Egg and Larval Fish Production from Marine Ecological Reserves

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Part One

Overview of Santa Barbara Basin Marine Reserve Study Sites and Research Plan

Introduction

The Marine Resources Protection Act (MRPA) created four California marine ecological reserves and provided funds to begin studying them. The Marine Ecological Reserves Research Program (MERRP) was subsequently created by the California Department of Fish and Game (CDFG) and is administered by the California Sea Grant College Program (Sea Grant). MRPA was followed by passage of the Marine Life Management Act (MLMA) of 1998 and the Marine Life Protection Act (MLPA) of 1999. These State legislative activities coupled with Federal fishery management decisions at the Pacific Fisheries Management Council (PFMC), and the reauthorization process for the Channel Islands National Marine Sanctuary (CINMS) all advocate a network of marine protected areas (MPAs) along California's coast that will: 1) Conserve biodiversity and ecological functions and 2) Benefit fishery resources by protecting adult spawning potential and providing eggs and larvae to augment recruitment in fished areas outside of the reserves. Little is known about how such a system should be implemented, how reserves should be spaced, and how much area would be needed to accomplish the various goals.

Most sedentary, benthic species that occupy rocky habitats rely on pelagic eggs and larvae as a means of dispersing between favorable adult habitats. The design of a reserve network requires knowledge about the dispersal patterns of eggs and larvae (ichthyoplankton) to: 1) Determine the degree to which reserves can reseed fished areas and 2) Determine the appropriate spacing of reserves to maintain connectivity and guard against local extinctions. Recent studies have documented the existence of more and larger adult fishes near the borders of marine reserves suggesting local spillover of adults (Roberts et al. 2001). However, the study of the production and dispersal of ichthyoplankton presents additional challenges because of the difficulties of sampling and identifying eggs and larvae.

Our approach was to: 1) Describe the benthic habitat and the fish species that occurred at the four reserve sites and 2) Map and describe the ichthyoplankton distributions in the water overlying the various habitats. The null hypothesis was that eggs and larvae are rapidly mixed by ocean currents and are not correlated with the benthic habitat and fish community beneath the samples. The alternative hypothesis was that at some geographic scales, and for some species, the eggs and larvae in the water could be linked to the underlying fish communities and habitats that produced them. A corollary of this hypothesis was that the earliest life stages should be found nearest the habitats where spawning occurred and more distant habitats would have fewer and older life stages suggesting the direction and degree of dispersal. The study design and changing ocean conditions allowed us to compare:

1. Oregonian vs. San Diegan biogeographic provinces
2. Mainland vs. island
3. El Niño vs. La Niña conditions
4. Spring vs. summer spawning seasons
5. Sand vs. rock habitat
6. Reserves vs. adjacent fished areas
7. Depth

To achieve our study design we selected four study sites that varied in their habitat characteristics. Two study sites were located on the mainland, Vandenberg Reserve and Big Sycamore Reserve. These reserves are part of the State MRPA system of no-take reserves. The other two study sites, north Anacapa Island and south San Miguel Island, are part of the Channel Islands National Marine Sanctuary. The four sites were chosen to provide a basis for studying the production and dispersal of eggs and larvae within the greater Santa Barbara Basin current system. In this section we summarize the biogeographic characteristics, the prevailing oceanographic conditions, and the bathymetry of the region. In Part II we present detailed habitat maps of the four sites. These maps include information on boundaries, landmarks, ichthyoplankton sampling locations, habitat type, and bathymetry. In Part III we present a description of the ichthyoplankton sampling and results for commercially important species.

Overview of Region and Study Sites

Basin Topography and Location of Study Sites

The Southern California Bight has a typical basin and range type of topography. While some islands such as Santa Catalina Island are surrounded by deep water that can act as a barrier to the dispersal of benthic organisms, the four northern Channel Islands are essentially contiguous (Fig. 1). The Santa Barbara Basin is the most northern and most contained basin in the Bight. The Basin is bounded by the mainland on the north and the four northern Channel Islands on the south. Circulation patterns are complex but well studied (see below).

The four study sites surround the Basin (Fig. 2). The Vandenberg Reserve and the Big Sycamore Reserve are MRPA sites located on the mainland. The San Miguel Island and Anacapa Island sites are part of the Channel Islands National Marine Sanctuary.

Biogeographic Provinces

The Greater Santa Barbara Basin, herein defined as the Basin proper and the waters immediately adjacent to the Basin, is at the intersection of the Oregonian Cold Temperate Biogeographic Province and the San Diegan Warm Temperate Province (Briggs 1974). At the western end of the Basin, typical colder water species such as kelp greenling, black rockfish and red abalone are found, while at the eastern end warm water species such as spiny lobster, kelp bass, and California sheephead are more common. Long-term climate changes such as the Pacific Decadal Oscillation (PDO) and short-term changes such as ENSO events have profound influences on the oceanography, recruitment and biota of the Basin because of its position at the interface. Each research site contains some elements of the two faunas but Vandenberg and San Miguel are considered to be in the Oregonian Province and Big Sycamore and Anacapa are in the San Diegan Province (Fig. 2).

Sea Surface Temperature

AVHRR images of sea surface temperature are available from the NOAA Coastwatch web site (http://cwatchwc.ucsd.edu/). Sea surface temperatures in the Bight usually show the demarcation between the cooler nutrient rich southward flowing waters of the California Current that create upwelling around Point Arguello (Vandenberg Reserve) and continue past San Miguel Island and along the outer edge of the Bight. The warmer northernward flowing counter current extends up from Baja California Mexico along the mainland and flows past Big Sycamore Canyon Reserve and then is deflected offshore near Anacapa Island (Fig. 3, 4). The front between the two water masses moves with year and season but is one of the primary factors in defining the different faunas. The study period of the MERRP ichthyofauna cruises was unusual in that it included a strong El Niño in 1998 and a La Niña in 1999. The monthly composite sea surface temperatures for the spring and summer MERRP cruises in 1998 and 1999 are shown in Figures 3 and 4.

Circulation Patterns

Circulation patterns in the Basin have been well studied because of concerns about oil spills. Characteristic patterns of circulation have been described (Harms and Winant 1998, Dever et al. 1998, Winant et al. 1999, E. Dever pers. comm.) and estimates of daily movements of eggs and larvae can be inferred from drifter studies and moorings data. Animated drifter trajectories for times near our spring and summer 1998–1999 ichthyoplankton cruises were obtained from the Scripps Institution of Oceanography—Center for Coastal Studies web site (http://www.ccs.ucsd.edu/research/sbcsmb/moorings). Single frame images for spring and summer of 1998 and 1999 are shown in Figures 5 and 6. Although 1998 and 1999 differed greatly in water temperature due to the rapid transition from El Niño to La Niña conditions, the spring flows were similar and could be categorized as the upwelling synoptic state with flows moving down the coast, entering the western entrance of the Basin and leaving via the eastern entrance. Similarly the summer cruises (late June–early July) were both the convergent synoptic state of Dever. During these periods there was equatorward flow along the outer coast with water entering the western entrance of the Basin along the southern margin. There was also a northwestward flow into the eastern entrance of the Channel. This convergence results in a gyre in the western Basin and westward flow along the northern edge of the Basin with water exiting the western entrance to the Basin.

Figures

Figure 1. Bathymetry of the Southern California Bight

Yellow dots show the locations of the ongoing 60 plus year CalCOFI ichthyoplankton survey and data set. The colored contours indicate different ecological zones for benthic fish communities. The yellow zone (<30 m) is considered to be the nearshore and contains kelp forest and associated fish species. The orange zone (30–100 m) is typical outer shelf habitat and contains reef species such as bocaccio rockfish, *Sebastes paucispinis*. The red zone (100–300 m) contains deep reef and slope habitat with species such as the cowcod, *S. levis*. The turquoise region extends from 300–600 m and contains the deepest living commercially exploited rockfish species such as the blackgill rockfish, *S. melanostomus*. The blue regions along the outer shelf and within the basins typically have low oxygen and exclude live-bearing species such as the rockfishes (*Sebastes*). The different basins vary in oxygen content depending on the degree of constriction and deep mixing. The Santa Barbara Basin (green rectangle) is the most constricted Basin and has the least deep mixing. Very low oxygen and few fish species occur below 300 m in the center of the Basin.

Different benthic fish species may experience different barriers to adult dispersal depending on their preferred depth. A cowcod might view the northern Channel Islands and the ridge leading to San Miguel Island as contiguous habitat while a kelp dwelling rockfish would experience a barrier of open water between the two sites. The different island ridges and banks also restrict water movement and are important in interpreting the likely dispersal paths of eggs and larvae and in the potential connectivity of reserve sites.

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Figure 1. Bathymetry of the Southern California Bight

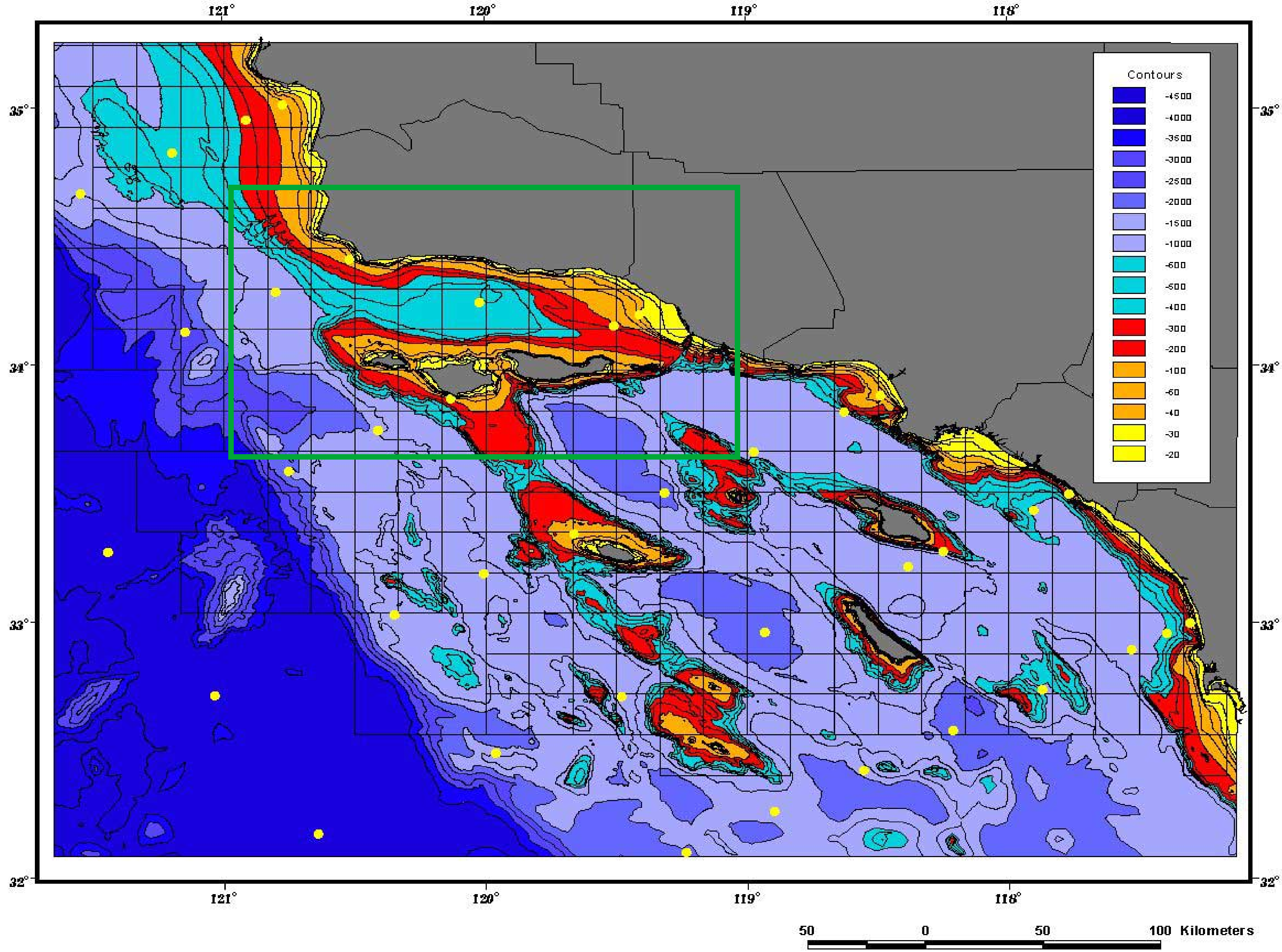

Figure 2. The greater Santa Barbara Basin study site

The Santa Barbara Basin is bounded by the mainland on the north and the four northern Channel Islands on the south. The western entrance between Point Conception and San Miguel Island is deep and broad and opens to the oceanic waters of the California Current and the Santa Maria Basin. The eastern entrance is much smaller and is restricted by a sill that runs from eastern Anacapa Island to the mainland. The locations of the four study sites were Vandenberg (VA), San Miguel (SM), Big Sycamore Canyon (SC) and Anacapa (AN). The locations of the individual ichthyoplankton sampling stations are noted by black dots. Sampling lines generally followed the 20, 40 and 60 m contours plus an offshore line. As seen best in the VA site the sampling pattern covered the reserve area and an equal area on either side to allow for comparisons between fished and unfished areas. The offshore line served as a comparison because it did not contain any shallow benthic habitat and could not serve as a source for eggs of nearshore species.

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Figure 2. The greater Santa Barbara Basin study site

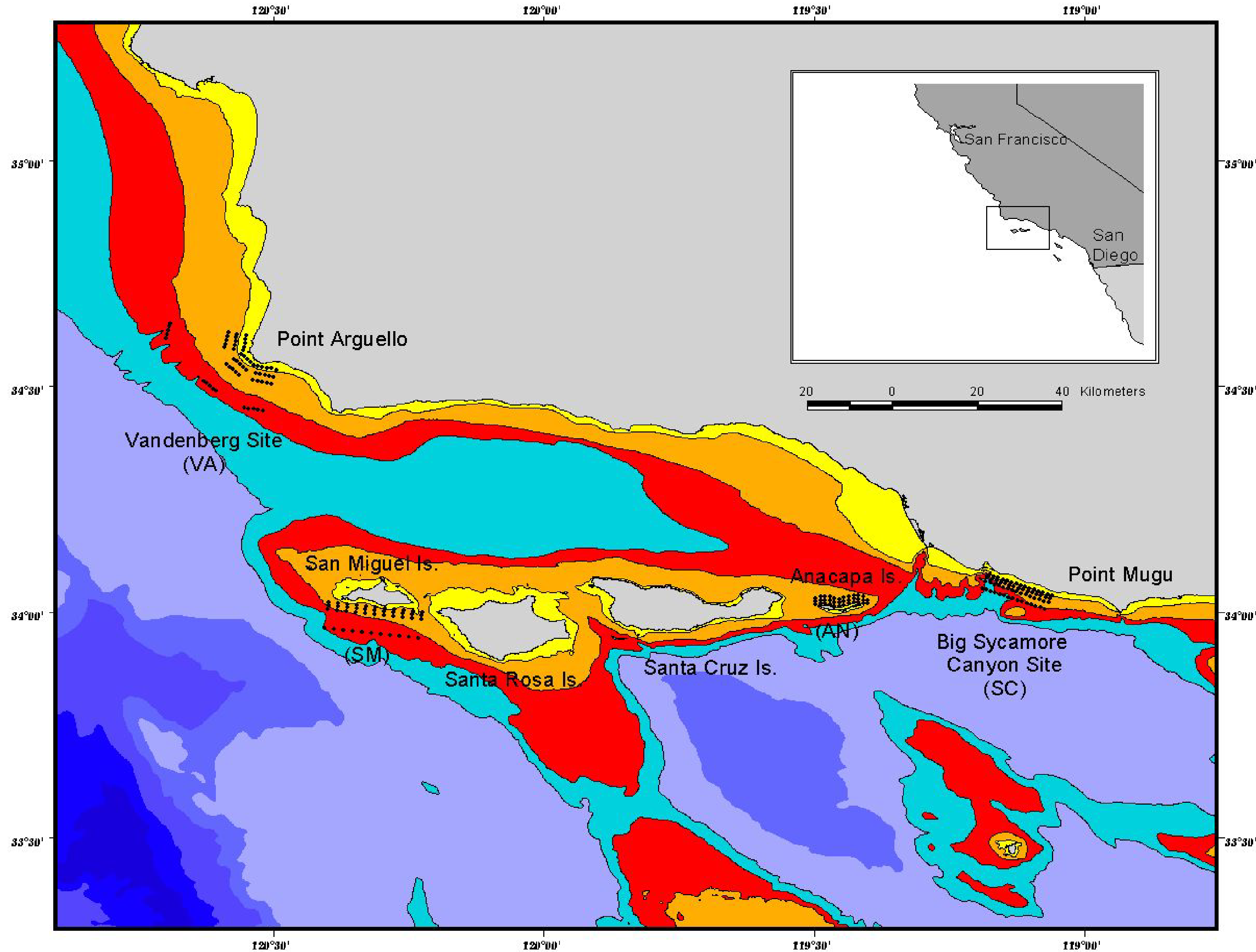

Figure 3. Sea surface temperature in 1998

Monthly average AVHRR sea surface temperature images were compiled for March and June 1998. The times of the actual cruises were February 19 to March 4 and June 12 to June 24, 1998. 1998 was an unusually warm El Niño year and perhaps the end of a warm regime that began in the mid 1970s. Kelp forests were absent or severely depleted at all sites except San Miguel Island. Weak upwelling can be observed at the Vandenberg (Point Arguello) site. The contrast between the cooler waters of the California Current that flow past the western two sites and the warm waters of the counter-current that bath the eastern sites at Big Sycamore and Anacapa is apparent. Areas of persistent cloud cover and insufficient data appear white.

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Figure 3. Sea surface temperature in 1998

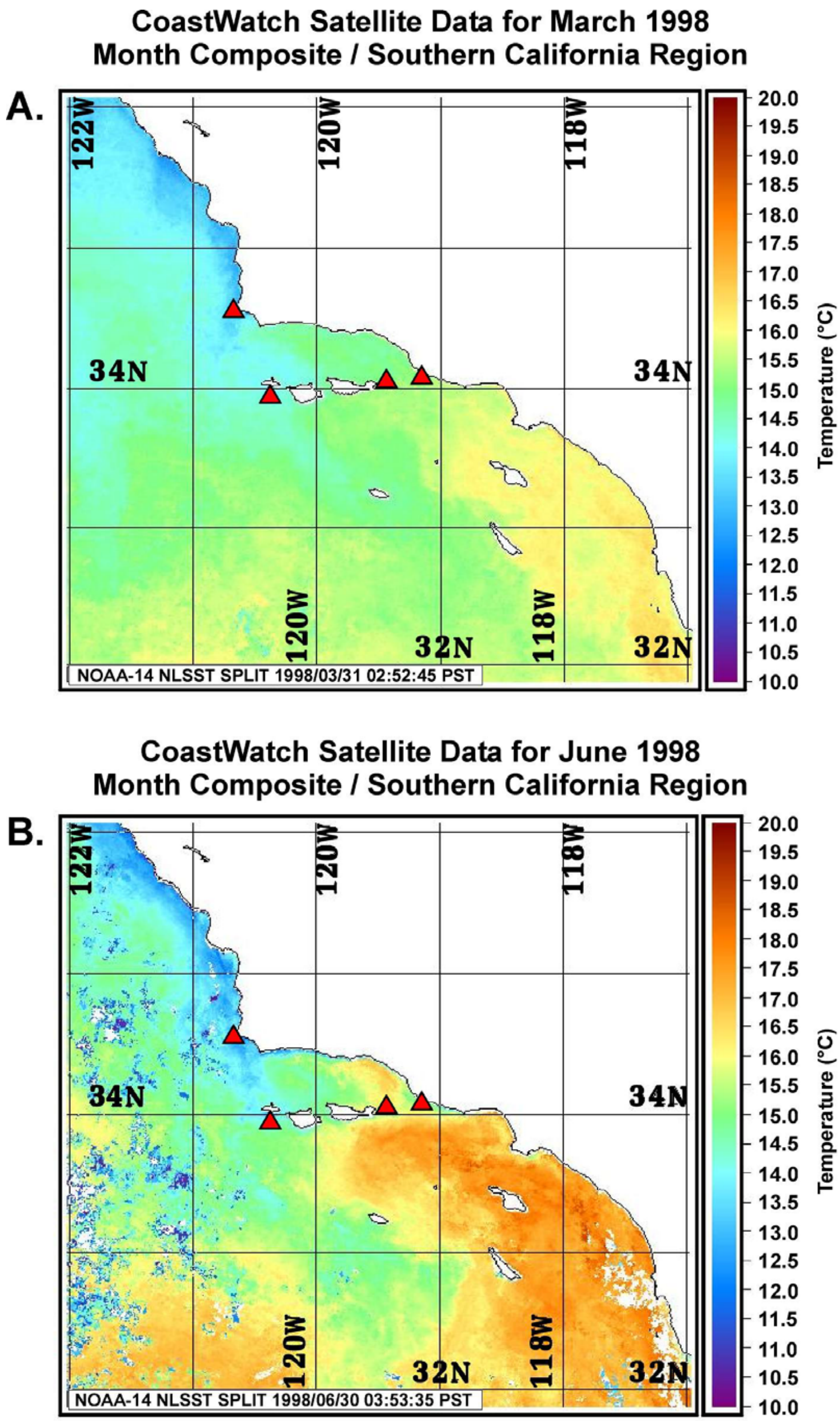

Figure 4. Sea surface temperature in 1999

Monthly average AVHRR sea surface temperature images were compiled for March and June 1999. The times of the actual cruises were February 25 to March 10 and June 28 to July 11, 1999. 1999 was an unusually warm El Niño year and perhaps the end of a warm regime that began in the mid 1970s. Kelp forests were absent or severely depleted at all sites except San Miguel Island. Weak upwelling is observed at the Vandenberg (Point Arguello) site. The contrast between the cooler waters of the California Current at the western two sites and the warm waters of the counter-current that bath the eastern sites at Big Sycamore and Anacapa are apparent.

The dramatic differences in water temperature between the 1998 El Niño and the 1999 La Niña are apparent from these images that have been set to a standard color scale. Although the locations of upwelling, and the positions of the California Current and the countercurrent are similar between years, the summer temperatures in 1999 were cooler than the spring temperature in 1998. Recovery of the kelp canopy was apparent by the summer of 1999.

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Figure 4. Sea surface temperature in 1999

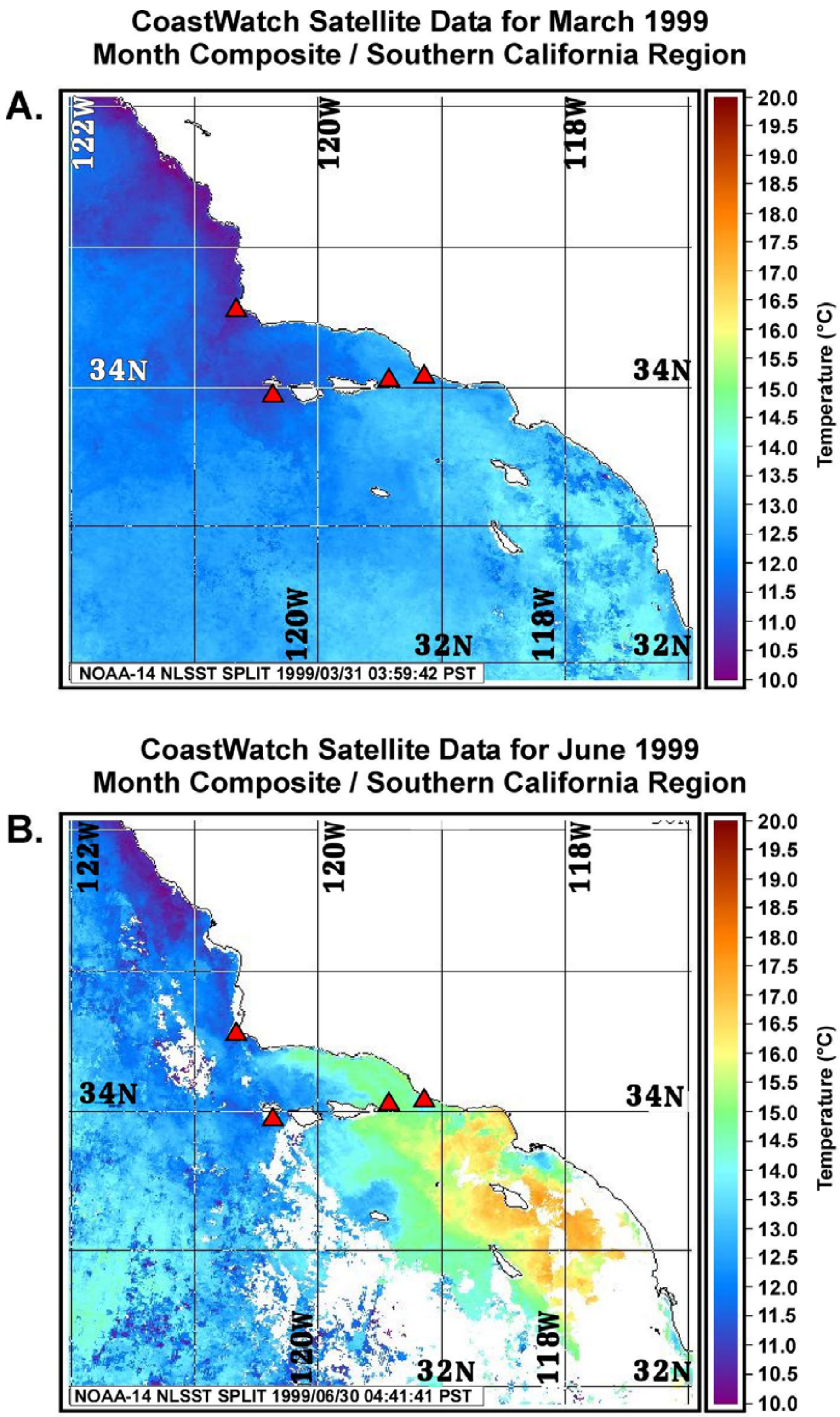

Figure 5. Surface currents in 1998

Animated depictions of circulation patterns in the Santa Barbara Channel–Santa Margarita Basin Circulation Study are available on the UCSD Center for Coastal Studies web site. Times of drifter deployment did not always coincide with the times for our ichthyoplankton cruises but are indicative of general circulation patterns observed in the study area. Fig. 5a shows a single still image of the conditions prevailing at the closest time interval to the spring 1998 cruise. The large black arrow is wind direction. The small black arrows are current directions and velocities from moorings and the red lines are surface drifter tracks. The images show the movement of water from the north past the Vandenberg reserve and entering the south side of the western entrance to the Santa Barbara Basin. Drifters show strong flow along the south side of the Basin with some water exiting the Basin at the eastern end. Drifter tracks are plotted hourly and show that during spring eggs and larvae from the Vandenberg site could easily be transported to all of the other sites within 24 to 48 hours, barring some active retention strategy such as remaining near the bottom.

Fig. 5b shows conditions during the summer consistent with the convergent synoptic state (E. Dever, pers. comm.). Drifters near Vandenberg were deflected offshore as waters were upwelled. The fate of larvae in the upwelled water is unknown but many species such as the rockfishes have typical planktonic larval phases of several months. The persistent eddy in the western portion of the Santa Barbara Basin is apparent in this drifter study and may be important for larval survival and dispersal within the Basin.

Movements of eggs and larvae from the San Diegan fauna that are contained within the waters of the Southern California Counter-Current tend to form an eddy and do not pass easily through the eastern entrance during spring and summer. Flow from the south through the Basin and up around Point Conception is called the relaxation synoptic state (E. Dever, pers. comm.) and occurs most frequently during late fall and winter prior to the spring transition. This is not a time of high spawning activity.

Figure 5. Surface currents in 1998

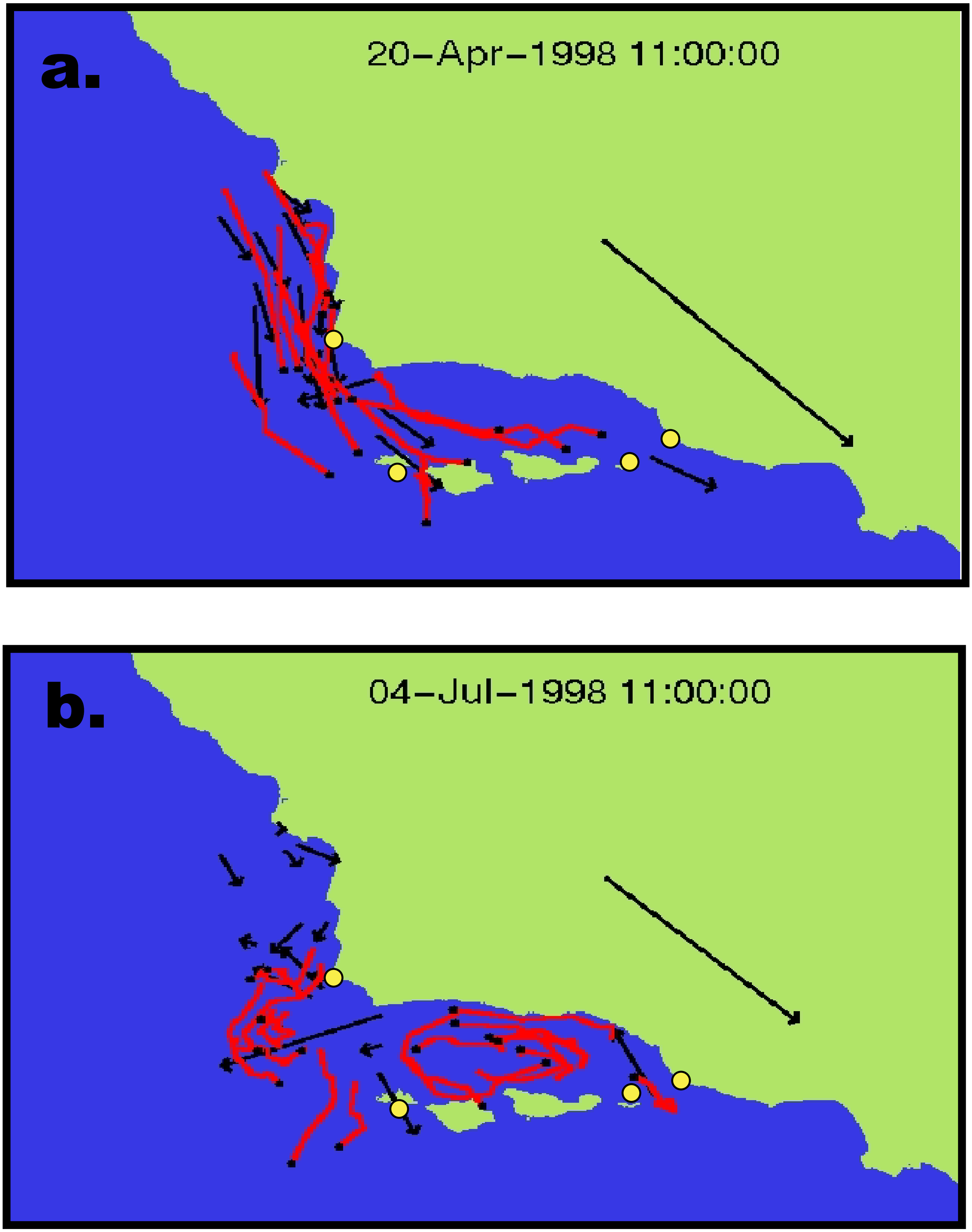

Figure 6. Surface currents in 1999

Animated depictions of circulation patterns in the Santa Barbara Channel-Santa Margarita Basin Circulation Study are available on the UCSD Center for Coastal Studies web site. Times of drifter deployment did not always coincide with the times for our ichthyoplankton cruises but are indicative of general circulation patterns observed in the study area. Fig. 6a shows a single still image of the conditions prevailing at the closest time interval to the spring 1999 cruise. The large black arrow is wind direction. The small black arrows are current directions and velocities from moorings and the red lines are surface drifter tracks. The images reflect the transition to colder water and stronger upwelling. Water is being displaced seaward from Point Arguello. The persistent eddy in the western portion of the Basin is apparent.

Drifters were not deployed at times relevant to the summer 1999 cruise (June 28 to July 11); however, mooring data was available (Fig. 6b). In keeping with the strong La Niña, upwelling persisted into the summer of 1999 with the advection of water from Point Arguello. Westward flow was apparent along the southern rim of the Basin.

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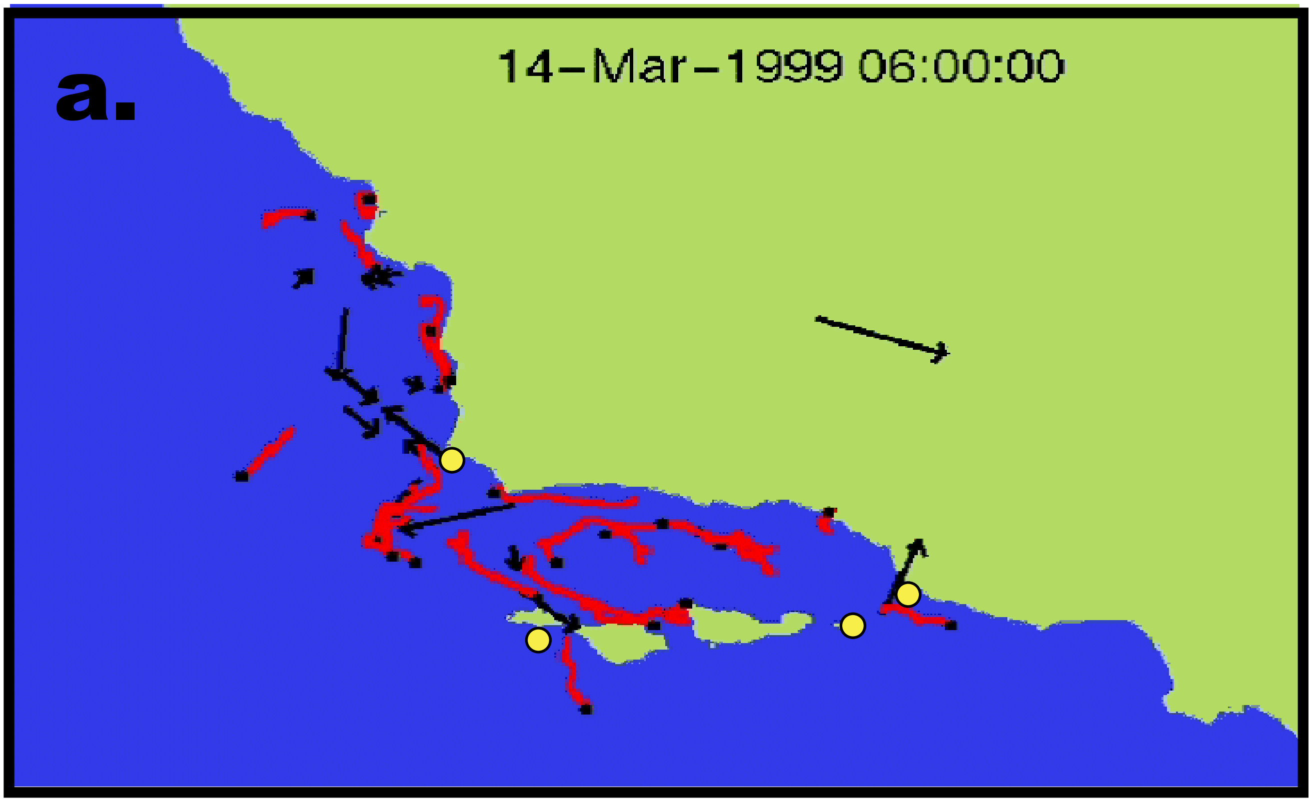
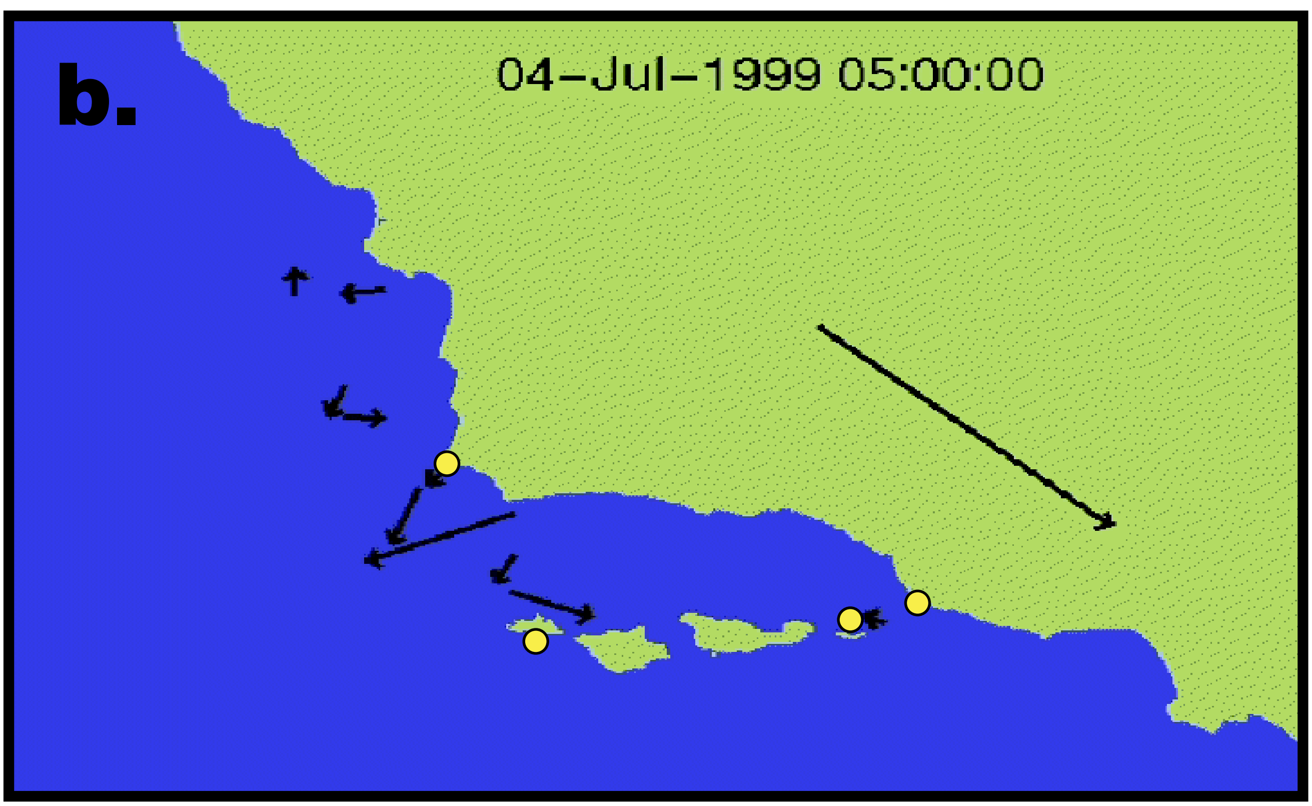
Figure 6. Surface currents in 1999





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