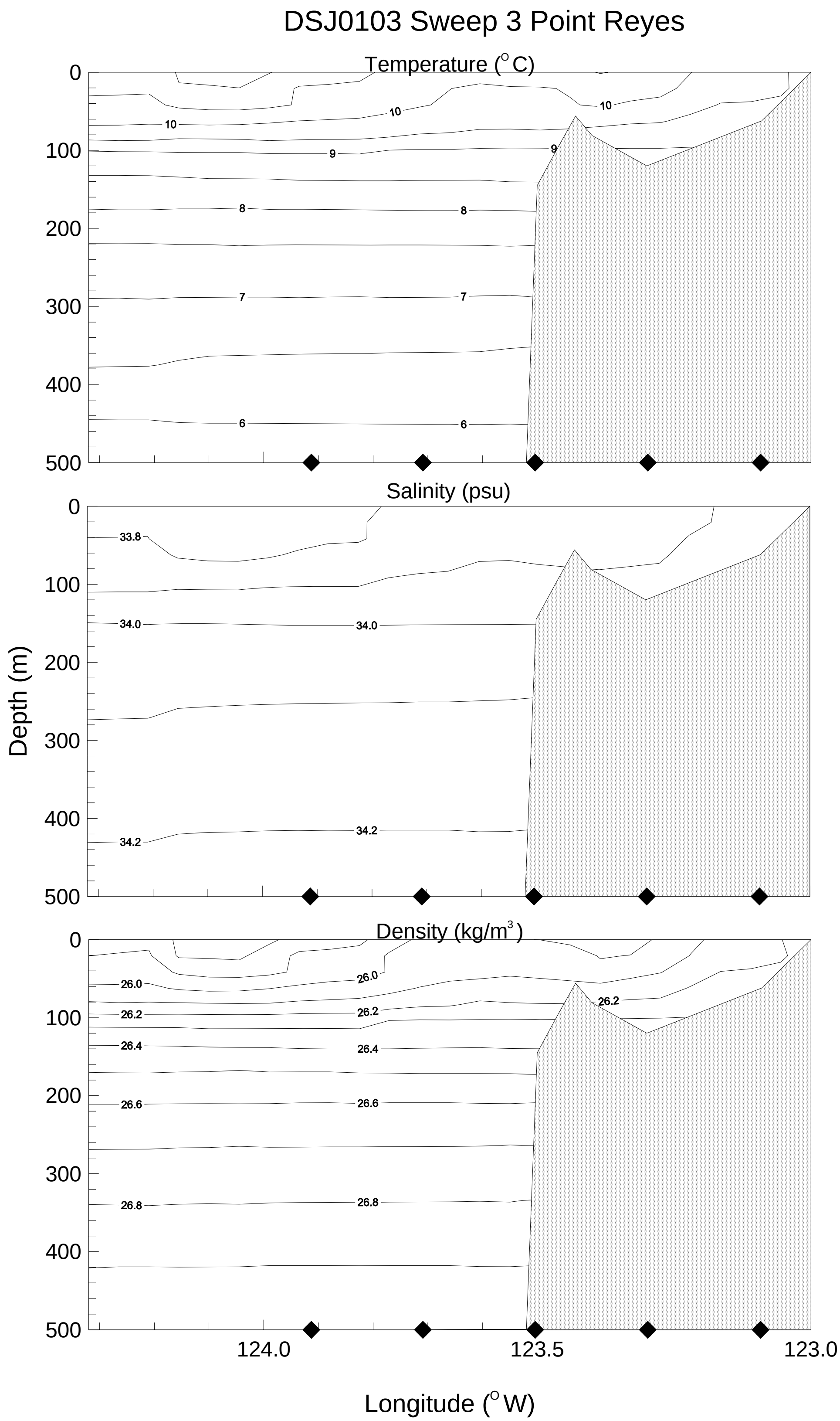


DSJ0103 Sweep 3 Davenport

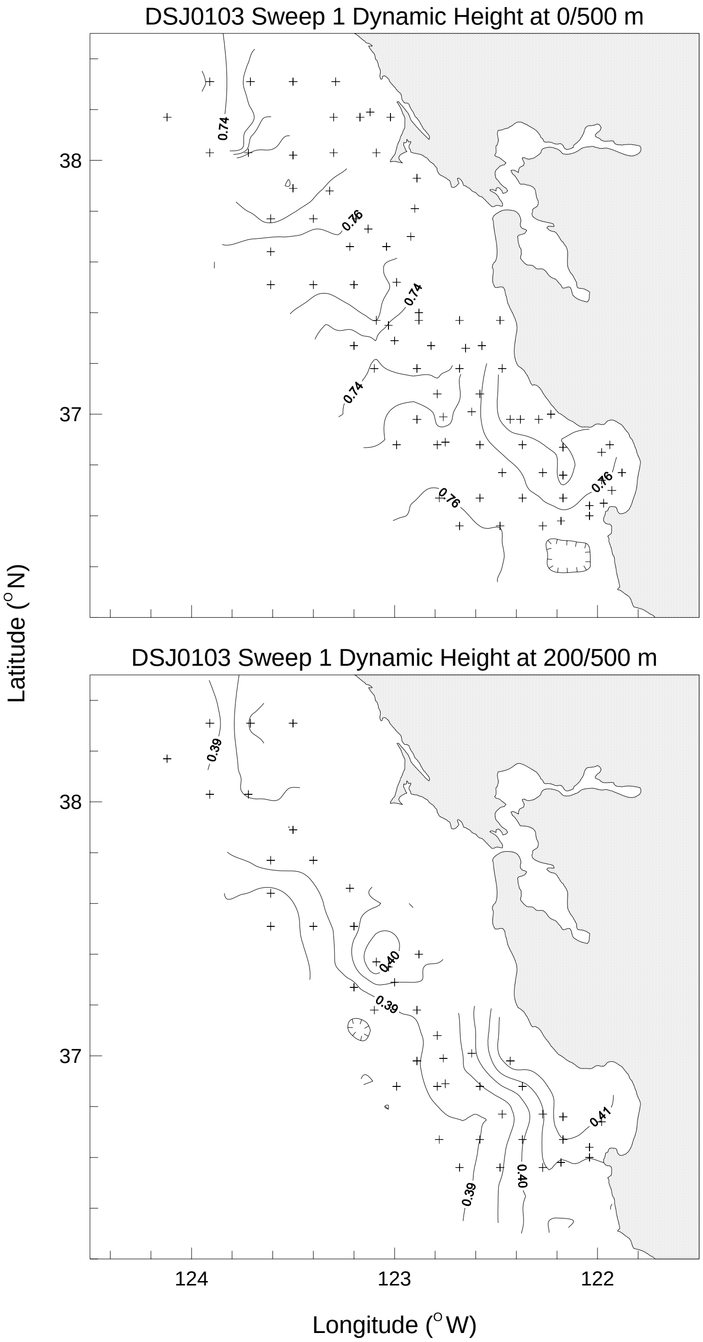


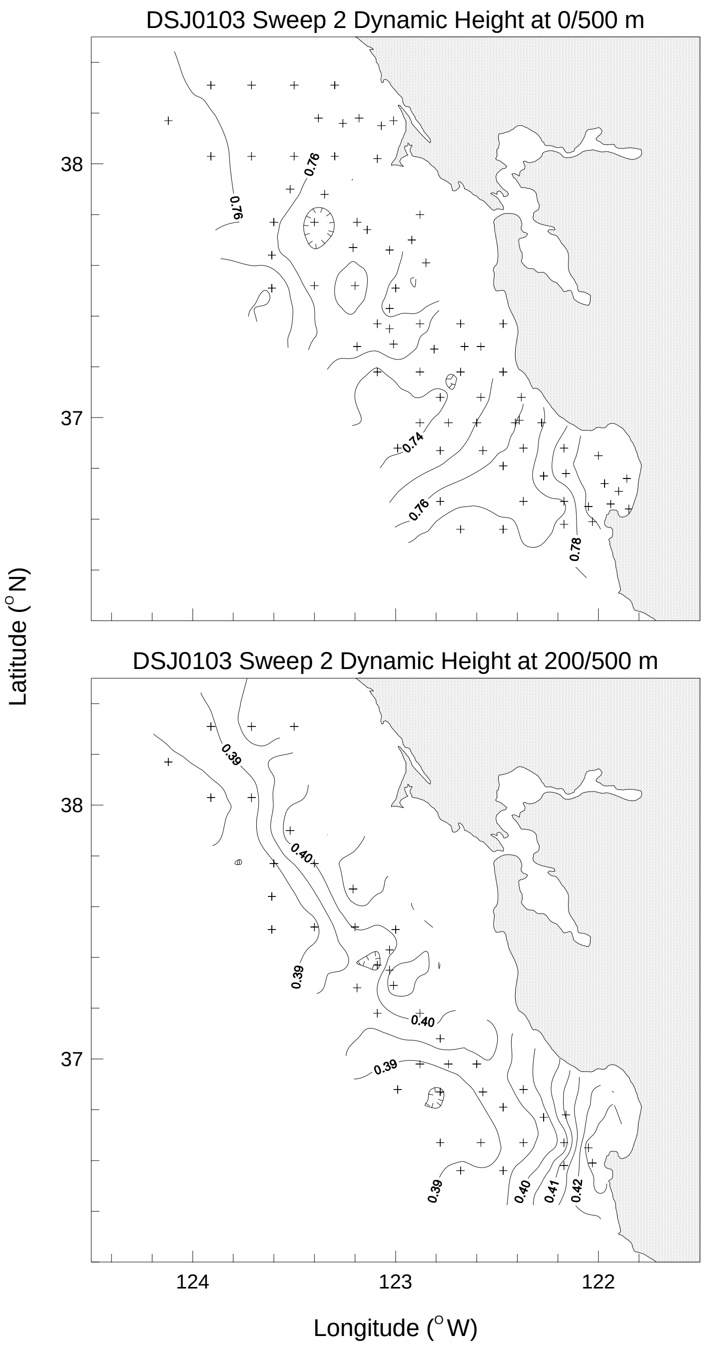

DSJ0103 Sweep 3 Pescadero
Temperature (°C)
10
10
9
9
8
7
Salinity (psu)
33.8
33.8
34.0
34.0
34.2
Density (kg/m³)
26.0
26.0
26.2
26.2
26.4
26.4
26.6
26.8
Depth (m)
0
100
200
300
400
500
123.0
122.5
122.0
Longitude (°W)

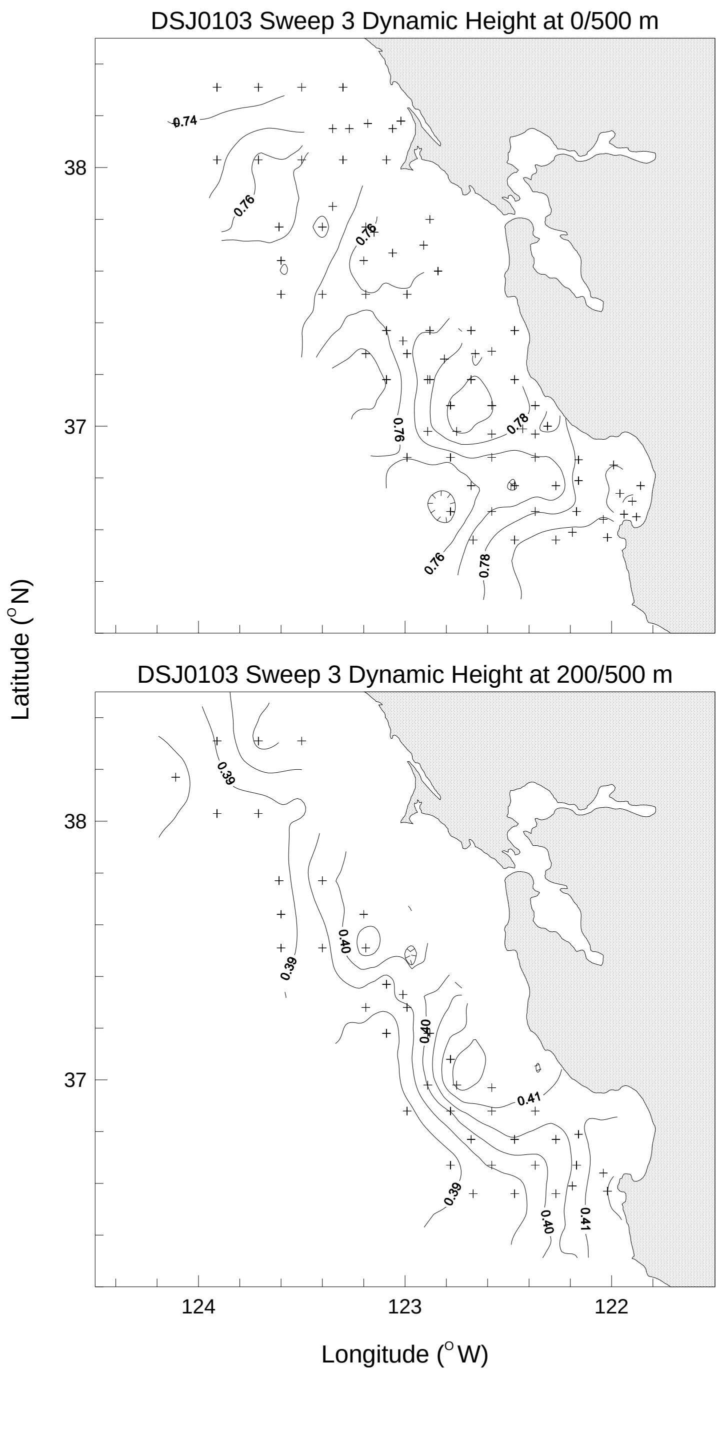

DSJ0103 Sweep 3 Farallones
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
124.0
123.5
123.0
0
100
200
300
400
500
11
10
9
8
7
6
33.8
34.0
34.2
25.8
26.0
26.2
26.4
26.6
26.8


DSJ0103 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
10
9
8
7
6
33.8
34.0
34.2
26.0
26.2
26.4
26.6
26.8

APPENDIX 9: DYNAMIC HEIGHT TOPOGRAPHY FOR DSJ0103


DSJ0103 Sweep 1 Dynamic Height at 0/500 m
0.74
0.76
0.74
0.74
0.76
0.76
38
37
Latitude (°N)
DSJ0103 Sweep 1 Dynamic Height at 200/500 m
0.39
0.40
0.39
0.41
0.39
0.40
38
37
124
123
122
Longitude (°W)


DSJ0103 Sweep 2 Dynamic Height at 0/500 m
0.76
0.76
0.74
0.76
0.78
38
37
DSJ0103 Sweep 2 Dynamic Height at 200/500 m
0.39
0.40
0.39
0.40
0.39
0.39
0.40
0.41
0.42
38
37
124
123
122
Latitude (°N)
Longitude (°W)


DSJ0103 Sweep 3 Dynamic Height at 0/500 m
0.74
0.76
0.76
0.76
0.78
0.76
0.78
DSJ0103 Sweep 3 Dynamic Height at 200/500 m
0.39
0.40
0.39
0.40
0.41
0.39
0.40
0.41
Latitude (°N)
38
37
124
123
122
Longitude (°W)

APPENDIX 10: INTEGRATED CHLOROPHYLL

DSJ0103 0-50m Integrated Chlorophyll