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ASSESSING THE FATE OF JUVENILE ROCKFISH AT OFFSHORE PETROLEUM PLATFORMS AND NATURAL REEFS IN THE SANTA BARBARA CHANNEL

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TECHNICAL SUMMARY

Study Title: Assessing the Fate of Juvenile Rockfish at Offshore Petroleum Platforms and Natural Reefs in the Santa Barbara Channel

Report Title: Assessing the Fate of Juvenile Rockfish at Offshore Petroleum Platforms and Natural Reefs in the Santa Barbara Channel

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Background and Objectives:

There are 27 oil and gas platforms in the waters off California. All platforms have a finite economic life, and the life spans of some California platforms may be nearing an end. Once oil and gas can no longer be produced from a platform, the platform must be removed, a process known as decommissioning. During the decommissioning process, the Minerals Management Service (MMS) conducts detailed environmental reviews of the proposed removal to evaluate the impacts on regional fish populations. The MMS may consider waiving the removal requirement to accommodate an alternative reefing option such as leaving the platform completely or partially in the water. A major question in the platform reefing debate deals with the issue of whether existing platforms are important to rebuilding local fish stocks whose populations have been seriously depleted. Because fish populations are usually limited by recruitment, habitat, or available energy it is important to determine if platforms provide critical habitat for early life history stages, particularly species that remain at platforms from the time of recruitment through reproductive maturity.

Results from MMS funded research show that platforms uniquely serve as shallow, offshore habitat that is suitable for recruitment of a number of fish species, particularly rockfishes (genus *Sebastes*), that also recruit to nearshore natural reefs. Scuba and submersible surveys show that bocaccio, an over-fished, economically important species, recruit as juveniles to midwater depths at platforms, then descend to the bottom habitat of the structures. These fish remain at the deeper platforms through the age of reproductive maturity. Platforms tend to have higher abundances of adult bocaccio, and other larger species such as cowcod and lingcod, than natural reefs. Platform Gail, for example, has by far the highest densities of mature bocaccio of any natural or human-made habitat, and the potential larval production at Platform Gail is higher than at any other site surveyed. Given that offshore platforms may be quite valuable as fish habitat for recruitment and production, an understanding of processes that affect the temporal and spatial variability of rockfish recruitment at platforms and an assessment of the fate of juvenile rockfishes that settle on platforms and natural reefs are needed.

Knowledge of the potential importance of platforms to the recruitment and survival of depleted rockfish stocks includes an assessment of the connectivity among the platforms and natural reefs, or the degree to which a platform receives individuals from other populations or contributes individuals to other populations. For reef-dwelling species with sedentary adults (e.g., many rockfish species), dispersal of pelagic early life stages (e.g., larvae and pelagic juveniles) by ocean currents is the principal mechanism connecting geographically separated populations. The goals of this project were 1) to determine if the delivery of juvenile rockfishes settling on offshore platforms is linked to ocean currents; and 2) to estimate the proportion of young rockfishes that, if offshore platforms in the eastern Santa Barbara Channel had been removed, would survive to settle out at a natural reef.

Opponents of platform reefing have focused on one aspect of the connectivity scheme between platforms and natural reefs by stating that if the platforms did not exist, all of these young rockfishes would have found, and settled upon natural reefs. Previous MMS-funded research investigated this possibility by simulating drift pathways, derived from high frequency radar measurements of surface currents, from a platform off Point Conception and found that most pelagic juvenile rockfish, bocaccio in particular, settling on the platform would otherwise have been transported offshore by surface currents and perished in the absence of the platform. This project expanded the previous research approach into another important geographic area, the eastern Santa Barbara Channel, where juvenile bocaccio and other rockfishes recruit in high abundances.

Description:

Fish surveys using scuba and oceanographic observations were carried out at two oil/gas production platforms, Gilda and Gail, in the eastern Santa Barbara Channel from May through August 2004. This period corresponds with the season of much of the rockfish recruitment in this area. Platform Gilda (34^{o} 10’N, 119^{o} 25’W; 62 m depth) and Platform Gail (34^{o} 10’N, 119^{o} 25’W; 225 m depth), separated by 7 km, are in a dynamic area where ocean currents are variable over a scale of several days and where fronts and eddies are observed. The specific objectives were 1) to determine if the dynamic, local and regional ocean circulation can account for variation in juvenile rockfish recruitment at platforms; and 2) to identify transport pathways to the platform and to nearshore reefs during the time of recruitment using *in-situ* time-series of the vertical profile of subsurface currents and water mass characteristics at each platform, high-frequency radar to map surface currents, and simulated drifter trajectories from the radar-derived surface current measurements.

Significant Results:

The findings demonstrate that the spatial scale of connectivity for rockfish populations in the eastern Santa Barbara Channel is greater than the Channel itself. Water currents from the Southern California Bight rather than from central California delivered pelagic juvenile rockfishes to offshore platforms, Gilda and Gail, in the eastern Santa Barbara Channel. However, potential for recruitment from local sources (larvae originating from adult populations residing in the Santa Barbara Channel including natural reefs and platforms) is not discounted, since the reconstruction of transport pathways from natal origin to juvenile settlement habitat were beyond the aims of this study.

Some synchrony in the recruitment season occurred among the four most commonly observed taxa of juvenile rockfishes (family Sebastidae): Bocaccio (*Sebastes paucispinis*), treefish (*Sebastes serriceps*), the copper-kelp-gopher-black and yellow complex of rockfishes (*Sebastes caurinus*, *Sebastes atrovirens*, *Sebastes carnatus*, *Sebastes chrysomelas* herein referred to as the copper rockfish complex), and squarespot rockfish (*Sebastes hopkinsi*). The recruitment season for all four taxa commenced after a significant change in surface and subsurface currents and water mass properties at the platforms. Bocaccio and treefish, the only two rockfishes relatively abundant at both Platforms Gilda and Gail, showed two temporal patterns—the seasonality of recruitment and the episodic pulses of settlement within the recruitment season—that were synchronized between the two platforms.

From the analysis of calculated HF radar surface current trajectories from Platform Gilda and subsurface current measurements from ADCPs at both study sites, we estimate that the majority of juvenile rockfish recruits from the offshore eastern Channel platforms, had the habitat not been in place, would have been transported to the mainland coast east of Santa Barbara where rocky reef habitat is uncommon. Future studies with better surface and subsurface current monitoring would improve this estimation. High frequency radar mapping has greatly improved throughout the Channel and coverage will be expanding along the California Coast. High-resolution maps of rocky reef habitat in the Santa Barbara Channel will be available in the future. Our findings have considerable bearing on the issue of high densities of young-of-the-year rockfishes recruiting to oil platforms and the decommissioning options that must eventually be considered for each platform. We conclude that the survivorship of juvenile rockfishes would be compromised in the absence of the platforms, because the time when the young fish are vulnerable in open water would be considerably extended. Nearshore rocky habitat for settlement is rare along the transport pathways from the platforms when westward currents from the Southern California Bight prevail during the recruitment season.

STUDY PRODUCTS

PAPER

2007 "Timing of fish settlement coincides with water mass advection into the Santa Barbara Channel, California, USA", M. M. Nishimoto, L. Washburn, M. S. Love, D. M. Schroeder, and B. Emery — Submitted to *Marine Ecology Progress Series*.

PAPERS PRESENTED

2005 "Is the delivery of juvenile fishes settling on offshore platforms linked to transport by ocean currents?", M. M. Nishimoto, L. Washburn, M. Love, D. Schroeder, and B.M. Emery, 8th International Conference on Artificial Reefs and Related Aquatic Habitats (CARAH). April 10-14. Biloxi, MS.

2005 "Some applications of current-measuring, high frequency radars on the South-Central California Coast", Libe Washburn, J.C. Ohlmann, M.M. Nishimoto, C.A. Blanchette, B. M. Emery, 5th Radiowave Oceanography Workshop, Costanoa Conference Center, Pescadero, California, 3-6 May.

2005 "Is the delivery of juvenile fishes settling on offshore platforms linked to transport by ocean currents?", Nishimoto, M. M., L. Washburn, M. Love, D. Schroeder, and B. Emery. American Fisheries Society Annual Meeting, Anchorage, AK, September 11-15, 2005.

2006 "Is the Timing of Juvenile Reef Fish Settlement Linked to Local and Regional Ocean Current Patterns?", Nishimoto, M M, L. Washburn, M. Love, B. Emery, D. Schroeder, AGU/ASLO Ocean Sciences Meeting, 20-24 February, Honolulu, HI.

Assessing the Fate of Juvenile Rockfish at Offshore Petroleum Platforms and Natural Reefs in the Santa Barbara Channel

Mary M. Nishimoto, Milton S. Love, Libe Washburn, Donna M. Schroeder, Brian M. Emery

Abstract

This project investigated the role that currents play in delivering fish recruits to platforms and assessed the likelihood of fish recruits encountering natural reef habitat if offshore platforms in the eastern Santa Barbara Channel had been removed. Fish surveys using scuba and oceanographic observations were carried out at two oil/gas production platforms, Gilda and Gail, from May through August 2004. The recruitment season for bocaccio (*Sebastes paucispinis*), the most abundant juvenile rockfish species observed, and other rockfishes began in late June after the rapid advection of a low salinity water mass into the eastern Santa Barbara Channel from the Southern California Bight. The change in water masses was evident where most of the fish settled on the platforms, about 25 m depth, and the low salinity water mass occupied the platforms throughout the observed recruitment season. The findings demonstrate that the spatial scale of connectivity for rockfish populations in the eastern Santa Barbara Channel is greater than the Channel itself. Water currents from the Southern California Bight rather than from central California delivered juvenile rockfishes to the platforms. From the analysis of calculated high frequency radar surface current trajectories from Platform Gilda and subsurface current measurements at both study sites, we estimate that the majority of juvenile rockfish recruits from the offshore eastern Channel platforms, had the habitat not

been in place, would have been transported to the mainland coast east of Santa Barbara where rocky reef habitat is uncommon.

Introduction

Rockfishes (genus *Sebastes*) are the most abundant fishes recruiting to the 27 oil and gas platforms off central and southern California. About 35 species of rockfishes dominate three distinct assemblages found around platforms in the Santa Barbara Channel and off central California: the platform bottom, the surrounding shell mound, and midwater assemblages (Love et al. 2003). The bottom and shell mound harbor adult and subadult individuals. The midwater assemblages are composed almost entirely of juvenile fishes. Rockfish recruitment (herein defined as young fish leaving a pelagic existence to settle into nursery or adult habitat) tends to be higher at platforms than natural reefs in the Santa Barbara Channel and off Point Conception; and within a season, densities of young-of-year rockfishes can vary tremendously among platforms or among reefs (Love et al. 2005).

The importance of platforms as nursery habitat was demonstrated by Love et al. (2006) who assessed that in one year, 2003, about 20% of the average number of juvenile bocaccio (*Sebastes paucispinis*) that survive annually throughout the geographic range of the species (Alaska Peninsula to central Baja California) recruited to eight platforms off southern California. By comparison, juvenile bocaccio recruitment to nearshore natural nursery grounds, as determined through regional scuba surveys, was low in the same year. When these juveniles that recruited to the platforms become adults, they will contribute about one percent (0.8%) of the additional amount of fish needed to rebuild the over-fished Pacific Coast population. Given that offshore platforms may be quite valuable as fish habitat for recruitment and production, an understanding of processes that affect the temporal and spatial variability of rockfish recruitment at platforms and an assessment of the fate of juvenile rockfishes that settle on platforms and natural reefs is needed.

Rockfishes, like many marine organisms, occupy spatially distinct habitats (e.g., rocky reefs and platforms) and have a pelagic phase in their early life histories when they are vulnerable to dispersal away from their local population. For rockfishes, recruitment usually occurs after a 3-6 month pelagic phase (through the larval and pelagic juvenile stages) when the juveniles are about 3-9 cm in length (Love et al. 2002). Most rockfish settlement at platforms and nearshore rocky reefs off California occurs during May-July, although the timing for a particular species varies among years (Love et al. 2003). Most species of rockfish settle in relatively shallow water habitat and eventually move to the deeper habitats of adults. Platforms are unique habitat that are similar to seamounts where juvenile rockfishes commonly are abundant (Love et al. 2002): the platforms extend vertically through the water column and provide shallow water substrate in offshore open water environments with the platform legs serving as structure leading to bottom habitat.

Defining connectivity among populations or the degree to which a population receives recruits from other populations or contributes recruits to other populations is a major unanswered question in ecology (Warner and Cowen 2002, Sale et al. 2005) and is an important matter of concern in regard to platform decommissioning when evaluating the habitat value of the structures (Schroeder and Love 2004). Numerical modeling studies show that the distribution and transport of prerecruits in the pelagic environment control to some extent the spatial and temporal variability of recruitment (Roughgarden et al. 1988, Siegel et al. 2003, Cowen et al. 2006, Byers and Pringle 2006). Such studies have facilitated a growing body of empirical research focused on identifying the origin of recruits to estimate the proportion from local and remote sources using genetic and biogeochemical markers (e.g., Jones et al. 1999, Swearer et al. 1999, Thorrold et al. 2001, Wares et al. 2001, Miller and Shanks 2004). However, few empirical studies have investigated processes leading to the settlement of recruits (e.g., Paris and Cowen 2004, Sotka et al. 2004), or in particular, directly examined hydrography or flow field to reconstruct pathways of the observed recruits during their pelagic phase (e.g., Schmitt and Holbrook 2002, Roughan et al. 2005, Shanks 2006). In this study, we directly examined water mass dynamics and ocean current variability to reconstruct a portion of the pelagic history of newly settled juvenile fish—the probable pathways taken by the recruits during the days to weeks before settlement.

Fish surveys and oceanographic observations were carried out on two oil/gas production platforms (Gilda and Gail) in the eastern Santa Barbara Channel. Both platforms historically have harbored high densities of young-of-year rockfishes (Love et al. 2003; Love et al. 2006). Offshore platforms provide a unique opportunity to investigate recruitment. Because habitat created by the platform structure and encrusting biota is similar among platforms, the temporal and spatial variability of the recruitment process can be examined without the confounding effect of variable habitat complexity (e.g., low vs. high relief substrate, presence vs. absence of kelp) which can be problematic in natural reef studies (Pineda 2000). Also, currents in offshore areas can be observed with minimal boundary effects, such as tidal bores and near-bottom turbulence, due to interactions with a shallow seafloor that will vary among nearshore shallow areas.

This project was aimed at the overarching goal of determining the importance of platforms as offshore nursery grounds by investigating the role that currents play in delivering fish recruits to platforms and assessing the likelihood of fish recruits encountering natural reef habitat along current-driven transport pathways beyond the platforms' geographic locations if the structures had been removed.

Methods

Fish surveys and oceanographic observations were carried out at two oil/gas production platforms, Gilda and Gail, in the eastern Santa Barbara Channel from May through August 2004 (Fig 1A). This period corresponds with the season of much of the rockfish recruitment in this area (Love et al. 2002). Platform Gilda (34^{o} 10'N, 119^{o} 25'W; 62 m depth) and Platform Gail (34^{o} 10'N, 119^{o} 25'W; 225 m depth), separated by 7 km, are in a dynamic area where ocean currents are variable over a scale of several days and where fronts and eddies are observed (Winant et al. 1999). The specific objectives were 1) to determine if the dynamic, local and regional ocean circulation can account for variation in rockfish recruitment at platforms; and 2) to identify transport pathways to the platform and to nearshore reefs during the time of recruitment using A) *in-situ* time-series data of the water mass characteristics and vertical profiles of subsurface currents at each platform and B) high frequency (HF) radar to map surface currents and to generate simulated surface drifter trajectories.

Study Area

The Santa Barbara Channel is a biogeographic transition zone for marine flora and fauna, separating the strong coastal upwelling regime extending from Point Conception to Washington from the warmer waters of the Southern California Bight (Horn et al. 2006, Blanchette et al. 2006). The Southern California Bight is defined as the region east of the Santa Rosa Ridge and includes the Santa Barbara Channel (Figure 1B) (Bray et al. 1999). Circulation in the channel is complex and variable containing a number of distinct water masses of the California Current System (Harms and Winant 1998, Winant et al. 1999, Nishimoto 2000). For instance, in the Channel, coastal water from central California, upwelled water from Point Conception at the western entrance of the channel, and water from the Southern California Bight influence the dynamic hydrography. The circulation in the Santa Barbara Channel consists primarily of a cyclonic (counterclockwise) flow that varies in strength through the year: It is strongest spring through fall and weakest or absent in winter. The cyclonic flow tends to drive westward flow along the mainland, the northern boundary of the channel, and eastward flow along the Channel Islands, the southern boundary. Unidirectional flows toward the east or west occur mostly in the winter, but also occur intermittently throughout the year. Currents carry a diversity of larval and juvenile fish species into the Santa Barbara Channel that can recruit to adult habitats (Nishimoto 1999).

Estimating the Abundance of Newly Settled Juvenile Fish

Fish surveys were conducted at both platforms every 3-4 days to estimate the density and size distribution of species. Observers used scuba to survey three depths between 5 and 30 m. Horizontal cross members at 5 m were surveyed at both platforms, and cross members at 11 m and 26 m below the surface at Platform Gilda, and 12 m and 31 m at Platform Gail were also surveyed. Scuba divers visually surveyed fishes along rectangular belt transects (2m width x 2m height) that coursed along the perimeter and portions within the structure. Two belt transects included all four legs and bounded approximately two-thirds of the area of the platform at each depth. Scuba divers identified, counted, and estimated the sizes of all fishes observed with the aid of a measuring guide on the data recording slate. Observers were trained to estimate the total length of fishes to the nearest centimeter. This survey method has been used in assessments of fish populations at platforms (Love et al. 2003).

We used the survey counts and size distributions to estimate the abundance of newly-settled juvenile fishes during the survey period. "New recruits" are defined as the increase in the number of a fish taxon within 2-cm TL size classes from one survey to the next at a platform. We used this approach to distinguish the new recruits from individuals that may have settled during the previous survey. A reasonable assumption is that an increase in size class abundance is not due to individual growth within the few days between observations. Mortality and emigration to deeper, unsurveyed portions of the platform are not factored into the estimate.

The temporal variability in the relative abundance of these new recruits (i.e., the timing of the settlement pulses at a platform) are compared between platforms. Kendall's correlation coefficient, τ_b, was used to determine the degree of synchrony in settlement patterns at the two platforms (SPSS for Windows, Release 11.5.0, 2002-2005). The statistic is a measure of the tendency of concordant changes (i.e., corresponding increases and decreases) in recruit abundance at the two platforms from one paired survey to the next. The value, τ_b, ranges from 1 (perfect concordance or synchrony between the two platforms) to -1 (perfect discordance with every increase at one platform corresponding with every decrease at the other platform and vice versa).

In order to examine the episodic nature of recruitment and investigate its relationship to variability in ocean circulation, our analysis focused on the timing of settlement of the most abundant juvenile rocky reef-dwelling fishes that recruit to platform habitat. Summary tables regarding the full species assemblage observed in this study are presented in Appendix 1.

Local and Regional Oceanographic Observations

Various oceanographic data collected by us and others were examined to determine if temporal patterns of juvenile fish settlement were related to ocean circulation. Oceanographic monitoring at the platform sites included conductivity-temperature-depth (CTD) profiling on fish survey dates and near-continuous conductivity-temperature (CT) logging and acoustic Doppler current profiling (ADCP). Ocean surface currents were measured by a HF radar array throughout the survey period (Fig. 1A).

An ADCP (600 KHz Workhorse Sentinel by RD Instruments) and a CT recorder (SBE37-SMP Microcat by Sea-Bird Electronics, Inc.) were mounted as a package to the southeast leg of each platform: Gilda at 23 m and Gail at 26 m depth. Scuba diving logistics limited the depth of the package which was deployed a few meters above the deepest level surveyed at the platforms. The ADCP logged data every 6 minutes, the CT recorder every 3 minutes. The ADCP was upward-looking and tilted away from the platform to avoid physical interference by the structure. Approximately every 4 weeks, the ADCP and CT recorder were retrieved to upload data, and the instruments were redeployed the following day. Processing of the ADCP data accounted for the tilted orientation of the instrument. The effective current profile range was 10.2 - 22 m from the surface at Platform Gilda (29 bins) and 17.2 - 24.9 m at Platform Gail (19 bins). The bin interval was 0.4 m. The range was more limited at Platform Gail compared to Platform Gilda, because the instrument was tilted at a greater angle at Platform Gail affecting the quality of the data with distance from the instrument.

We used an SBE 19 with pump (Sea-Bird Electronics, Inc.) to profile the water column within 100 m of the platform on every survey date starting on 10 June. The CTD was deployed down to about 60 m (2 meters from the bottom) at Platform Gilda and to at least 100 m at Platform Gail. CTD data and the CT data were processed to attain salinity and potential temperature using the software provided by the manufacturer. When we cross-checked the CTD and the two CT instruments, we found a discrepancy in salinity measurements. The salinity measurements from the CTD were consistently lower than that from the CT instruments at corresponding depths and time. We applied a linear-based correction of 0.0783 PSU to the salinity data from the CTD.

We examined local water mass properties in the context of the regional hydrography using survey data from the California Cooperative Oceanic Fisheries Investigations (http://www.calcofi.org/newhome/data/data_archives.htm). We used potential temperature and salinity data from the 13-28 July 2004 CalCOFI survey and descriptions of large-scale circulation patterns off Southern California (Bray et al. 1999) to define regional hydrographic signatures and to identify the source of the water masses that occupied the platform habitat during our study (Fig 1B).

Hourly HF radar surface current mapping provided a view of the dynamic flow field around the platforms and most of the Santa Barbara Channel. Funded in part by MMS, Dr. Libe Washburn and his laboratory at the Institute for Computational Earth System Science (ICESS), at the University of California at Santa Barbara, have been monitoring the surface circulation patterns around platforms using HF radar. (Also know as Coastal Ocean Dynamics Applications Radar (CODAR).) Although the HF radar system was originally developed to predict the movement of spilled oil, an equally important use is related to the study of the recruitment of marine larvae to coastal populations. Surface current mapping data are provided to the public (http://www.icess.ucsb.edu/iog/realtime/index.php). Surface currents in the western Santa Barbara Channel have been continuously mapped since 1998; however, mapping of the eastern Channel was initiated for this study. Four radar systems (12-13 MHz) positioned on the mainland coast of the Channel produce time series of radial current components (herein referred to as "radials") out to a maximum range of 40-80 km offshore (Fig 1A). As discussed by Emery et al. (2004), the actual range and overall coverage area changes in time. Radials are obtained as spatial averages over sectors of the sea surface measuring

5 degrees in azimuth by 1.5 km in range. Radials in each sector are computed over 10 minute intervals. Total current velocity vectors are estimated by averaging all radials each hour observed over circular areas of the sea surface with 3 km radii. The circles are centered on points on a square grid with two km spacing between points. The least square technique described by Gurgel (1994) is used to combine radials within the circular areas to estimate the eastward and northward current components at each grid point.

Current measurements obtained by HF radar are fundamentally different from the current measurements from fixed-point current meters. This is due to the fact that radar measurements are inherently averaged in space and time. With this limitation in mind, we used the radar measurements from a point on the mapping grid near each platform location to estimate local surface currents. The time series of surface current patterns from the HF radar and subsurface currents from the ADCP were used to interpret the near-field flow at the platforms.

Time series data from the ADCP, CT logger, and surface current mapping were low-pass filtered with a 1/36 hr^{-1} cuttoff frequency to suppress tidal variations.

Estimating Transport Pathways from a Platform to Natural Habitat

To assess the importance of a platform as nursery habitat for rockfish recruits, and to investigate the possibility that platforms in the eastern Channel may reduce recruitment of rockfishes to natural nearshore habitat, we estimated transport pathways from the platform to nearshore habitat. Using the same technique detailed in Emery et al (2006), we evaluated simulated surface drifter pathways (termed “trajectories”) derived from HF radar mapping to estimate transport from the platform to nearshore habitat in the Channel. Hourly surface current velocity measurements were integrated forward in time using a fourth order Runge-Kutta algorithm to simulate drifter deployments originating from Platform Gilda (see details in Emery et al. 2006). Platform Gail was excluded from the analysis because of its location outside of the area of sufficient radar coverage. Simulated drifter trajectories from Platform Gilda were initiated every four hours from 30 April through 31 August 2004. Trajectories ended where they encountered spatial gaps. The boundary was defined as the 50-m bathymetric contour and where the number of drifters that encountered spatial data gaps in the offshore area was minimized. Spatial gaps occurred more frequently with increasing distance south from the study platforms resulting in a boundary within 4-km of Platform Gilda. As in Emery et al (2006), we assumed that appropriate shallow water juvenile habitat exists inshore of the 50-m isobath for the rockfishes that commonly recruit to the platforms.

To estimate the proportion of young rockfishes that, if Platform Gilda did not exist would survive to settle out at a natural reef, we evaluated the spatial distribution of points where trajectories crossed the coverage boundary (Fig 2). If a trajectory crossed the coverage boundary more than once before ending, the first position on the boundary was tallied. The boundary was divided into 1-km long segments or bins. (The first bin is a 2-km bin for the 206-km long boundary.) The first bin starts at the northwestern corner of the coverage area on the 50-m isobath. The first 81 bins (81 km of the boundary) represent nearshore habitat along the mainland of the Santa Barbara Channel. The boundary then crosses the deep waters of the eastern Channel to the 50-m isobath off the northeastern end of Santa Cruz Island. The nearshore habitat within the 50-m isobath of the mainland has considerably less rocky habitat than the islands due to the greater amount of sediment available to nearshore from mainland drainages (Guy Cochran, USGS, pers. comm.).

Results

Synchrony in Juvenile Fish Recruitment

The latter half of June marked the onset of the rockfish recruitment season (Fig 3). Some synchrony in settlement occurred among the four most commonly observed taxa of juvenile rockfishes (family Sebastidae): Bocaccio (*Sebastes paucispinis*), treefish (*Sebastes serriceps*), the copper-kelp-gopher-black and yellow complex of rockfishes (*Sebastes caurinus*, *Sebastes atrovirens, Sebastes carnatus*, *Sebastes chrysomelas* herein referred to as the copper rockfish complex; all are members of the subgenus *Pteropodus* (Li et al. 2006)), and squarespot rockfish (*Sebastes hopkinsi*). All four taxa showed a settlement pulse within one week from 28 June to 6 July that exceeded the abundance of new recruits observed on previous survey dates.

Time series of two size classes of new recruits, 6 cm TL or less and 10 cm TL or less, are shown in Figure 3A-H for comparison, because little information on the range of size at settlement for these juvenile species is available, especially at the deeper limit of this survey. The first settlement event of bocaccio was comprised of young-of-year fish measuring 6-12 cm TL. Woodbury and Ralston (1991) documented that juvenile bocaccio as large as 12 cm TL and 4 months old based on otolith ageing were pelagic in open water off Central California indicating that the large individuals we observed were newly settled recruits. For treefish, the first observance was one recruit 4 cm TL at Gilda and one at 10 cm TL at Gail. The three squarespot rockfish observed on the initial settlement dates at the two platforms measured between 7 and 10 cm TL. Copper complex rockfish exhibited the narrowest size range of 3-4 cm TL on the first settlement dates at the two platforms. The broad size ranges observed during the initial settlement events indicate that the time of parturition, duration of the pelagic phase of the juvenile recruits, and perhaps intraspecific growth rates are highly variable within species.

The timing of settlement was synchronized between the two platforms for at least two rockfish species. Bocaccio and treefish occurred at both Gilda and Gail and clearly exhibited two temporal patterns: the seasonality of recruitment and episodic pulses of settlement within the recruitment season (Fig 3A-D). The abundances of the copper rockfish complex and squarespot rockfish were too low at one of the two platforms to make a comparison.

The onset of the juvenile bocaccio recruitment season in the eastern Santa Barbara Channel was abrupt and occurred about 1 July. Previous to this date, relatively low levels of settlement occurred between 24 May and 21 June at Platform Gail (Fig 3A) and on one occasion, 1 June, at Platform Gilda (Fig 3B). Nearly all the juvenile bocaccio, which we defined as 10cm TL or less, occurred at the deepest depth surveyed: only one of 1046 juveniles counted at Platform Gilda occurred in shallower water (11m depth); and 0.2% of 4851 juveniles counted at Platform Gail occurred at 12 m depth; no bocaccio were observed at 5 m depth at either platform. Within the recruitment period, variability was somewhat synchronized between the study sites. During the recruitment season, abundance of new recruits increased on 10 occasions at Platform Gail and 8 times at Platform Gilda. Six of these events occurred simultaneously between platforms. The time series of bocaccio recruit abundance at the two platforms were significantly concordant during the study period (τ_b=0.363, SE=0.127, t=2.843, p=0.004, N=31).

As with bocaccio, variability in treefish settlement was somewhat synchronized between the two platforms. With one exception (an 8 cm fish observed at Platform Gail on 1 June), the first appearance of new recruits (defined as 6 cm TL or less) occurred at Platform Gail on 21 June (Fig. 3C and D). All treefish observed were 14 cm TL or less; 21% and 46% of treefish were juveniles 6cm TL or less at Platform Gail and Platform Gilda, respectively. Initial settlement of new recruits at Platform Gilda soon followed on 28 June, coinciding with a pulse at Platform Gail. The two largest settlement events of new recruits at Platform Gail on 22 July and 30 Aug corresponded with large pulses at Platform Gilda. The time series of treefish recruit abundance at the two platforms were significantly concordant during the study period (τ_b =0.596, SE=0.106, t=5.438, p<0.0005, N=31).

The copper rockfish complex and squarespot rockfish recruited in substantial numbers to Platform Gilda (Figure 3E and 3F). Like bocaccio and treefish, recruitment of both taxa occurred primarily at the deepest level surveyed. Of the 479 juveniles of the copper rockfish complex counted, defined as individuals 6 cm TL or less, 449 (94%) were counted at the deepest level surveyed at Platform Gilda. The initial settlement pulse of the copper rockfish complex was observed on 6 July (Fig 3E). It was the largest of six events observed. Only 3 juveniles of the copper rockfish complex were observed at

Platform Gail during July and August. The rarity of the complex at Platform Gail prohibited our evaluation of the synchrony in settlement between platforms.

Among the four rockfish taxa, squarespot rockfish showed the latest peak in settlement, in late August (Fig 3F). All squarespot rockfish at Platform Gilda occurred at the deepest level surveyed and ranged in size from 3 to 14 cm TL. Juveniles, which we defined as 10 cm TL or less, comprised 76% of these fish. The first occurrence of squarespot rockfish was on 21 May. New recruits were not observed again until 14 June followed by a pulse on 1 July. Only 3 squarespot rockfish, all 10 cm TL or less, were observed at Platform Gail in late July. We could not evaluate the synchrony in squarespot rockfish settlement between platforms because of the rarity of squarespot rockfish recruits at Platform Gail.

Blacksmith (*Chromis punctipinnis*, family Pomacentridae), the most abundant juvenile fish observed on the platforms, had a recruitment pattern that differed from rockfishes. Juvenile blacksmith, which we defined as 6cm TL or less, were observed at both platforms during the first two weeks in May when juvenile rockfishes were absent (Figs 3G and 3H). Unlike the juvenile rockfishes, blacksmith occurred in the upper water column: At Platform Gail, 51% and 39% of all juvenile blacksmith observed occurred at the uppermost and intermediate levels, respectively, while at Platform Gilda, these values were 19% and 77%, respectively. Juveniles comprised 10.9% of all blacksmith observed. Blacksmith are mature at about 14 cm TL and 2 years of age (Limbaugh, 1955). Adults 15 cm TL or larger comprised 49.9% of this species observed. The juveniles typically schooled with adults and were not closely associated with the substrate as were juvenile rockfishes. The settlement patterns of the blacksmith recruits at the two platforms were not synchronized (τ_b=0.161, SE=0.162, t=0.986, p=0.324, N=31).

Oceanographic Changes and Juvenile Fish Recruitment

The onset of the season of juvenile rockfish settlement was preceded by a change of water masses in the study area. The time series of salinity, measured near the deepest depth surveyed at both platforms and where most of the juvenile rockfishes settled, displayed a steep decline in salinity from values higher than 33.6 to less than 33.45 during the first two weeks of June (Fig. 4). The CTD time series of average salinity from 15-40 m also exhibits this change (Fig. 4). The time series of the vertical profiles of salinity and potential temperature from CTD casts (Fig. 5) show that the low salinity values were associated with a mid-depth water mass centered between 15 and 40m from the surface. The advection of the low salinity water mass is evident in the salinity profile at both platforms during the first week of the CTD time series from 10-17 June (Figs.5A and 5B). Vertical expansion and intensification of the low salinity water mass at the platforms preceded the onset of the recruitment season when all four rockfish taxa showed a settlement event within one week from 28 June to 6 July. A strong thermal gradient is associated with the low salinity water mass; however, temperature alone, as shown for Platform Gilda in Figure 5C shows, is not useful for interpreting the water mass dynamics.

During the recruitment season, water near the deep level where most juvenile rockfish settled resembled water from the inshore and offshore regions of the Southern

California Bight (Fig. 1B, red and green stations) as shown by moored temperature and salinity (TS) from 23 m at Gilda (●) and 26 m at Gail (♦), and TS profiles, 0 to 100 m, from CalCOFI (red and green lines) (Fig. 6). In comparison, before the recruitment period, water properties (Fig. 6, Gilda (**x**), Gail (+)) resembled upwelled water characteristic of the Pt. Conception region at the western entrance of the Channel (Fig 1B, blue stations; Fig. 6, blue TS lines) and an offshore band extending southwestward from Point Conception along the Santa Rosa Ridge, the boundary of the Southern California Bight (Fig 1B, cyan stations; Fig. 6, cyan TS lines.)

Currents also indicate that the subsurface, low salinity water mass that advected into the Channel was from the Southern California Bight. Surface and subsurface current patterns changed over the course of the survey (Fig. 7). During the first week in May, currents were northwestward. No CTD casts were done at this time. CT data from Platform Gilda indicated salinity was relatively low (<33.4) (Fig. 4). No rockfish recruited at this time; however, settlement of blacksmith juveniles occurred at both platforms. From the second week in May through the first half of June, surface currents had a persistent eastward component, and the subsurface currents were highly variable in direction and magnitude. No rockfish or blacksmith juveniles recruited to the platform at during this period. Currents bringing recently upwelled water from the Point Conception area or recirculating channel water to the platforms would have had a strong eastward or southward component. In contrast, currents with a persistent northwestward component characterized the study area during the rockfish recruitment season (Fig. 7). The subsurface currents were coherent between the two platforms with the westward component typically near 10 cm s^{-1} with a maximum about 20 cm s^{-1} and the northward component somewhat weaker. Northwestward currents delivered water from the Southern California Bight through the eastern entrance of the Santa Barbara Channel to the platforms.

An abrupt reversal in surface current patterns in mid-June (Fig 8) corresponds with that observed in the ADCP time series (Fig 7). The HF radar maps show strong eastward surface current flow throughout the offshore area of the eastern Channel on 10 June (Fig 8). The flow weakened and cyclonic flow was evident south of Platforms Gilda and Gail on 12 June. The surface current flow in the eastern Channel turned predominately poleward by 14 June and the surface current flowed through the eastern entrance and through the gap between Santa Cruz Island and Anacapa Island from the Southern California Bight into the Channel. The surface currents continued along the mainland coast following the isobaths of the Channel. Radar coverage did not extend far enough to the west to determine whether currents continued northward around Point Conception. The maps indicate that the currents over the deeper slope turned in a cyclonic direction and were directed offshore in the Channel.

Transport Pathways from Platforms to Nearshore Habitat

Based on our finding that the onset of the season of juvenile rockfish settlement was preceded by a change of water masses at the platforms, the time series of trajectories was divided into three ensembles. Period 1 (1 May – 12 June, 258 trajectories) is when very little or no recruitment of rockfish species occurred, and surface and subsurface currents were variable with strong eastward flow. Period 2 (13 June – 27 June, 90 trajectories) is a transition to westward flow. Period 3 (28 June – 31 Aug, 387 trajectories) is the observed recruitment season. The distribution of trajectories differed among the three time periods (Figure 9 and Table 1). Figures 9A and 9B show that the first ensemble is characterized by trajectories with eastward or northeastward pathways from Platform Gilda to nearshore habitat, 50 m or shallower, and southward pathways that hit spatial data gaps between the platform and Anacapa Island. Sixty-seven percent of the trajectories intersected (green asterisks on Figure 9A) or hit a spatial gap (pink dots on Figure 9A) near the mainland boundary numbered 81 or less (refer to Fig 2 for the enumeration of the boundary in Fig 9A; Table 1). Many of the trajectories ended at spatial gaps in the radar coverage (red open dots on Figure 9A) on the mainland shelf north and northeast of Platform Gilda and after moving southeastward along the bathycontours. Few trajectories ended south of the platform over the deep channel or near the islands.

In contrast, the second ensemble is comprised of almost entirely of trajectories with pathways that ended on the mainland shelf north of Platform Gilda (Fig 9C, red open dots). Sixteen percent of the 90 trajectories crossed the offshore portion of the boundary and are accounted in the histogram at the positions numbered between 82 and 100 (Fig. 9D, Table 1); however, all but five of these trajectories turned back into the coverage area and hit a spatial gap on the mainland shelf north of Platform Gilda (Fig. 9C). Only three trajectories cross into the western Channel: one crosses the 50 m boundary on the mainland shelf then moves westward following isobaths of the mainland slope; and two do not cross the mainland coverage boundary but meander in the middle of the Channel, then move southwestward across the western Channel toward Santa Rosa

Island (Fig. 9C). Currents at the surface had a stronger northward component as indicated by the trajectory results than subsurface currents which were dominated by westward flow (Fig 7A, negative U component).

The third ensemble pattern (Figs 9E and 9F) encompasses much of the trajectory distributions of the first two ensembles; however, some differences are evident. Seventy-two percent of the surface trajectories intersected or hit a spatial gap near the southern offshore boundary (Table 1), a substantially higher proportion than would be expected from the subsurface current patterns and water mass analysis that indicates a northwestward current from the southern California Bight was delivering rockfish recruits to the platforms. The discrepancy is due to the surface currents diverging from the subsurface flow. Currents at the surface had a stronger southward component (Fig 7B, black line) as indicated by the trajectory results, than currents in midwater where rockfish recruited (Fig 7B, blue and red lines).

Discussion

Water Mass Effect on the Timing of the Recruitment Season

The change in water masses at the platforms which preceded the onset of the recruitment season was driven by the dynamics of larger-than-channel scale currents. Water mass and current flow data from our study indicates that rockfish recruits were delivered to the platforms by currents from the Southern California Bight rather than from central California. The recruitment season for bocaccio, the most abundant juvenile rockfish species that we observed, and other rockfishes began in late June after the rapid advection of a low salinity water mass into the Santa Barbara Channel from the Southern California Bight (Figures 4, 5, and 6). The change in water masses was evident where most of the fish settled on the platforms, about 25 m depth, and the low salinity water mass occupied the platforms throughout the observed recruitment season. Subsurface current measurements at the platforms and surface current mapping show that the reversal from eastward (equatorward) currents to westward (poleward) currents occurred within several days (Figs 7 and 8). Surface current maps in Figure 8 show Southern California Bight waters moving into the channel through the eastern entrance and the gap between Anacapa Island and Santa Cruz Island.

In contrast, before the recruitment season commenced, water mass properties at the two platforms were relatively saline and resembled upwelled water from the Point Conception region and the more saline offshore waters of the Southern California Bight located immediately south of the Channel (Fig. 5). Currents at the platforms were variable but were predominately from the western Channel (Fig. 6). Waters from the western Channel would tend to be more saline due to the influence of wind-induced upwelling at Point Conception or cyclonic circulation upwelling waters within the channel (Harms and Winant 1998). When cyclonic circulation is persistent, the western Santa Barbara Channel is an area of retention and potentially a source of juvenile rockfish recruits (Nishimoto and Washburn, 2002); however, our examination of daily surface current maps indicates that cyclonic circulation was episodic throughout the study period. Pelagic stages of nearshore demersal invertebrates and fishes, including larval and juvenile rockfishes, are relatively rare in newly upwelled water such as that from Point Conception (Nishimoto 2000, Wing et al. 1998). We observed that very few rockfish settled when relatively saline waters that likely flowed from the western channel occupied the platforms.

Our observation of the water mass change at the platforms may have been a signal of the seasonal transition from spring to summer conditions in the Southern California Bight. Seasonal variations have been observed on the regional scale of the Southern California Bight (Lynn and Simpson 1987, Bray et al. 1999) as well as in the channel (Harms and Winant 1998). In the spring, equatorward alongshore flow predominates in the bight at all depths to 500 m. We observed this flow as an eastward current at the platforms during the first portion of our study (Fig 7). Poleward alongshore flow develops in the summer and persists through the fall and winter throughout the bight except for the western part of the Santa Barbara Channel where cyclonic circulation predominates (Bray et al. 1999). The core of the poleward flow shoals through the late summer from about 100m in July to the surface in early October. The development, intensification and expansion of the low salinity water mass that we observed below 15 m in the Eastern Channel (Fig. 5), although shallower than expected, may be associated with this phenomenon that could deliver recruits to the platforms.

Larval import from outside a local area is needed to sustain most populations. Cowen et al. (2006) used a biophysical model that resolved the eddy field in the Caribbean region and showed that typical larval dispersal distance between nearshore spawning and settlement locations were on the scale of 10 to 100 km for a variety of reef fish species. We infer from our study that the scale may be at the upper end of this range for populations of at least some rockfish species in the Santa Barbara Channel.

Various lines of evidence from other studies suggest connectivity between the Santa Barbara Channel and the Southern California Bight. Matala et al. (2004) found that bocaccio populations in the Santa Barbara Channel were genetically indistinguishable from coastal populations in the Southern California Bight (Santa Monica Bay) and off Northern Baja California. Furthermore, these three coastal populations south of Point Conception formed a group that genetically differed from populations north of Point Conception and from Tanner Bank, an offshore ridge, south of the Santa Barbara Channel, that is in the path of the California Current. Otolith elemental signatures of pelagic juvenile shortbelly rockfish (*Sebastes jordani*) collected north of Point Conception differ from that of fish collected in the Channel (Nishimoto et al. 2003). The delivery of larvae and pelagic juveniles from the coastal area north of Point Conception into the Channel may be restricted by persistent spring and summer upwelling at the headland that functions to some extent as a hydrographic barrier to dispersal.

Platform Effect on Rockfish Recruitment to Natural Nearshore Habitat

From our analysis of the surface current trajectories derived from HF radar and the subsurface current measurements at the platform, we estimate that the majority of juvenile rockfish recruits from Platform Gilda would have been transported northward and northeastward toward Carpinteria and Ventura or would have been transported westward along the mainland slope during the recruitment season if the platform did not exist. Subsequently, as our trajectory results (Fig 9C) indicate, recruits transported by westward currents along the mainland coast would eventually be advected offshore because of reoccurring cyclonic circulation pattern of the western Channel rather than onshore toward nearshore habitat along the mainland or north of Point Conception. The mainland coast within the 50-m isobath has considerably less rocky habitat than the islands due to the greater amount of sediment from mainland drainages (Guy Cochran, USGS, pers. comm.). The nearshore habitat off Anacapa Island and eastern Santa Cruz Island could receive some recruitment from the location of Platform Gilda, because currents, although prevailing from the Southern California Bight during the recruitment season, were variable in the east Channel and transient, smaller scale eddy or meandering flows could transport recruits to the islands.

Although our study indicates that the recruits that we observed at the platforms were delivered by currents from the Southern California Bight, the potential for recruitment from local sources (larvae originating from adult populations residing in the Santa Barbara Channel) at times within the year that we did not observe or in recruitment seasons of other years cannot be discounted. Adult rockfish populations of all the species we observed in our study, including those less abundant and not discussed, reside on nearshore and offshore rocky reefs throughout the Channel. Adult bocaccio, kelp rockfish, gopher rockfish, and other species of rockfishes reside on the bottom under the platform study sites or on the structure itself. Love et al. (2005) found that Platform Gail had by far the highest densities of mature bocaccio of any natural or human-made habitat, and the potential larval production at platform Gail was much higher than at any other site surveyed. Some studies from other areas indicate that self-recruitment to a local population can be significant (e.g., Swearer et al. 1999, Jones et al. 1999)

Eddies occur year-round throughout the Southern California Bight and in the Santa Barbara Channel (DiGiacomo and Holt 2001), and may be important in the connectivity scheme linking distant rockfish populations since larvae can be carried away from a local population by alongshore or cross-shelf currents and subsequently can be entrained and mixed in an eddy with larvae from other sources. Nishimoto and Washburn (2002) observed significantly higher densities of pelagic juvenile rockfish in a persistent cyclonic eddy in the western Santa Barbara Channel than in surrounding waters. Rockfish larvae are found throughout the Southern California Bight and north of Point Conception and are abundant primarily from December through April (Moser et al. 2000). Larval dispersal is extensive; rockfish larvae have been collected more than 400 km offshore far beyond the extent of adult habitat, although 80% of the larval rockfish catch occurs within 100 km of the mainland or in the vicinity of the offshore islands and shallow ridges of the Southern California Bight. (Moser et al 2000). Bocaccio larvae, for example, are moderately abundant in the Santa Barbara Channel; the highest abundances historically have been offshore of Point Conception, south of the islands that border the Santa Barbara Channel, and northeast of San Nicolas Island in the vicinity of the reoccurring Southern California Eddy (Moser et al 2000). The likelihood of a larvae dispersing from natal habitat and encountering eddies is expected to be greater for species such as rockfishes that have relatively long planktonic durations. In regard to our study, it is possible that juvenile rockfishes in offshore waters where natural habitat for settlement is not available, as in the hypothetical case of Platform Gilda's absence, could be retained for some time in a recirculating eddy then advected to nearshore habitat; however, vulnerability in open water to mortality factors (e.g., predation, starvation) is prolonged.

Conclusion

Our findings demonstrate that the spatial scale of connectivity for rockfish populations in the eastern Santa Barbara Channel is greater than the Channel itself. Water currents from the Southern California Bight delivered pelagic juvenile rockfishes to offshore platforms, Gilda and Gail, in the eastern Santa Barbara Channel. However, we do not discount the potential for recruitment from local sources (larvae originating from adult populations residing in the Santa Barbara Channel including natural reefs and platforms), since the reconstruction of transport pathways from natal origin to juvenile settlement habitat were beyond the aims of this study.

From the analysis of calculated HF radar surface current trajectories from Platform Gilda and subsurface current measurements from ADCPs at both study sites, we estimate that the majority of juvenile rockfish recruits from the offshore eastern Channel platforms, had the habitat not been in place, would have been transported to the mainland coast east of Santa Barbara where rocky reef habitat is uncommon. Future studies with better surface and subsurface current monitoring would improve this estimation. High frequency radar coverage and mapping will be expanding along the California Coast. High-resolution maps of rocky reef habitat in the Santa Barbara Channel will be available in the future. Our research, although limited in scope, has considerable bearing on the issue of high densities of young-of-the-year rockfishes recruiting to oil platforms and the decommissioning options that must eventually be considered for each platform. We conclude that the survivorship of juvenile rockfishes would be compromised in the absence of the platforms, because the time when the young fish are vulnerable to dispersal in open water would be considerably extended, and nearshore rocky habitat for settlement is rare along the transport pathways from the platforms when westward currents from the Southern California Bight prevail during the recruitment season.

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Figure captions

Figure 1. Bathymetric maps of the Santa Barbara Channel and the Southern California Bight with CalCOFI water mass reference areas. (A) The Channel: triangles show high frequency radar locations; squares show locations of oil and gas production platforms; Platforms Gilda and Gail, the study sites, are circled. (B) Six water mass regions of geographically distinct locations (see inset color code) are designated in the standard station grid (partially mapped) of triennial CalCOFI surveys. Water mass data (potential temperature and salinity (TS) from 0-100 m) from the six areas were used as references to identify the sources of water masses observed at the platforms (see Figure 6).

Figure 2. Map of the coverage boundary around Platform Gilda (red circled square) where trajectories derived from high-frequency (HF) radar were initiated every 4 hours from 30 April – 31 August, 2004. Blue tick marks are separated by 1 km, and numbers delineate the boundary of sufficient surface current measurements. Triangles show HF radar locations and squares show platform locations. Platform Gail is circled in black. Red lines are bathymetric contours (labeled in meters).

Figure 3. Number of new recruits per survey from 3 May through 31 August, 2004, of bocaccio rockfish at (A) Platform Gail and (B) Platform Gilda; treefish rockfish at (C) Platform Gail and (D) Platform Gilda; (E) copper-complex rockfishes from Platform Gilda; (F) squarespot rockfish at Platform Gilda; and blacksmith at (G) Platform Gail; and H) Platform Gilda. Open circles show the sum of new recruits from 2-cm size bins of

10 cm TL and less. Closed circles show the sum of new recruits from 2-cm size bins of 6 cm TL and less.

Figure 4. 36-hour filtered time series of salinity (black line) from CT loggers deployed at (A) 26 m depth at Platform Gail and (B) 23 m depth at Platform Gilda. Closed circles are salinity from the CTD casts at the same depths as the CT logger at each platform.

Figure 5. Contoured time series of the vertical profiles of salinity at (A) Platform Gail and (B) Platform Gilda; and (C) potential temperature at Platform Gilda. Black horizontal lines at 30 m and 26 m on the Gail and Gilda plots, respectively, indicate the depths of the crossmembers where the majority of the juvenile rockfish recruits were observed.

Figure 6. Identification of water mass signatures at the platforms. TS plots from the six CalCOFI water mass reference regions mapped in Figure 1B (TS lines and regions have corresponding color codes) are laid over the mean TS from 24 hours preceding each survey at Platforms Gilda and Gail before (indicated by **x** and **+**, respectively) and after (indicated by ● and ♦, respectively) the nominal onset of the rockfish recruitment season, 28 June 2004.

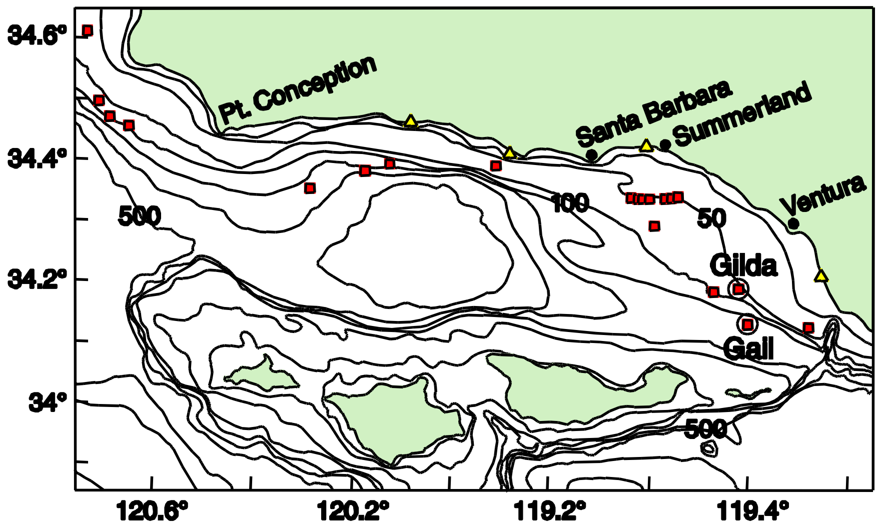
Figure 7. Time series of 36-hour filtered surface and subsurface currents at Platforms Gilda and Gail. (A) U component (eastward is positive) and (B) V component (northward is positive) of radar-derived surface currents (black line) and subsurface currents (blue lines with red line representing the shallowest bin depth) from the ADCP deployed at

Platform Gilda. (C and D) Same for Platform Gail. The surface current measurements are from the nearest radar mapping grid point to the southeast of each platform. The effective current profile range was 10.2 - 22 m at Platform Gilda (29 bins) and 17.2 - 24.9 m from the surface at Platform Gail (19 bins). The bin interval was 0.4 m.

Figure 8. High-frequency radar maps of 25-hour mean surface currents from 10 June, 12 June, 14 June, and 16 June 2004 show abrupt transition from eastward currents to northwestward currents in the eastern Santa Barbara Channel.

Figure 9. Maps showing the trajectories derived from HF radar initiated at Platform Gilda every 4 hours from three time periods (A) 30 Apr – 12 June, (C) 13 June – 27 June, and (E) 28 June – 31 August, 2004; and the histograms (blue bars, left-hand scale) and cumulative frequencies (bold line, right-hand scale) for the same time periods, respectively (B, D, F), showing the fraction of trajectories (%) intersecting 4-km bins around the coverage boundary. The boundary on the maps is delineated by blue dots separated by 1 km, and the numbers correspond with distance along the x axis on the histograms. Green asterisks show where trajectories intersected the boundary and pink dots show where trajectories hit data gaps within the boundary. Red open circles mark the end of every trajectory when it hit a spatial gap in the radar coverage. Red lines are bathymetric contours (labeled in meters).

A)


34.6°
34.4°
34.2°
34°
Pt. Conception
Santa Barbara
Summerland
Ventura
500
100
50
Gilda
Gail
500
120.6°
120.2°
119.2°
119.4°

B)

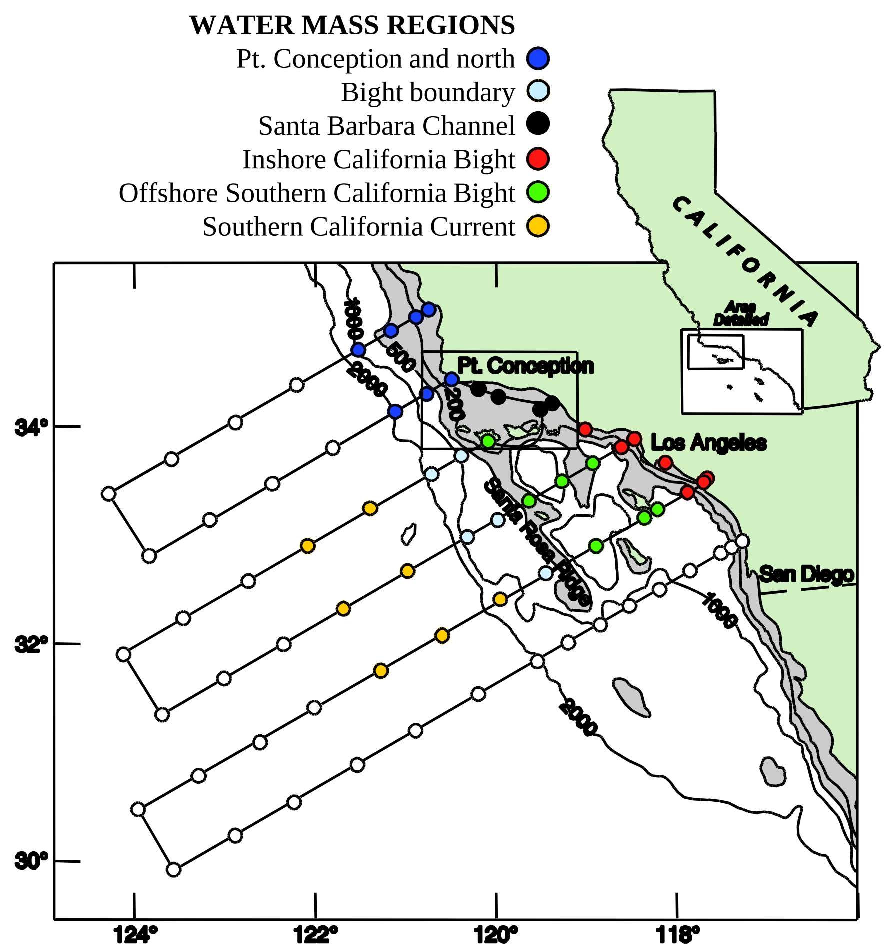

WATER MASS REGIONS
Pt. Conception and north
Bight boundary
Santa Barbara Channel
Inshore California Bight
Offshore Southern California Bight
Southern California Current
CALIFORNIA
Area Detailed
Pt. Conception
Los Angeles
Santa Rosa Ridge
San Diego
1000
500
2000
200
1000
2000
34°
32°
30°
124°
122°
120°
118°

Figure 1.

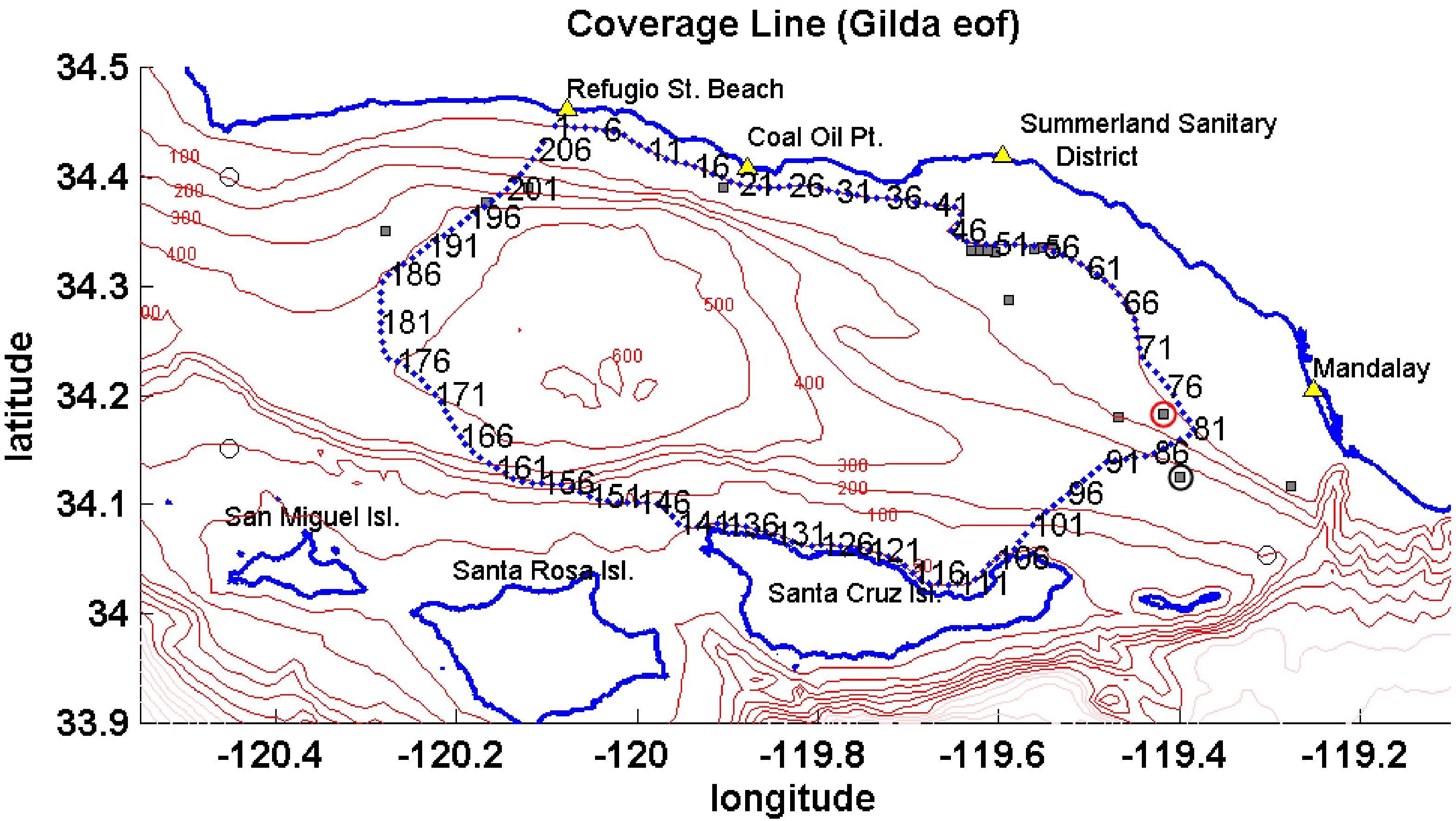

Coverage Line (Gilda eof)
latitude
longitude
Refugio St. Beach
Coal Oil Pt.
Summerland Sanitary District
Mandalay
San Miguel Isl.
Santa Rosa Isl.
Santa Cruz Isl.
34.5
34.4
34.3
34.2
34.1
34
33.9
-120.4
-120.2
-120
-119.8
-119.6
-119.4
-119.2

Figure 2.

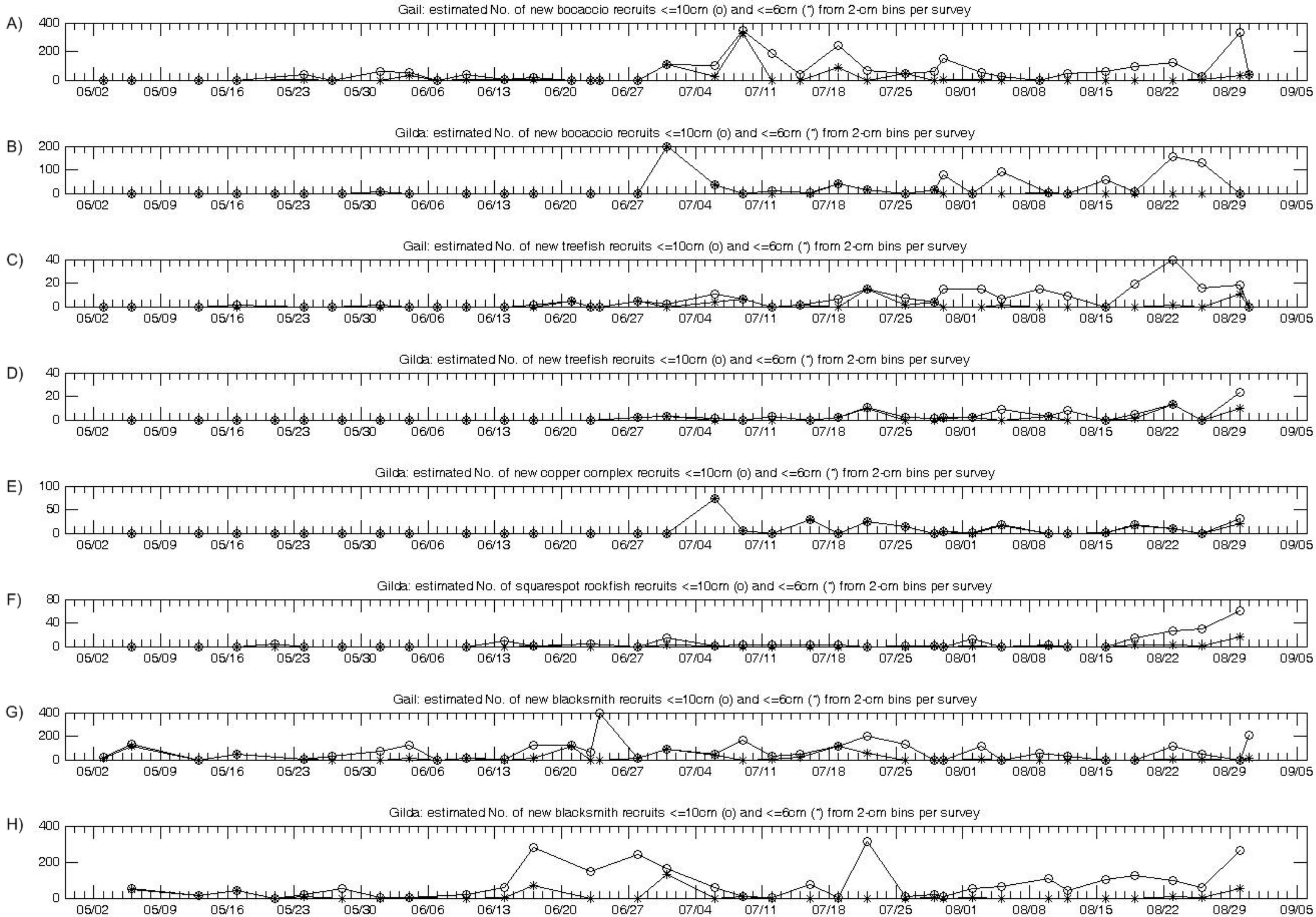
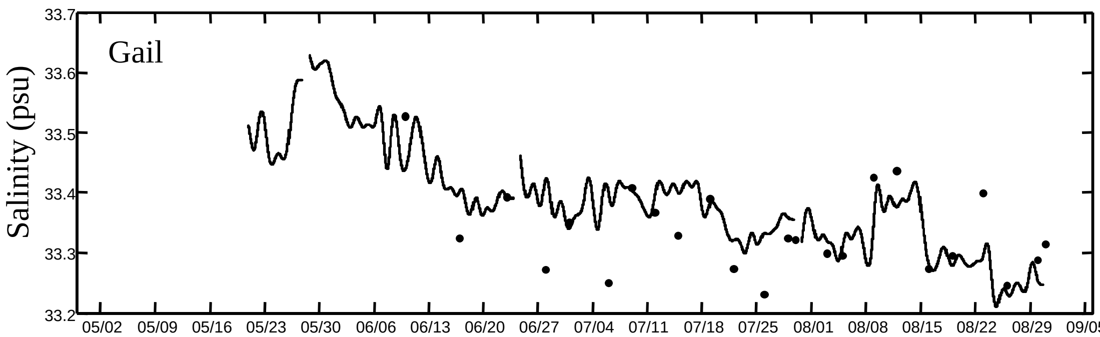

A)
Gail: estimated No. of new bocaccio recruits <=10cm (o) and <=6cm (*) from 2-cm bins per survey
0 200 400
B)
Gilda: estimated No. of new bocaccio recruits <=10cm (o) and <=6cm (*) from 2-cm bins per survey
0 100 200
C)
Gail: estimated No. of new treefish recruits <=10cm (o) and <=6cm (*) from 2-cm bins per survey
0 20 40
D)
Gilda: estimated No. of new treefish recruits <=10cm (o) and <=6cm (*) from 2-cm bins per survey
0 20 40
E)
Gilda: estimated No. of new copper complex recruits <=10cm (o) and <=6cm (*) from 2-cm bins per survey
0 50 100
F)
Gilda: estimated No. of squarespot rockfish recruits <=10cm (o) and <=6cm (*) from 2-cm bins per survey
0 40 80
G)
Gail: estimated No. of new blacksmith recruits <=10cm (o) and <=6cm (*) from 2-cm bins per survey
0 200 400
H)
Gilda: estimated No. of new blacksmith recruits <=10cm (o) and <=6cm (*) from 2-cm bins per survey
0 200 400
05/02 05/09 05/16 05/23 05/30 06/06 06/13 06/20 06/27 07/04 07/11 07/18 07/25 08/01 08/08 08/15 08/22 08/29 09/05

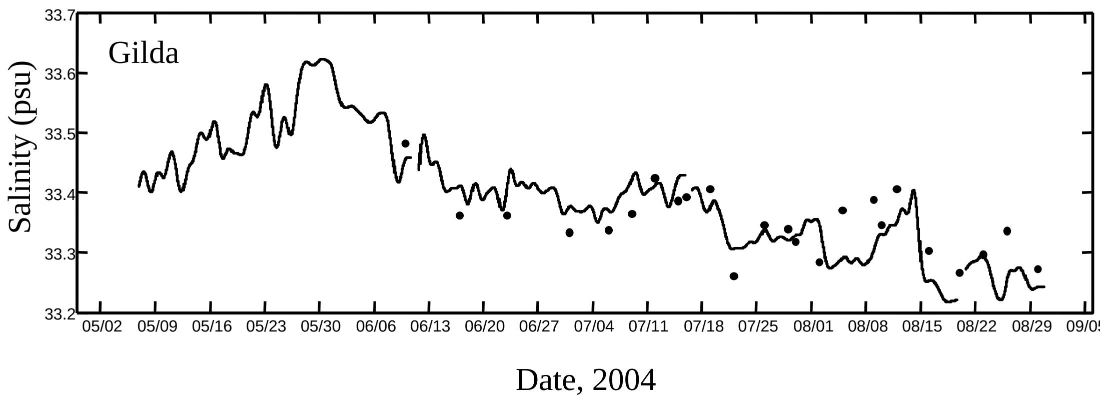
Figure 3.

A)



33.7
33.6
33.5
33.4
33.3
33.2
Salinity (psu)
Gail
05/02
05/09
05/16
05/23
05/30
06/06
06/13
06/20
06/27
07/04
07/11
07/18
07/25
08/01
08/08
08/15
08/22
08/29
09/05

B)



33.7
33.6
33.5
33.4
33.3
33.2
Salinity (psu)
Gilda
05/02
05/09
05/16
05/23
05/30
06/06
06/13
06/20
06/27
07/04
07/11
07/18
07/25
08/01
08/08
08/15
08/22
08/29
09/05
Date, 2004

Figure 4.

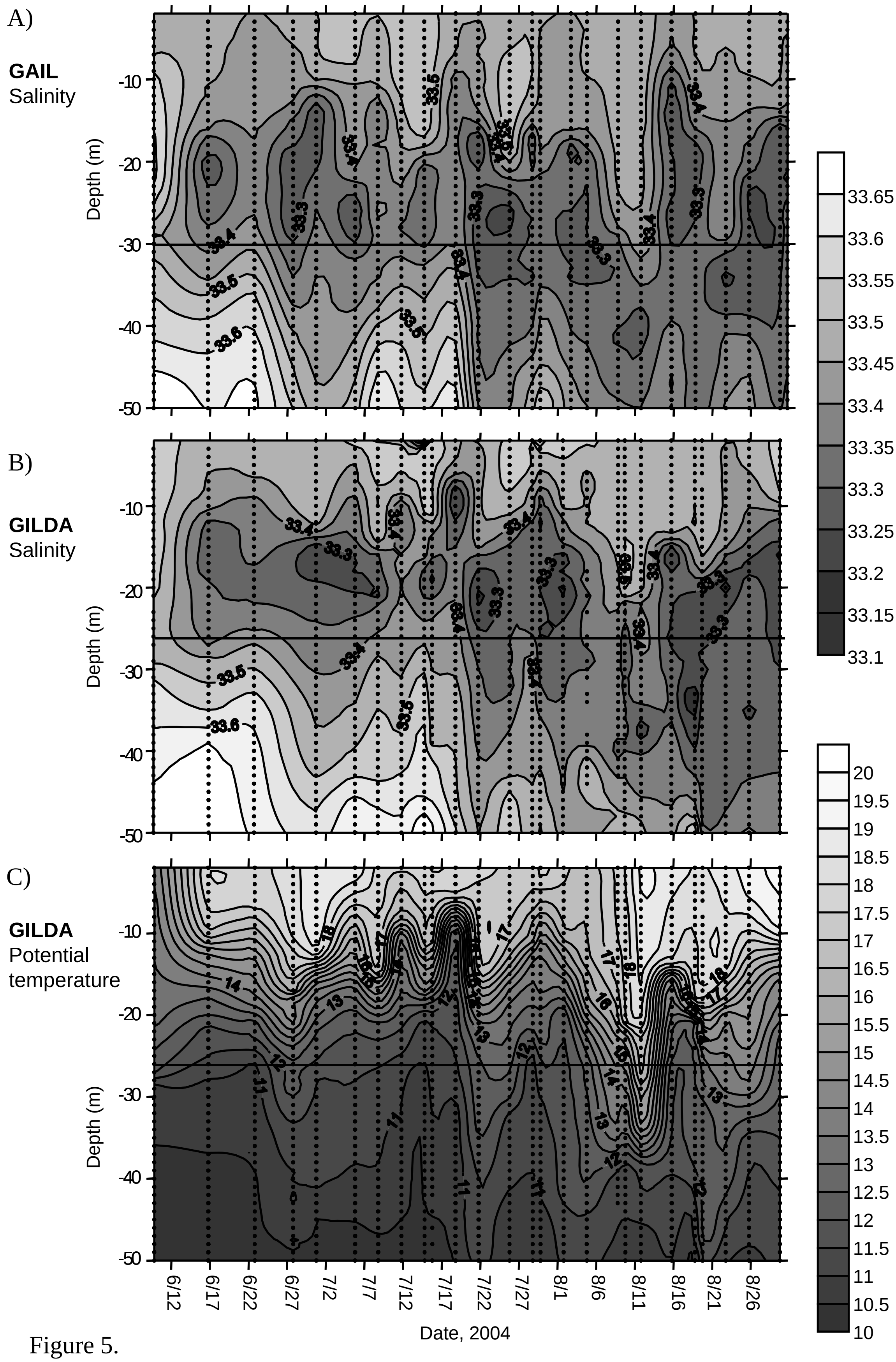
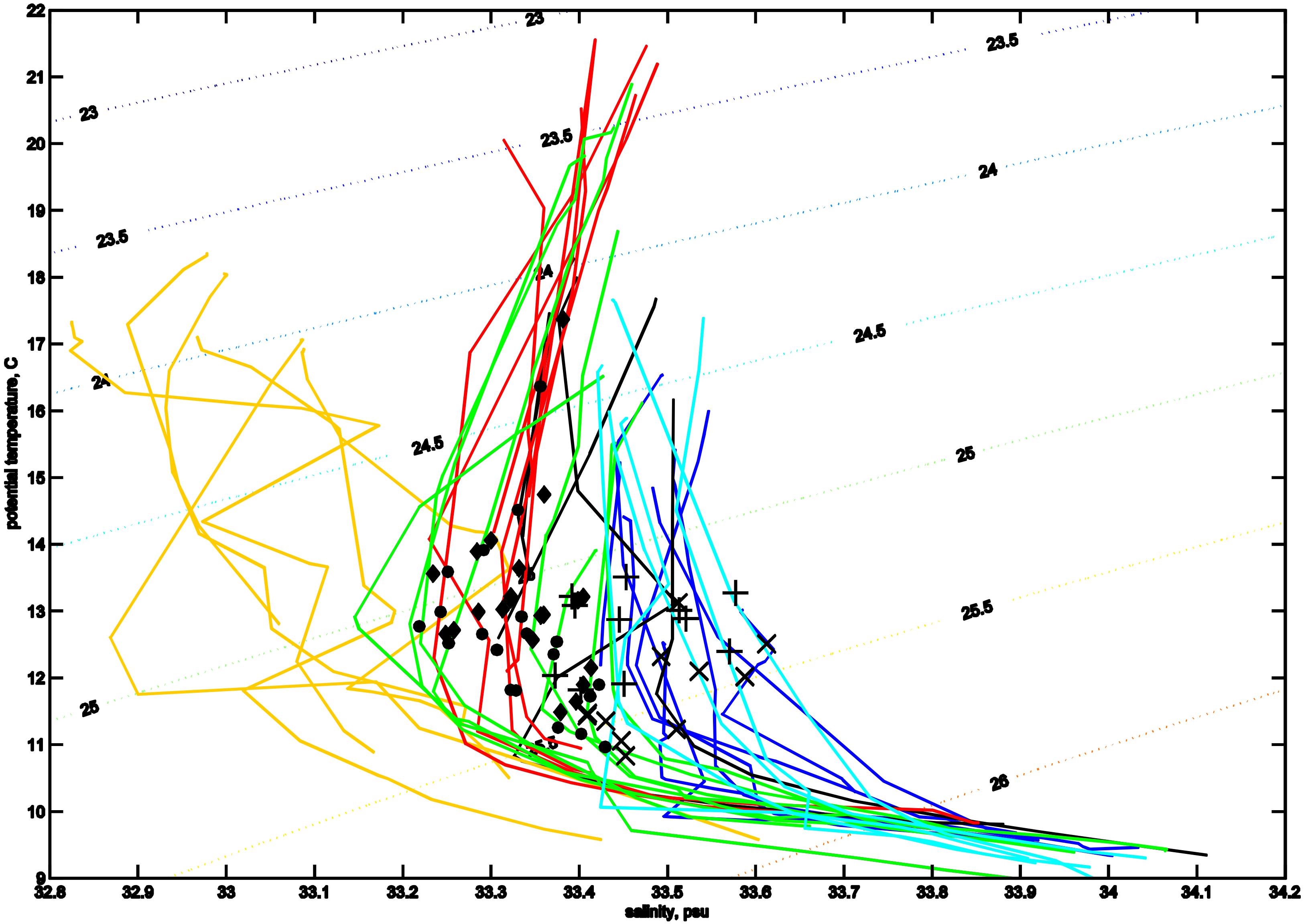

A)
GAIL
Salinity
B)
GILDA
Salinity
C)
GILDA
Potential
temperature
Depth (m)
Date, 2004
6/12
6/17
6/22
6/27
7/2
7/7
7/12
7/17
7/22
7/27
8/1
8/6
8/11
8/16
8/21
8/26

Figure 5.



potential temperature, C
salinity, psu
22
21
20
19
18
17
16
15
14
13
12
11
10
9
32.8
32.9
33
33.1
33.2
33.3
33.4
33.5
33.6
33.7
33.8
33.9
34
34.1
34.2
23
23.5
24
24.5
25
25.5
26

Figure 6.

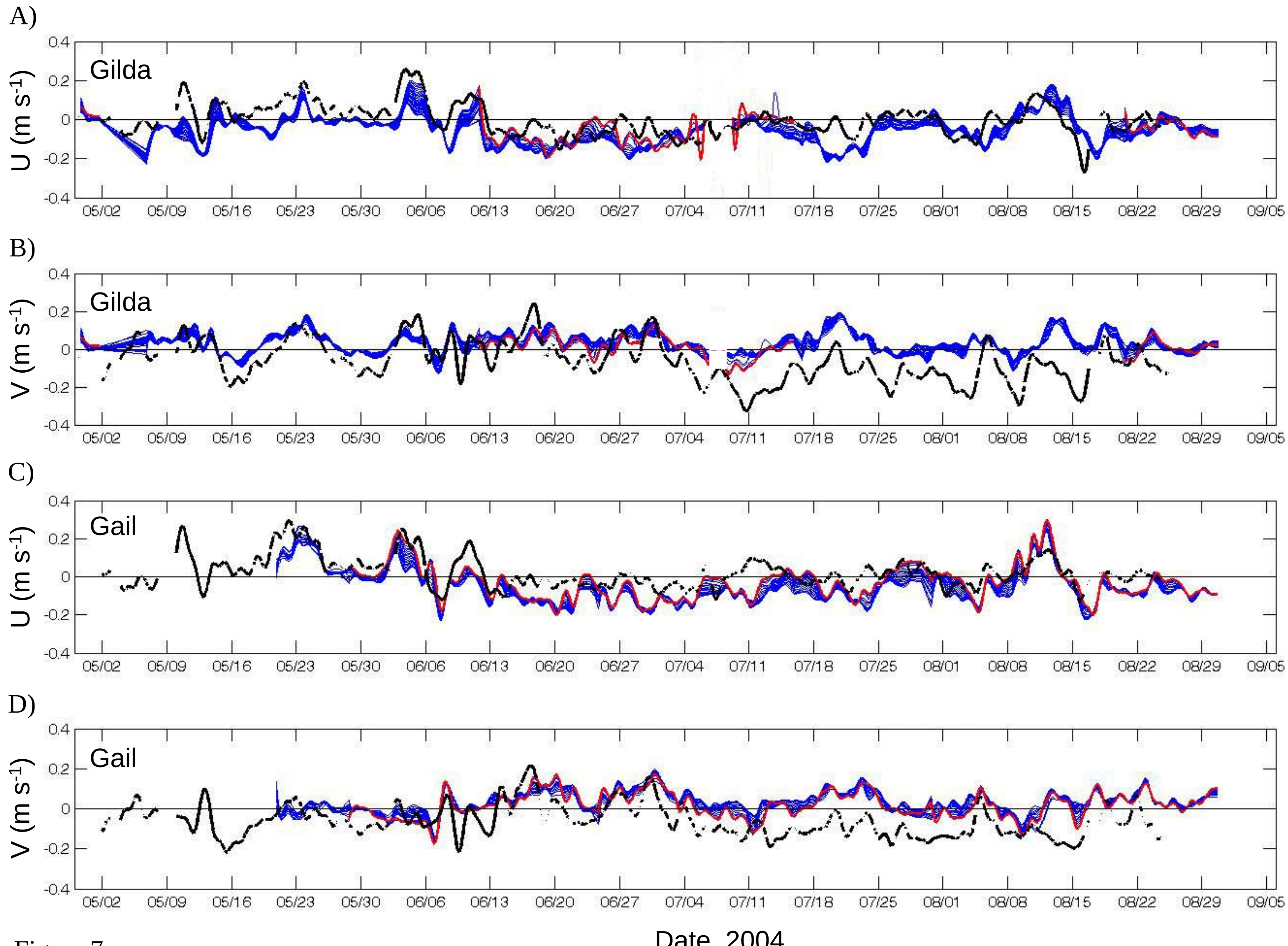
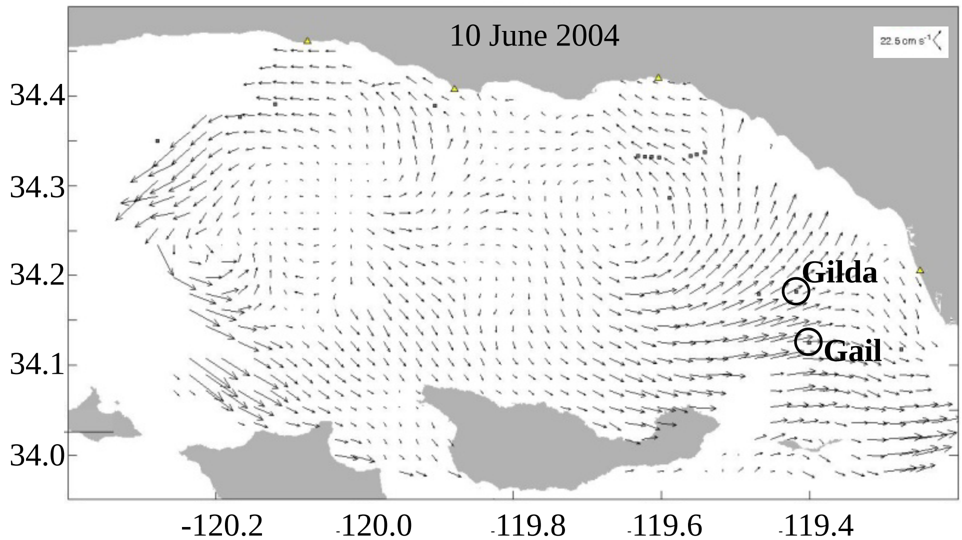

A)
Gilda
U (m s-1)
0.4
0.2
0
-0.2
-0.4
05/02
05/09
05/16
05/23
05/30
06/06
06/13
06/20
06/27
07/04
07/11
07/18
07/25
08/01
08/08
08/15
08/22
08/29
09/05
B)
Gilda
V (m s-1)
C)
Gail
U (m s-1)
D)
Gail
V (m s-1)
Date, 2004

Figure 7.

A)


10 June 2004
22.5 cm s-1
34.4
34.3
34.2
34.1
34.0
Gilda
Gail
-120.2
-120.0
-119.8
-119.6
-119.4

B)

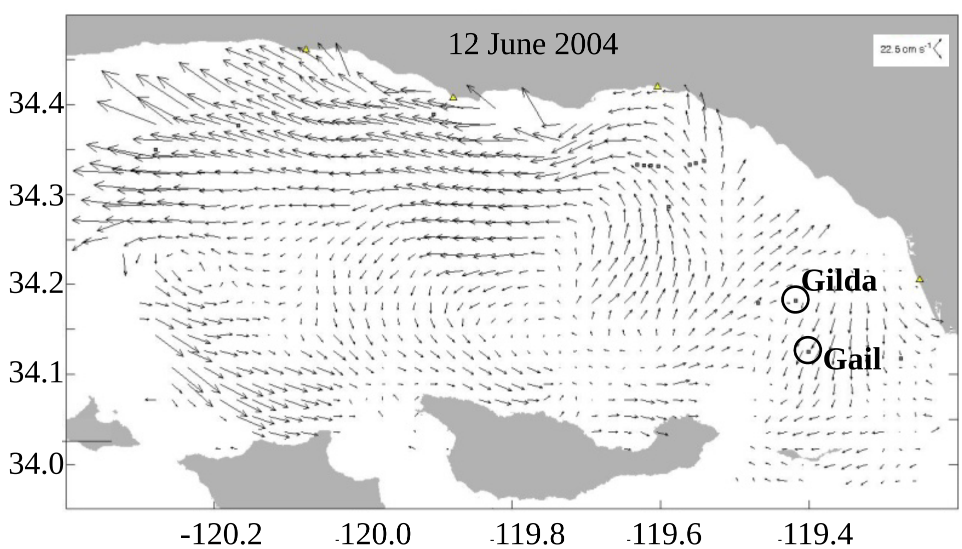
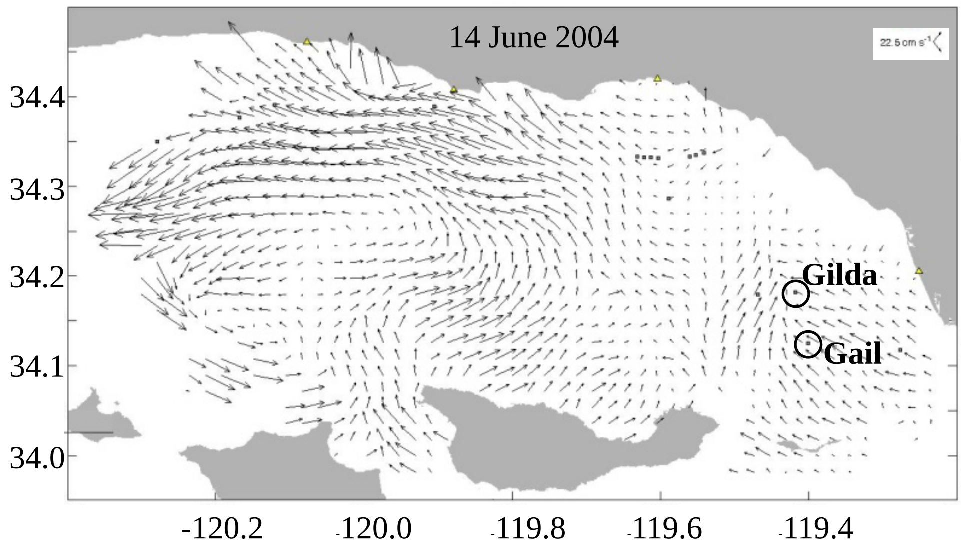

12 June 2004
22.5 cm s-1
34.4
34.3
34.2
34.1
34.0
Gilda
Gail
-120.2
-120.0
-119.8
-119.6
-119.4

Figure 8.

C)



D)

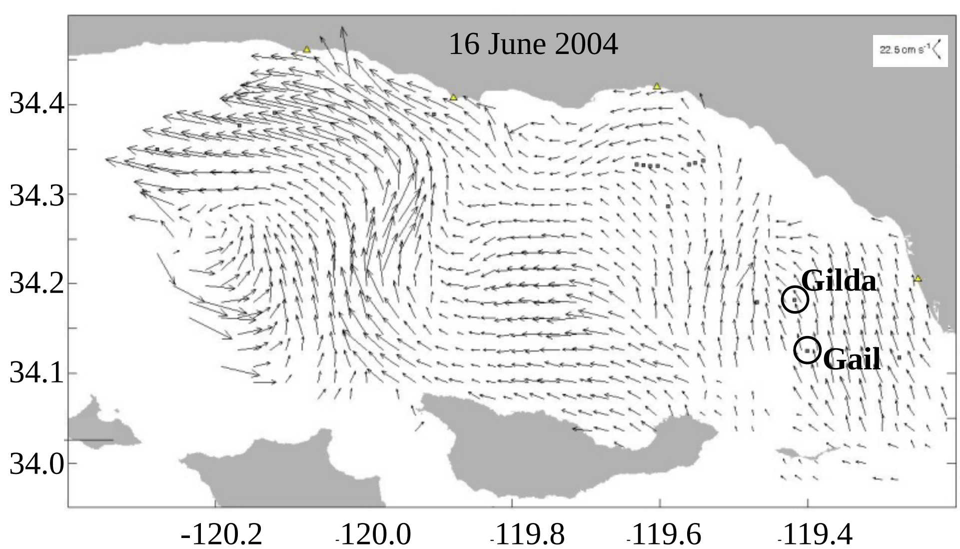
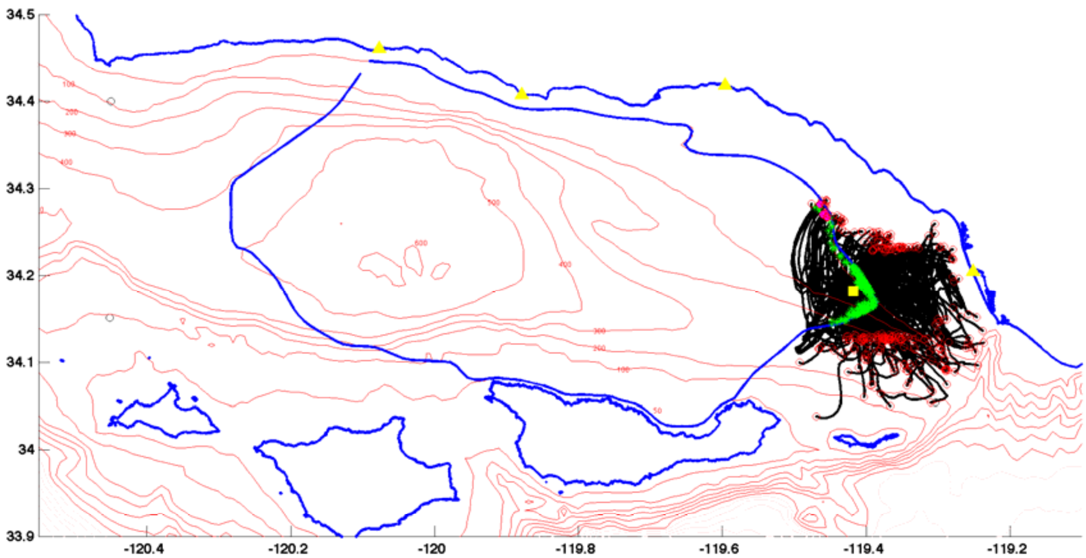


Figure 8 continued.

A)


34.5
34.4
34.3
34.2
34.1
34
33.9
-120.4
-120.2
-120
-119.8
-119.6
-119.4
-119.2

B)

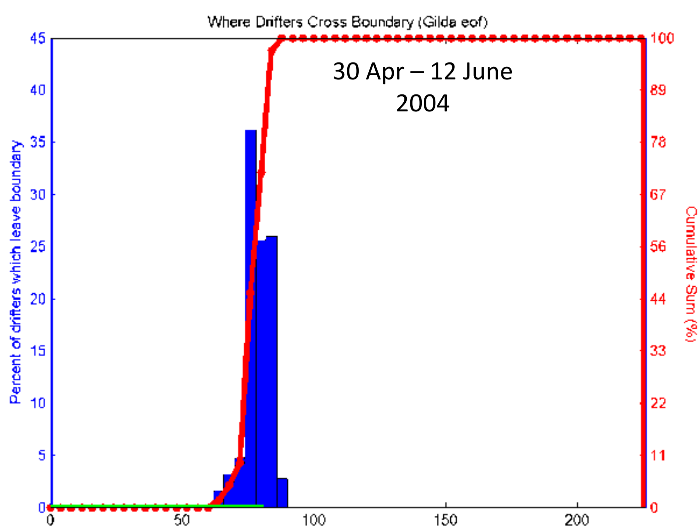
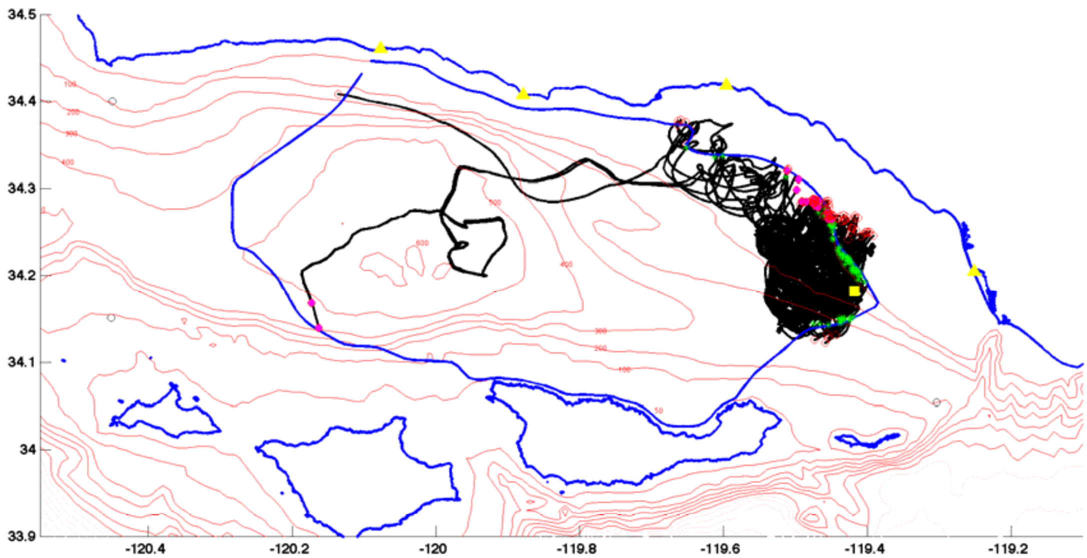

Where Drifters Cross Boundary (Gilda eof)
30 Apr – 12 June
2004
Percent of drifters which leave boundary
Cumulative Sum (%)
Position along coverage boundary
0
50
100
150
200
5
10
15
20
25
30
35
40
45
11
22
33
44
56
67
78
89
100

Figure 9.

C)



D)

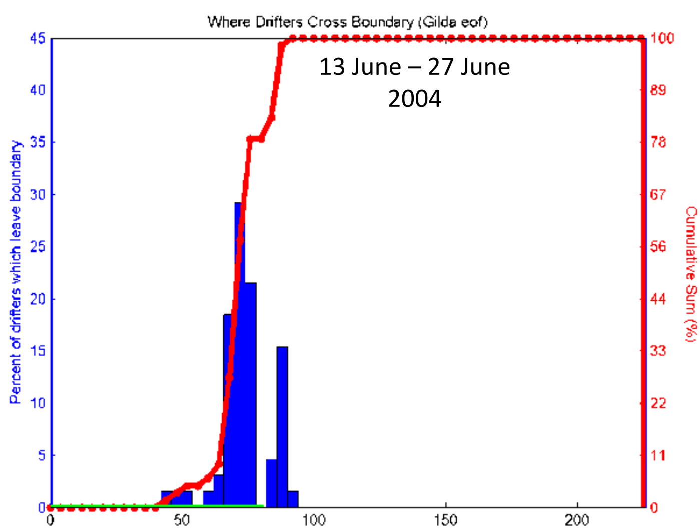
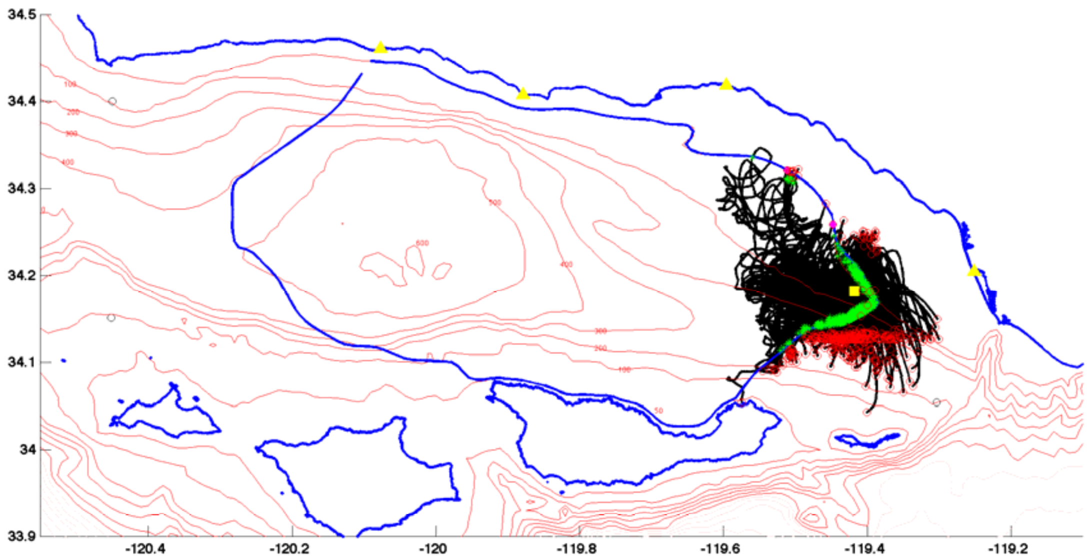


Figure 9 continued.

E)



F)

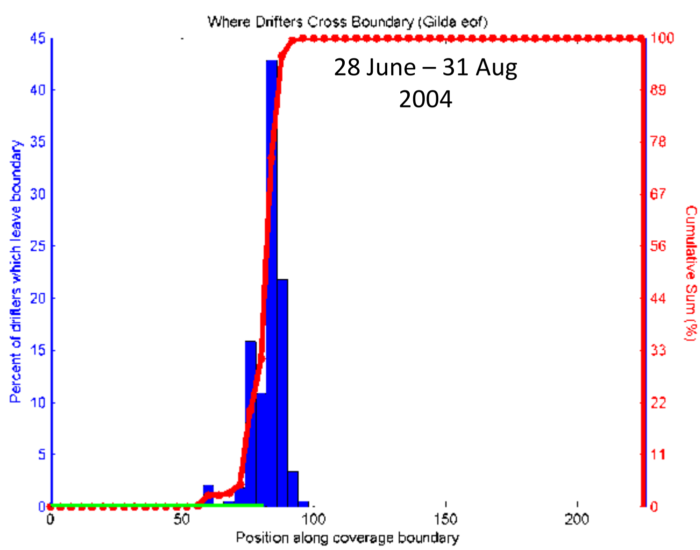


Figure 9 continued.

TABLE 1. Statistics for trajectories released from Platform Gilda from 30 April through 31 August, 2004.

Time period	Total number of trajectories	% Trajectories intersecting or hitting hole near inshore boundary, markers 1-81	% Trajectories intersecting or hitting hole near southern offshore boundary, markers 82-105	% Trajectories intersecting or hitting hole near Santa Cruz Is. Boundary, markers 106-141	% Trajectories intersecting or hitting hole near western offshore boundary, markers 142-206
30 April - 12 June	258	67	33	0	0
13 June - 27 June	90	82	16	0	2
28 June - 31 August	387	28	72	0	0

APPENDIX 1A. Fishes observed at Platforms Gail and Gilda. Size range and sum of all individuals and of those 10 cm TL or less from all surveys. Taxa have been sorted by total abundance of fish at both platforms.

		Size range (cm TL)		Number of fish counted			
				All sizes		10 cm TL or less	
Species	Common name	Gail	Gilda	Gail	Gilda	Gail	Gilda
Chromis punctipinnis	Blacksmith	2-42	3-32	12069	5074	5043	3440
Sebastes spp.	All rockfishes	3-42	3-38	6729	2586	5460	2172
Medialuna californiensis	Halfmoon	10-23	10-30	1485	1733	39	51
Oxylebius pictus	Painted greenling	3-15	3-15	156	815	122	567
Paralabrax clathratus	Kelp bass	15-45	12-45	463	503		
Engraulis mordax	Northern anchovy	5	3-5	100	650	100	650
Scorpaenichthys marmoratus	Cabezon	6-42	5-40	41	145	5	12
Phanerodon furcatus	White seaperch	-	10-30	0	81		11
Girella nigricans	Opaleye	-	20-40	0	73		
Damalichthys vacca	Pile perch	20	10-30	1	66		2
Gibbonsia species	Unidentified kelpfish	-	6-15	0	36		19
Rhinogobiops nicholsii	Blackeye goby	4	8-14	1	10	1	3
Alloclinus holderi	Island kelpfish	-	8-10	0	3		3
Mola mola	Ocean sunfish	-	80	0	3		
Syngnathus spp.	Unidentified pipefish species	20	15	1	1		
Anarrhichthys ocellatus	Northern wolffish	-	80	0	1		
Brachyistius frenatus	Kelp surfperch	3	-	1	0	1	
Citharichthys spp.	Sanddab species	-	16	0	1		
Embiotocidae	Unidentified surfperch species	-	20	0	1		
Hexagrammos decagrammus	Kelp greenling	-	7	0	1		1
Paralabrax maculatofasciatus	Barred sand bass	-	33	0	1		
Total				21047	11784	10771	6931

APPENDIX 1B. Rockfishes (Genus *Sebastes*) observed at Platforms Gail and Gilda. Size range and sum of all individuals and of those 10 cm TL or less from all surveys. Taxa have been sorted by total abundance of fish <=10cm TL.

		Size range (cm TL)		Number of fish counted			
				All sizes		10 cm TL or less	
Species	Common name	Gail	Gilda	Gail	Gilda	Gail	Gilda
Sebastes paucispinis	Bocaccio	3-24	4-15	5817	1082	4851	1046
Sebastes serriceps	Treefish	3-14	4-11	531	157	500	156
Sebastes atrovirens, carnatus, or caurinus	Copper-complex juv. rockfishes	3-10	3-8	5	505	5	505
Sebastes hopkinsi	Squarespot rockfish	4-10	3-14	3	400	3	305
Sebastes entomelas	Widow rockfish	8-10	4-12	27	69	27	48
Subgenus *Sebastomus*	Unidentified rosy-type rockfish	12	3-7	1	74		74
Sebastes flavidus or serranoides	Yellowtail	7-12	4-12	29	27	28	24
Sebastes caurinus	Copper rockfish	8-33	9-15	95	19	20	5
Sebastes mystinus	Blue rockfish	3-15	5-20	15	65	14	1
Sebastes carnatus	Gopher rockfish	8-36	10-14	11	4	4	2
Sebastes dalli	Calico rockfish	10-12	10-15	4	6	2	4
Sebastes auriculatus	Brown rockfish	7-23	-	11	0	2	
Sebastes diploproa	Splitnose rockfish	6	-	2	0	2	
Sebastes atrovirens	Kelp rockfish	12-32	10-36	18	95		1
Sebastes chrysomelas	Black-and-yellow rockfish	10-12	-	3	0	1	
Sebastes melanops	Black rockfish	18	9	1	1		1
Sebastes ruberrimus	Yelloweye rockfish	8	-	1	0	1	
Sebastes rastrelliger	Grass rockfish	12-42	18-38	117	29		
Sebastes serranoides	Olive rockfish	15-40	12-20	38	53		