DRIFT BOTTLE OBSERVATIONS OF THE NEARSHORE SURFACE CIRCULATION OFF CALIFORNIA, 1977-1983

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ABSTRACT

This report summarizes results of drift bottle studies off the California coast from June 1977 through September 1983. Approximately 2,000 bottles were released and 253 recovered. The results indicate that there are important seasonal, regional, and year-to-year variations showing a complicated pattern of nearshore surface flow off California.

North of Point Conception, a southward flow predominates, except in fall and winter when a northward flow is apparent. Anomalous summer counterflows in the vicinity of headlands occur in some years. There is also evidence of an intensified northward-flowing countercurrent in the winters of 1977-78 and 1979-80, and a strong spring reversal in 1980.

South of Point Conception, the nearshore circulation is characterized by a large variability in the direction of flow, with indications of an eddy in the area between Santa Catalina Island and the mainland.

RESUMEN

Este es el resumen de los resultados de estudios del movimiento de botellas de deriva en las corrientes costeras de California durante el período de junio de 1977 a septiembre de 1983. Se largaron approximadamente 2.000 botellas y se recuperaron 253. Los resultados obtenidos indican que existen fluctuaciones (según la estación, la región y el año) que complican el patrón general de las corrientes superficiales de las áreas costeras de California.

Al norte de Pt. Concepción predomina una corriente con dirreción al Sur excepto durante el otoño e invierno cuando se observa una corriente hacia el norte. En algunos años, se observan contracorrientes anómalas cerca de los cabos durante el verano. También existe evidencia de una contracorriente con dirección al norte durante los inviernos de 1977-78 y 1979-80 con un fuerte cambio de dirección durante la primavera de 1980.

Al sur de Pt. Concepción, la circulación costera se caracteriza por una marcada variación en la dirección de la corriente, con indicacciones de la presencia de un remolino en el área entre la Isla de Santa Catalina y el continente.

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INTRODUCTION

The circulation off the California coast is composed of a southward flow, the California Current, and a northward subsurface flow beneath it, known as the California Countercurrent or Undercurrent. North of Point Conception, a northward flow develops at the surface in fall and winter, when it is known as the Davidson Current. South of Point Conception and inshore of the Channel Islands the circulation forms a semipermanent counterclockwise eddy. Hickey (1979) reviewed the known features of these currents in detail and emphasized that the relationships between them are still unclear. Significant variations in this overall pattern are also apparent, but not yet well understood (Sverdrup et al. 1942; Reid et al. 1958; Hickey 1979).

During summer (May-August) northwesterly winds prevail, and the circulation is characterized by upwelling and offshore transport of surface waters. Southwesterly or westerly winds predominate during winter (November-February), with onshore transport of surface waters. Transitional periods between these major seasons occur during spring (March-April) and fall (September-October). Oceanic conditions often occur near the coast during the fall transitional period.

Drift bottle studies have helped to document seasonal trends and regional differences in the circulation of the California Current system (Tibby 1939; Reid 1960; Schwartzlose 1963; Hamby 1964; Burt and Wyatt 1965; Wyatt et al. 1972; Crowe and Schwartzlose 1972; Schwartzlose and Reid 1972; Crowe[1]). Drift bottle observations have also contributed to the historical record of interannual current fluctuations that are the focus of recent analysis (McLain and Thomas 1983). This report will summarize indications of seasonal, regional, and year-to-year variations in the nearshore surface circulation off California observed in drift bottle studies from June 1977 through September 1983.

METHODS

The drift bottle studies were conducted under the direction of the Extension Marine Fisheries Specialist at the University of California, Davis, by members of 4-H clubs and other educational groups. This is a contin-

[1]F. Crowe. Unpublished drift bottle data, 1971-81. Marine Life Research Group, Scripps Institution of Oceanography, La Jolla, California 92093.

TABLE 1
Drift Bottle Releases North of Point Conception, 1977-83

Season of recovery	Direction of drift	Number of recoveries	Mean minimum rate of drift (km/day)
Sep.-Oct.	North	25	4.9
Nov.-Feb.	North	9	7.1
Mar.-Apr.	North	6	15.7
	South	34	3.5
May-Aug.	North	14	10.0
	South	65	16.8

uing study with two purposes: (1) to obtain long-term drift measurements of surface currents off California, and (2) to teach youth about currents through direct study of coastal waters. Each study group selects the time, location, and size of release. Twenty release points were located north of Point Conception and 27 to the south, with releases distributed throughout the year. Most release points were within 40 km of the mainland. The drift bottles were heavy glass bottles ballasted with sand to minimize windage. Dewees and Wyatt (1977) presented details of the procedure.

Tables 1 and 2 show the direction of drift, number of recoveries, and mean minimum rate of drift by season of recovery for releases north of Point Conception (Table 1) and south of Point Conception (Table 2). Table 3 shows the number of release points with returns by season and region of recovery. Since the exact number of bottles released is not known for some of the release points, the tables include only the number of recoveries. The seasons in the tables represent the upwelling season (May-August), the Davidson Current season (November-February), and the two transitional seasons (September-October and March-April). Estimates of drift rates in the tables and text represent minimum speeds, based on the earliest recovery at a given point and an assumed straight line of travel from point of release to point of return.

TABLE 2
Drift Bottle Releases South of Point Conception, 1977-83

Season of recovery	Direction of drift	Number of recoveries	Mean minimum rate of drift (km/day)
Sep.-Oct.	North	9	5.1
	South	4	8.4
	East	3	5.5
Nov.-Feb.	North	7	2.1
	South	13	5.4
	East	3	3.0
Mar.-Apr.	South	37	7.2
	East	2	6.1
May-Aug.	North	10	7.9
	South	3	3.8
	East	3	0.4
	West	2	0.1

Recoveries from the Galapagos Islands and Hawaii not included.

TABLE 3
Drift Bottle Release Points with Returns Compared to Total Number of Release Points, 1977-83

Region	Releases	Seasons			
		Sep.-Oct.	Nov.-Feb.	Mar.-Apr.	May-Aug.
North of Pt. Conception	Release points with returns	3	5	5	4
	Total no. of release points	4	5	5	6
South of Pt. Conception	Release points with returns	5	5	8	3
	Total no. of release points	5	7	11	4

Figures 1 through 7 show the paths of drift for all recovered bottles by the year of release. Solid circles represent release points for which there were recoveries. Open circles represent release points with no recoveries. The month of release is indicated at these points. Solid lines represent the inferred path of travel for particular recoveries. A dashed line indicates a generalized direction of travel. A number in parentheses at the shore end of a line gives the total number of bottles recovered in cases where more than one bottle appeared to travel a particular route.

RESULTS

Drift Bottle Returns

About 2,000 drift bottles were released over the seven-year period (1977-83), and 253 (12.6%) were returned (Tables 1 and 2). The farthest northern return was from Pacific Beach, Washington, in March 1978. The southernmost recovery was from a May 1979 release in the San Pedro Channel that was reportedly found at Isla Santa Cruz, the Galápagos Islands, Ecuador, a month later. Since it is unlikely that this bottle could drift so quickly, we assume that someone carried it to the Galápagos. A bottle recovered in Hawaii in July 1978, a year after its June 1977 release off Point Hueneme, in Ventura County, traveled at a minimum rate of 11.2 km/day. It probably was carried south by the California Current and then west by the North Equatorial Current. Wyatt et al. (1972) reported a Hawaiian return from a July 1978 release off Newport, Oregon, with a comparable time at sea and rate of drift.

Nearshore Surface Circulation North of Point Conception

A northward flow is evident in the majority of returns from release points north of Point Conception in fall and winter (Figures 1, 3, 4, and 7). In spring, the direction of flow reverses, and returns indicate a dom-

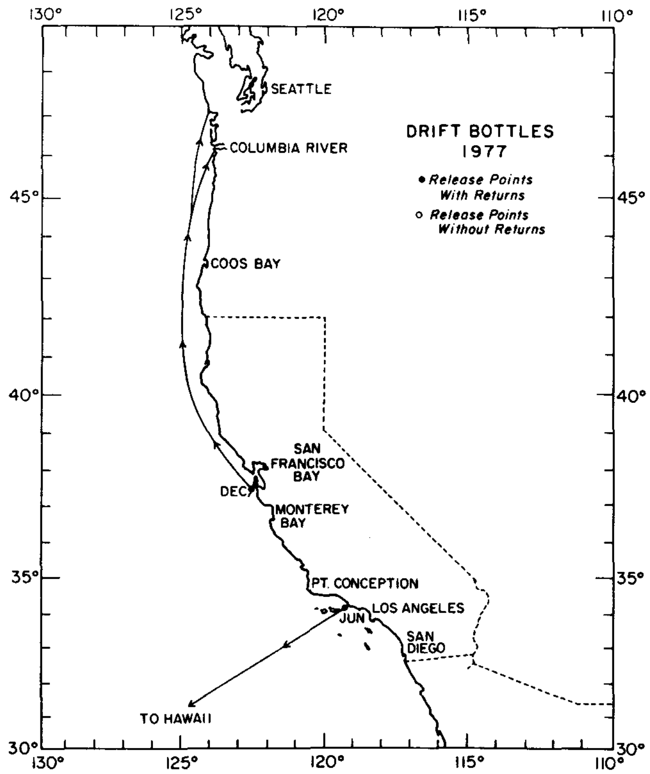

Figure 1. Drift bottle releases and recoveries for 1977.

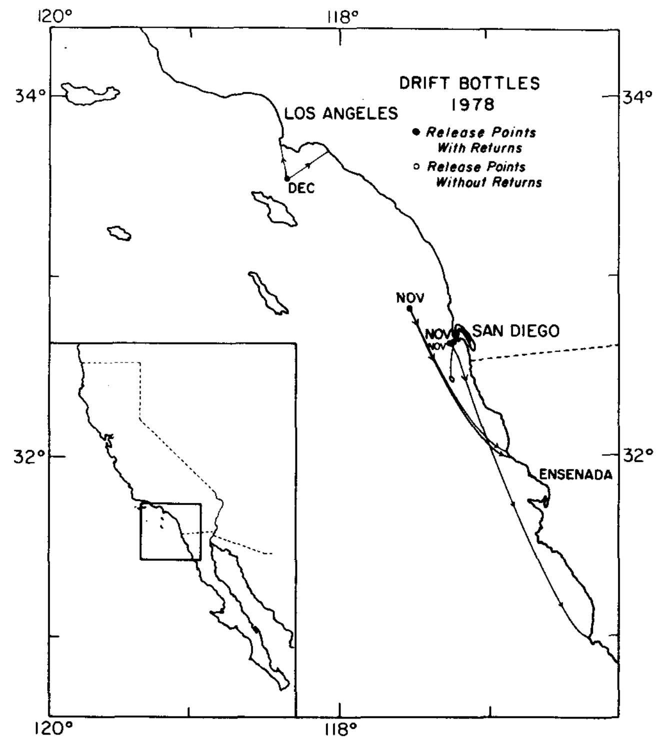

Figure 2. Drift bottle releases and recoveries for 1978.

inant southward flow from May through August (Figures 4, 5, and 7).

Returns from 1983 nearshore releases off Bodega Head indicate a reversal of flow within a three- to four-month period, with all returns from a June release showing a southward drift at a minimum rate of 22.2 km/day, whereas all those from a September release drifted north at a minimum of 6.2 km/day (Figure 7).

The strongest northward flow occurred in the winters of 1977-78 (Figure 1) and 1979-80 (Figure 3), when five bottles reached Oregon and Washington in March. This was also the greatest drift for any release north or south of Point Conception, ranging from 13-20 km/day for a distance of 1,300-1,800 km. By contrast, returns in March 1981 from releases earlier in the month traveled south an average of only 55 km at a rate of 5.3 km/day (Figure 5).

Figure 3 also shows two long-distance recoveries to the south in March 1980. These were from the same November 1979 release location at Point Conception that had long-distance northward returns.

A striking variation in the summer pattern of surface movement occurred in July 1980. All recoveries from a July 1980 nearshore release off Davenport, Santa Cruz County, flowed north and back to shore (Figure 4), counter to the usual summer offshore transport of coastal waters caused by upwelling. These returns showed a minimum rate of drift of 11.1 km/day for an average distance of 20 km.

Nearshore Surface Circulation South of Point Conception

We observed a variability in the direction of surface circulation in the area between Santa Catalina Island and the mainland that was unlike any other area we studied (Figures 2-7). Drift both to the north and south occurred in all months except February and March, when there was a dominant southward flow. Some returns also indicated an easterly or westerly component to the drift.

Recoveries from three release points off San Diego (Figure 2) showed more uniformity in the direction of drift, with four of five returns flowing south—three as far as Baja California, apparently picked up offshore by the California Current. One bottle drifted northward into San Diego Harbor.

DISCUSSION

Our observations support the generalization that a southward flow dominates nearshore circulation off the California coast most of the year. The seasonal appearance of the Davidson Current from November through February (Figures 1, 3, and 4) is an important feature of nearshore surface circulation north of Point Conception. The comparatively low percentage of releases with returns from May through August north of

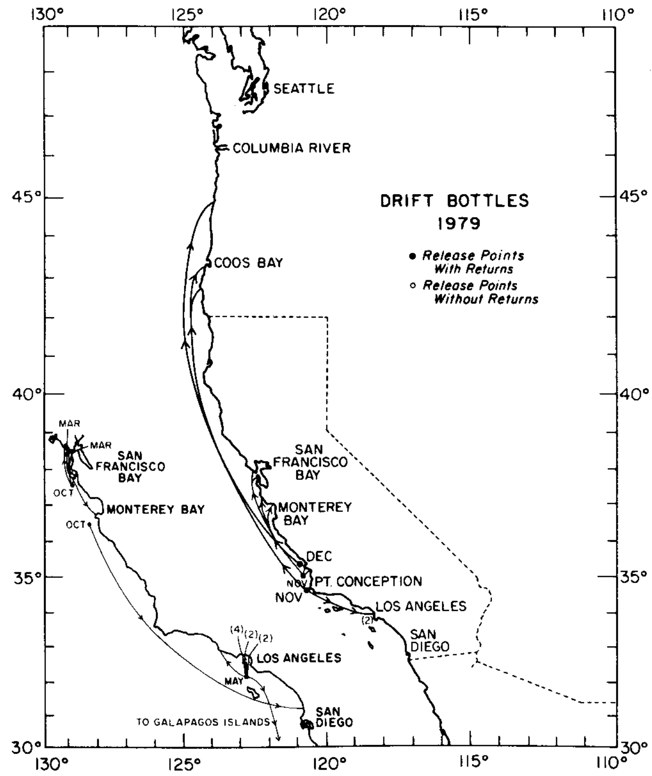

Figure 3. Drift bottle releases and recoveries for 1979.

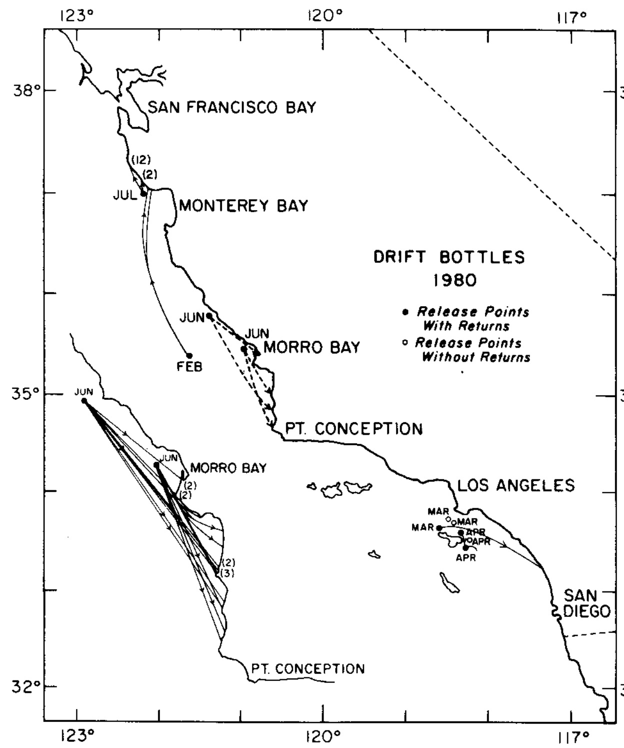

Figure 4. Drift bottle releases and recoveries for 1980.

Point Conception (Table 3) suggests that offshore transport of drift bottles is usually significant during the upwelling season, an observation commonly made by other drift bottle investigators (Schwartzlose 1963; Burt and Wyatt 1965; and Wyatt et al. 1972). We also found evidence of local eddies and countercurrents that complicate this overall pattern and point to the importance of seasonal, regional, and interannual variations in the nearshore surface circulation off California.

The most obvious variability is that associated with the Southern California Bight (Figures 2-7). Drift bottle studies by Tibby (1939), Crowe and Schwartzlose (1972), and Crowe[2] indicate that eddies are a major factor in the circulation of the Channel Island area. Drogue measurements by Schwartzlose and Reid (1972) confirmed the presence of many small eddies inshore of the Channel Islands. We found that the nearshore waters between Santa Catalina Island and the mainland circulate in an eddy in most months except February and March, when southward flow predominates. This supports Schwartzlose's (1963) observation that eddies do not exist in the Channel Island area in March, April, and May.

In other areas, we observed countercurrents that appeared irregularly. The reversal of flow that we observed off Bodega Head between June and September 1983 (Figure 7) was not evident in drift bottle studies by Hamby (1964), who suggested that there is a prevailing northward current throughout the year off Bodega Head. The July 1980 countercurrent off Santa Cruz (Figure 4) also appears to be unusual. No drift bottles were returned from our releases off Santa Cruz in July 1982 (Figure 6), a finding consistent with summer upwelling, but not indicated by our observations in July 1980.

Results of drift studies by other investigators also suggest that anomalous late summer and early fall countercurrents occur from time to time off certain parts of the California coast. The anomalous northward flow that we observed off Santa Cruz in July 1980 is similar to a pattern observed in Monterey Bay in 1972. Blaskovich (1973) described a counterclockwise flow in this area from June to September 1972. During the same period Griggs (1974) noted a significant northward flow, which was apparent despite northerly winds. Schwartzlose (1963) observed a shoreward movement of drift bottles between San Francisco and Monterey Bay that was occasionally to the north in summer. Some returns from a June 1981 release off San Mateo County by Crowe[3] also flowed

[2]See footnote 1, page 68.

[3]See footnote 1, page 68.

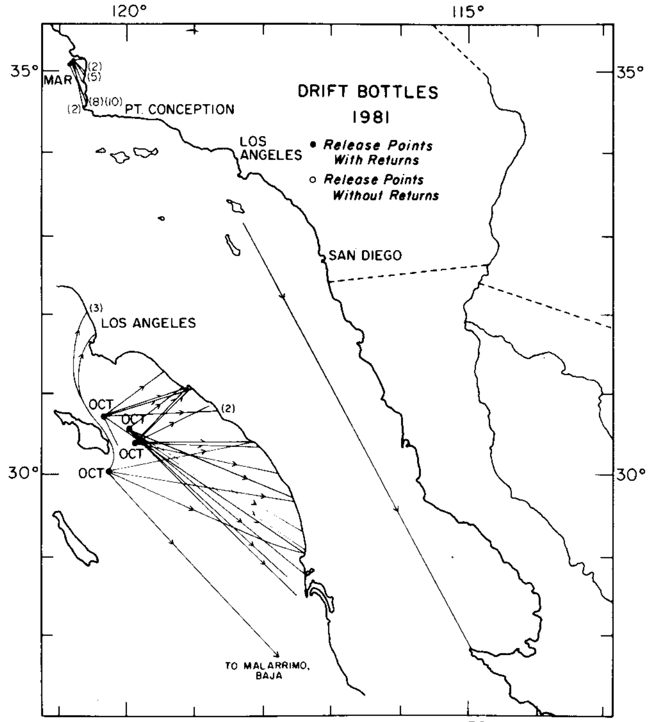

Figure 5. Drift bottle releases and recoveries for 1981.

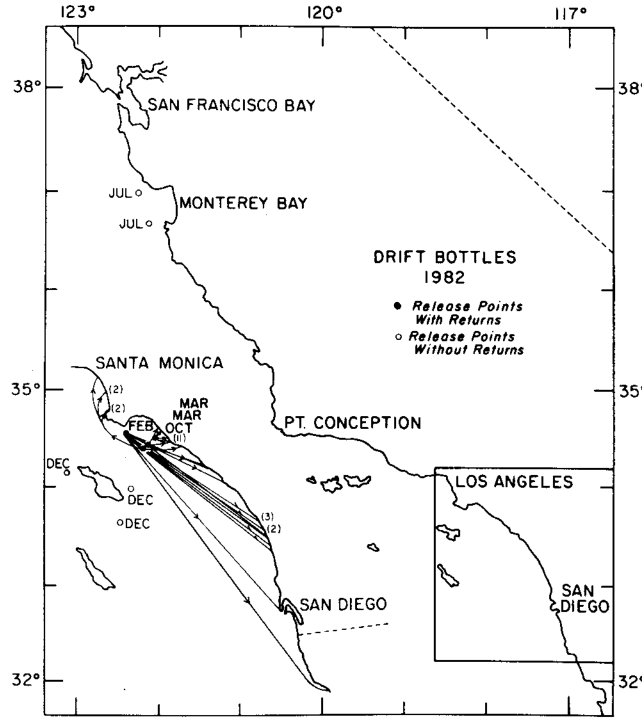

Figure 6. Drift bottle releases and recoveries for 1982.

north and shoreward, whereas his releases in the same area in other years generally had no returns.

At least two possible explanations exist for these findings and for our observations of a countercurrent off Bodega Head in September 1983 and Santa Cruz in July 1980. Sverdrup et al. (1942) suggested that as upwelling ceases toward the end of summer, the current breaks down into a number of eddies nearshore, some of which move coastal waters toward shore, particularly in areas between centers of upwelling.

An alternative explanation is suggested by recent work emphasizing the importance of interannual fluctuations in the California Current system associated with unusual oceanographic conditions. McLain and Thomas (1983) suggested that the anomalous summer counterflow observed by Blaskovich (1973) and Griggs (1974) in the Monterey area was due to an intensification of the alongshore current related to unusually high sea levels in 1972. Hickey (1979) proposed that there is a relationship between large-scale flow separations in the vicinity of headlands and unusual countercurrents that may occur in years of enhanced southward flow in the California Current. Our findings are consistent with these considerations. The summer countercurrents that we observed were in areas where headlands dominate the nearshore topography, and the summer countercurrent of 1983 was during a year of unusual oceanic conditions associated with a strong El Niño.

The intensified Davidson Current evident in the strong poleward drift of bottles that we observed during the winters of 1977-78 and 1979-80 may also have been related to unusual oceanographic events. McLain and Thomas (1983) noted that very strong onshore Ekman transport in winter, associated with above-normal sea level and dynamic height along the coast, occurred during these years and in the winters of 1957-58 and 1969-70, when very strong northward transport of drift bottles was also observed (Schwartzlose 1963; Crowe and Schwartzlose 1972). The long-distance recoveries of drift bottles both to the north and south of a November 1979 release at Point Conception (Figure 3) may be a related phenomenon, indicating a strong and rapid current reversal in spring following the enhanced northward flow of that winter. McLain and Thomas (1983) pointed out that pronounced spring reversals do not occur every year, but tend to follow winters of unusually high sea level and dynamic height. This may also account for the northern and southern returns from a winter release off Point Conception observed by Schwartzlose and Reid (1972) during the 1963-64 El Niño, also a year of high sea level and dynamic height (McLain and Thomas 1983).

We plan future drift bottle studies to clarify the

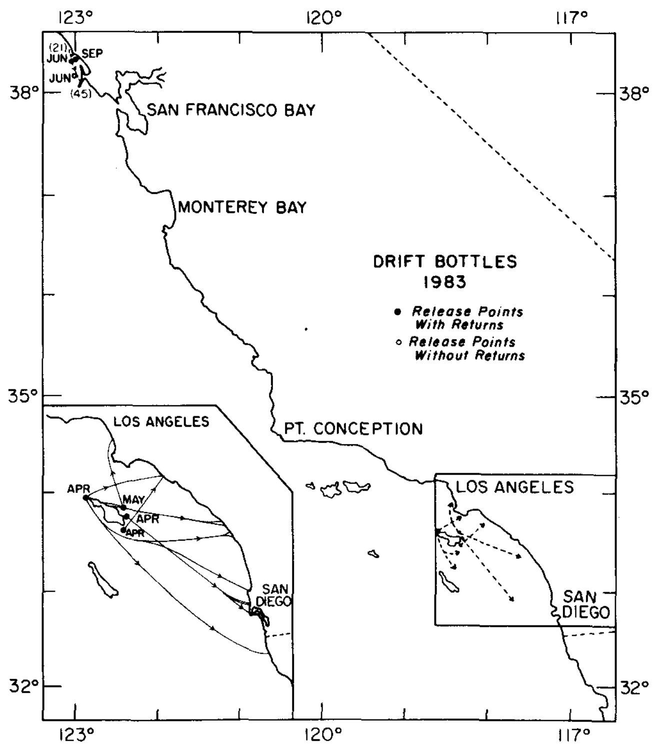

Figure 7. Drift bottle releases and recoveries for 1983.

significance of our observations. In particular, it would be useful to have more drift bottle releases in areas near headlands. Releases made from locations offshore as well as within the immediate vicinity of headlands could indicate to what extent flow separation occurs. Additional studies throughout the Southern California Bight would help to elucidate the complex circulation in this area. Yearly studies conducted in all areas would contribute important information about interannual variations. Indications of the direction of flow derived from drift bottle observations such as these can enhance our understanding of California's nearshore surface circulation in a way not possible by indirect measurements alone.

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