PART II

SCIENTIFIC CONTRIBUTIONS

NEARSHORE CURRENTS OF THE WESTERN UNITED STATES AND BAJA CALIFORNIA AS MEASURED BY DRIFT BOTTLES

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INTRODUCTION

The California Current flows southeast nearly parallel to the Pacific Coast of the United States and Baja California, Mexico, the year round. Along the eastern boundary of the current, near the shoreline, eddies and countercurrents complicate the current pattern. The Atlas of Pilot Charts (U.S.N.H.O., 1950) and Atlas of Surface Currents (U.S.N.H.O., 1947) show the countercurrent to exist in the winter months (November through February) from southern California north to British Columbia. From March through June the current is shown to be flowing southeast along the entire coast. In July the current continues southeast from Washington to central California, but at this time the southern California eddy appears, continuing through February.

In late 1954, Scripps Institution of Oceanography of the University of California began using drift bottles to study these seasonal variations of the eastern edge of the California Current. Drift bottles were released on the California Cooperative Oceanic Fisheries Investigation's (CalCOFI) cruises nearly every month for the following five and one-half years.

Drift bottles or cards had been used before along this coast with some success. Tibby (1939) reports on the results of releases off southern California during the months of March through July 1937. Drift bottles were used in Sebastián Vizcaíno Bay, Baja California, in September, 1952, and drift cards were used during a CalCOFI cruise in July, 1953. The cards in plastic envelopes were released in cooperation with the U.S. Bureau of Commercial Fisheries in Seattle. Other drift bottle data from offshore Canada and Alaska were reported by Dodimead and Hollister (1958) and Fofonoff (1960).

The purpose is to summarize the results of the CalCOFI drift bottle returns from January, 1955 through June, 1960, and other drift bottle data available at Scripps. It is not possible to show charts of all the releases and recoveries, therefore only examples of the different patterns of monthly returns are illustrated.

DRIFT BOTTLES

Four ounce commercial salad dressing bottles of clear, heavy glass were converted to drift bottles by inserting red postal cards (Fig. 1) and ballasting them with sand so that nine-tenths of the bottle was underwater. The bottles were then sealed with a cork and wax poured on the cork.

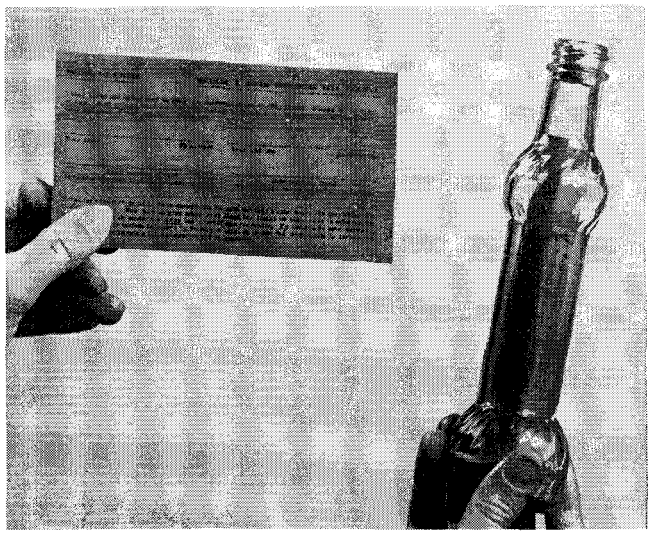

FIGURE 1. Drift bottle and postal card.

The message on the post-paid (U.S. only) card tells the purpose of the survey in English and Spanish and asks the finder to fill in the place, date, time of finding, and his name and address. Upon receipt of a card, a letter is sent to the finder telling where and when the card was released. When cards from Mexico are received, a letter in Spanish is sent with a peso enclosed to repay the sender for the Mexican stamp.

Normally twelve bottles are released on each regular station of the cruise pattern although there have been some variations of this procedure.

RELEASE AREAS

The areas covered by the cruises have varied somewhat during the five and one-half years and the patterns of releases have varied particularly after it was found that few returns came from bottles released at the western end of the patterns. During 1955 and 1956 bottles were released nearly every month of the year offshore as far as 120 miles and north to about 31° N. latitude. During the cruises in 1955, 1956, and 1957 few were released north of Point Conception (35° 24.4′ N.). 1957, 1958, and part of 1959, bottles

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were released at nearly every station. In 1958, 1959, and through June, 1960, the northern limit of the majority of the cruises was just south of San Francisco. Only on two cruises during the entire period were drift bottles released as far north as Cape Mendocino (40° N.).

From mid 1959 on, Scripps furnished drift bottles to be released on cruises made by the University of the Pacific and Oregon State University to fifty miles offshore, from Bodega Bay, California (38° N.), and Newport, Oregon (45° N.).

DRIFT BOTTLES RETURNS

From October, 1954 through June, 1960, 52,650 bottles were released and 2,439 were returned; a return of 4.6 percent. The shortest water distance between the release and the landing points has been used to compute speeds. The time used is the period between the release and the recovery. This gives minimum speed because the time the bottle lies on the beach before being found will reduce the apparent speed.

The greatest northward movement of any bottle recovered was from 25 miles south of San Clemente Island, southern California, to Schooner Cove on the west side of Vancouver Island, British Columbia. This was during the countercurrent season in the winter of 1957-58. The minimum distance of its travel was 1140 miles at a minimum speed of 0.26 knot. The greatest southward movement was from just south of Punta Abreojos, Baja California, to just north of Acapulco, Mexico, during the summer and fall of 1959. This was a minimum distance of 1040 miles at a minimum speed of 0.23 knot (Fig. 2).

To study the relation of the distance from shore of the release point and the percentage of returns, lines parallel to the coast were drawn on a chart at 20, 40, 80, 120, and 160 mile intervals from shore. The zones thus delineated were subdivided from north to south (Fig. 3). The number of bottles released was compared to the number returned from each of the areas on the chart using data from January, 1955 through December, 1959, (Table 1). No recoveries have been recorded from farther than 160 miles offshore. Because the southern California region was surveyed most frequently, 51 percent of the bottles were released there.

The significant results from Table 1 are as follows:

1. Eighty-two percent of the total number of returns were from releases in the southern California region;

2. Seventy-five percent of the bottles returned were released within 20 miles of the coast; and

3. There were returns from all distances offshore from releases only in the southern California region. In central and northern California no returns were made beyond the 40 mile line.

In a sample two years of data for the southern California region 41 percent of the bottles were found on Saturdays and Sundays. If only the winter months were considered, 51 percent of the recoveries were on those days.

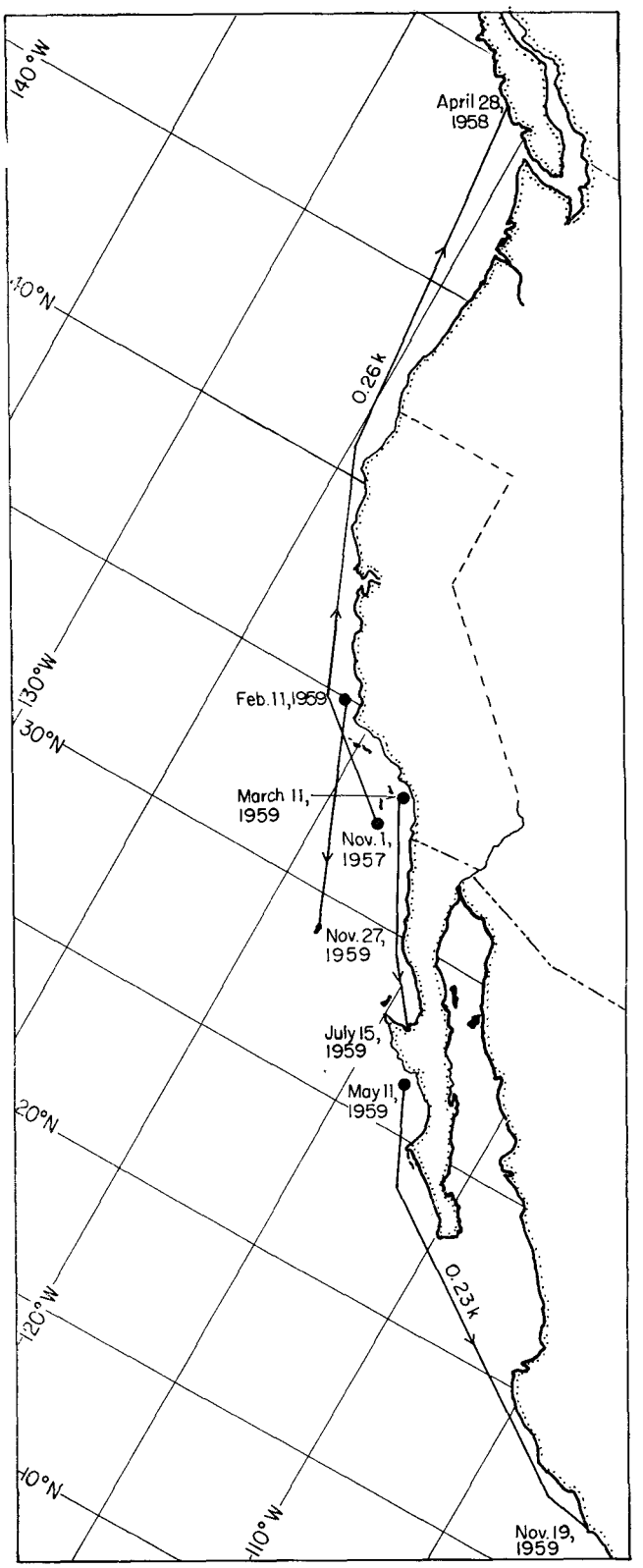

FIGURE 2. Extreme north and south movements of drift bottles.

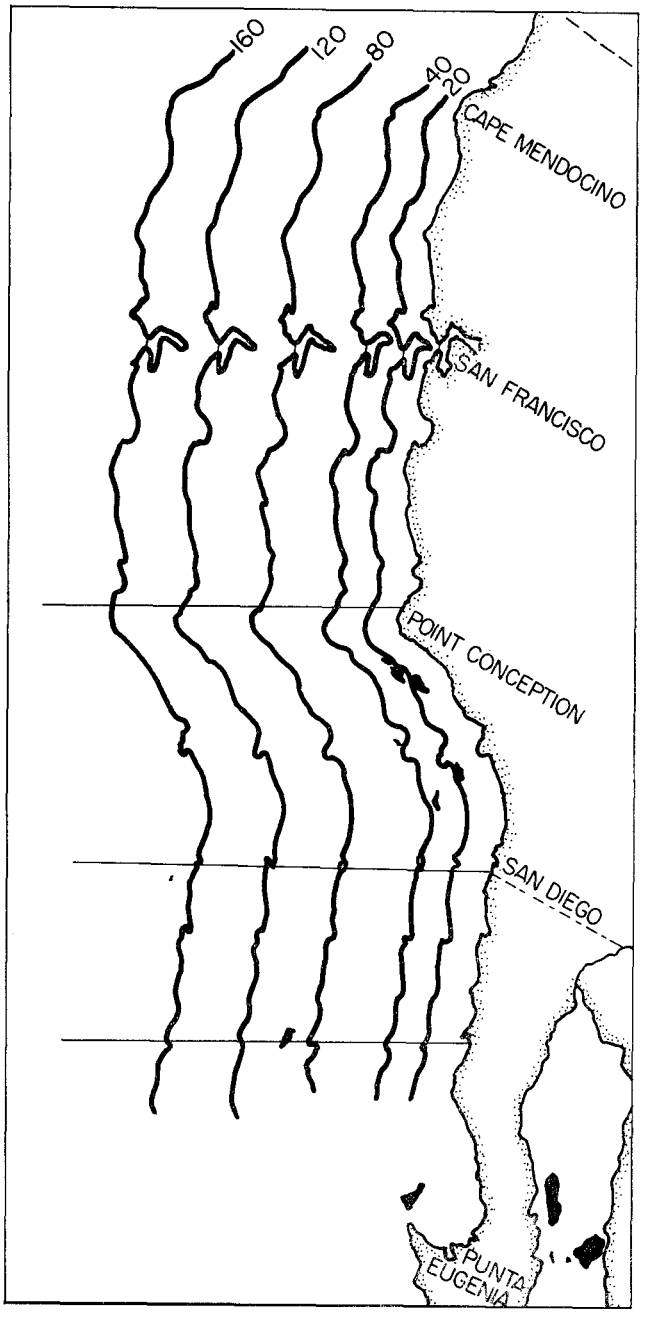

FIGURE 3. Delineation of areas for numbers of drift bottles released and returned. See Table 1 for summary of data.

TABLE 1

NUMBER OF DRIFT BOTTLES RELEASED AND RECOVERED BY DISTANCE FROM SHORE AND REGION OF RELEASE 1955-1959 IN AREAS SHOWN BY FIGURE 3

	Miles from shore					
	160	120	80	40	20-0	Total
North and Central California						
No. released	816	878	2,000	1,990	3,282	8,966
No. returned	0	0	0	23	222	245
Percentage returned	0	0	0	1.2	6.8	2.5
Southern California						
No. released	1,296	2,606	4,841	3,744	6,922	19,409
No. returned	2	17	181	282	1,305	1,787
Percentage returned	0.2	0.7	3.7	7.5	18.8	9.2
Northern Baja California						
No. released	888	1,296	2,532	2,280	2,552	9,548
No. returned	0	0	11	28	112	151
Percentage returned	0	0	0.4	1.2	4.4	1.6
Total						
No. released	3,000	6,780	9,373	8,014	12,756	37,923
No. returned	2	17	192	333	1,639	2,183
Percentage returned	0.1	0.3	2.0	4.2	12.9	5.8

ANALYSIS OF CURRENTS

In the analysis the returns are divided into six areas: Washington and Oregon, northern California, central California, southern California, northern Baja California, and southern Baja California. When examining these data it should be kept in mind that in most of the areas the returns were from releases no farther than 40 miles offshore and most of these returns were from releases within 20 miles of shore (Table 1).

Each month that drift bottles were released, a chart was prepared showing the position of release and the position of recovery. Table 2 summarizes the currents as derived from these plots. In most cases the drift along the coast could be classed as southerly or northerly, but in some cases the data indicated the current was southerly offshore and northerly near shore, as in the California eddy.

Table 2 indicates that for one year (1959) of data along the Washington and Oregon coasts, the countercurrent began as early as August and continued through May. In August, 1959, drift bottles were released at three stations (from near shore to 25 miles offshore) off Newport, Oregon, by personnel of the Department of Oceanography at Oregon State University. The drift bottles went northward, one as far as Grays Harbor, Washington, at a minimum speed of 0.13 knot. Recoveries from the September and October, 1959 cruises indicated that the countercurrent was about 25 miles wide with a speed of 0.25 knot. The current direction was southward beyond 25 miles. Although there were not data from the cruises off Oregon for two of the winter months, the data from along northern and central California indicate that the countercurrent continued. From the March and April returns, the countercurrent was found to be present as far seaward as the farthest releases, nearly 50 miles from shore, with minimum speeds as high as 0.9 knot (Fig. 4). The southward flow near the coast was at least 0.4 knot during 1959 when there was no countercurrent.

Before the latter part of 1959 there had been very few releases of drift bottles off northern California. But in August, 1959 the Pacific Marine Station at Dillon Beach of the University of the Pacific began releasing bottles from ten to twenty miles offshore. The results indicate the flow was southward along the coast from April through August (Table 2). The countercurrent did not appear there until December. But the returns from bottles released off central Cali-

fornia indicate that the countercurrent began as early as October along the northern and central California coast. The speeds calculated for the southerly current and countercurrent along the northern California coast exceeded 0.4 knot.

TABLE 2

MONTHLY ESTIMATE OF DIRECTION OF CURRENT FLOW FROM DRIFT BOTTLE RETURNS

Oregon-Washington

	J	F	M	A	M	J	J	A	S	O	N	D
1959						S	S	N	S/N	S/N	—	O
1960	O	—	N	N	S/N	—						

Northern California

	J	F	M	A	M	J	J	A	S	O	N	D
1959								S	O	—	O	N
1960	N	O	O	S	S	—						

Central California

	J	F	M	A	M	J	J	A	S	O	N	D
1955	—	S	—	—	O	O	O	O	—	N	N	N
1956	—	—	—	S/N	O	O	—	—	—	—	N	N
1957	—	N	—	—	S	S	X	—	—	N	N	N
1958	N	N	O	O	S	O	X	—	—	O	N	O
1959	N	N	—	S/N	O	O	S	O	—	N	N	N
1960	N	O	O	S	S	S						

Southern California

	J	F	M	A	M	J	J	A	S	O	N	D
1955	O	S	X	S	E	E	S	S	S	O	E	E
1956	X	X	X	S	S	X	E	—	—	E	E	E
1957	—	S	S	S	S	E	X	—	—	E	E	E
1958	E	X	E	S	S	X	S	—	X	E	E	X
1959	S	E	S	S	E	X	E	E	E	E	E	O
1960	O	S	S	S	X	S						

Northern Baja California

	J	F	M	A	M	J	J	A	S	O	N	D
1955	—	O	—	O	O	O	S	O	S	—	—	—
1956	—	O	O	—	—	O	—	—	—	—	—	—
1957	—	—	—	O	S	—	—	—	—	O	—	S
1958	—	S	O	S	O	S	O	—	S	S	S	S
1959	S	S	S	O	O	O	S	O	—	O	—	—
1960	O	O	O	O	S	O						

O — No returns or not enough to estimate flow direction.
X — Ample returns but complex flow pattern, both North and South from same area of release.
N — North flowing countercurrent.
S — Southeast flowing current.
S/N — Transition—Offshore current flowing south, inshore current flowing north.
E — Southern California eddy present.
— — No drift bottles released.

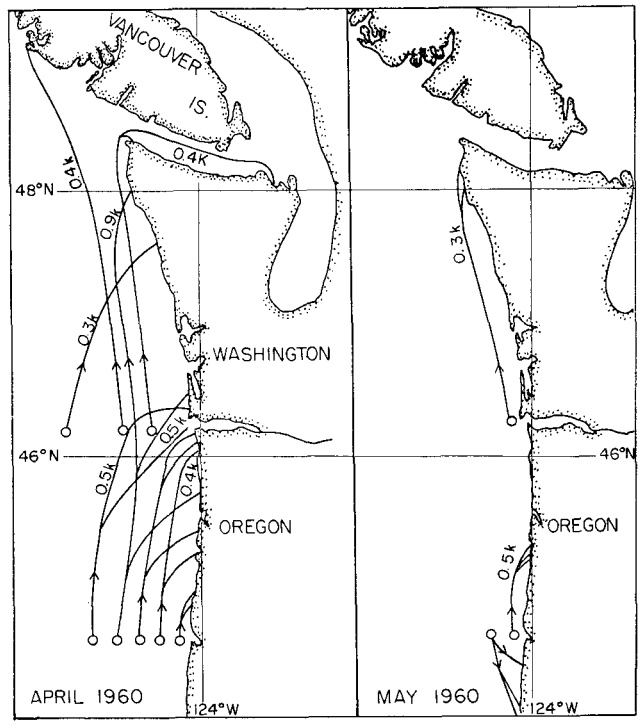

FIGURE 4. Drift bottle returns for April and May, 1960, along the Washington and Oregon Coasts.

There were many more returns from releases off central California. Most of the returns were during the countercurrent period, which began in October and ended between February and April. The strong period of the countercurrent is shown by the number of returns by months when drift bottles traveled more than 150 miles northwest along the central California coast.

J	F	M	A	M	J	J	A	S	O	N	D
33	1	0	0	0	0	0	1	0	5	18	5

Few bottles were returned from May through August. This indicates that the coastal waters were primarily moving offshore or parallel to shore with very little flow toward the coast.

There appears to be a movement toward shore between San Francisco and Monterey Bay and occasionally to the north during the summer (Figs. 5 and 6). The movement inshore as shown in Figure 5 was more than 0.5 knot for five days, from more than 50 miles offshore.

The most variable drift was observed in the channel island area off southern California where the data are most numerous. From Table 2 the southern California counterclockwise eddy was present most of the year. The months it commonly was not present were March, April, and May. In the months where the data are not clear, the confusion may have been caused by the eddy being present for a short period and then disappearing for a while, thus distributing the bottles in a confused pattern along the beaches.

The drift bottle returns do not tell much about the eddy. Figure 7 is an example of the returns when the

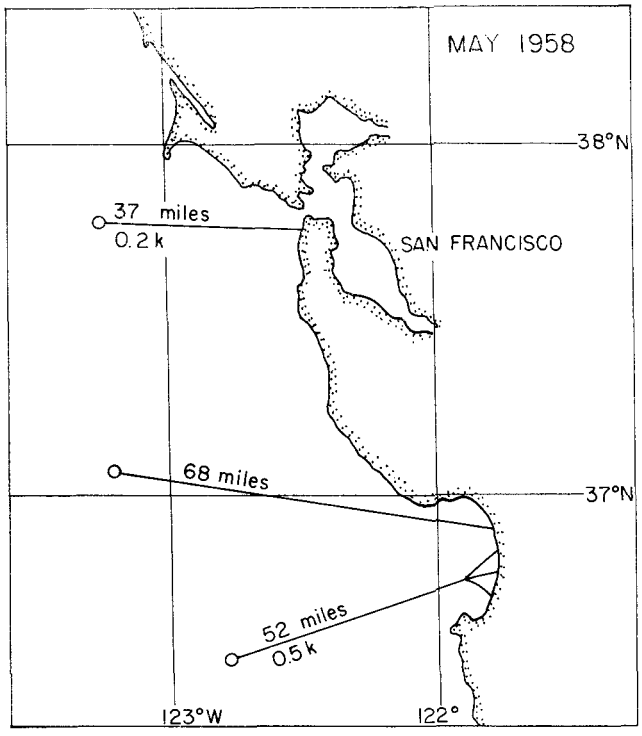

FIGURE 5. Movement of water toward shore off central California in May, 1958.

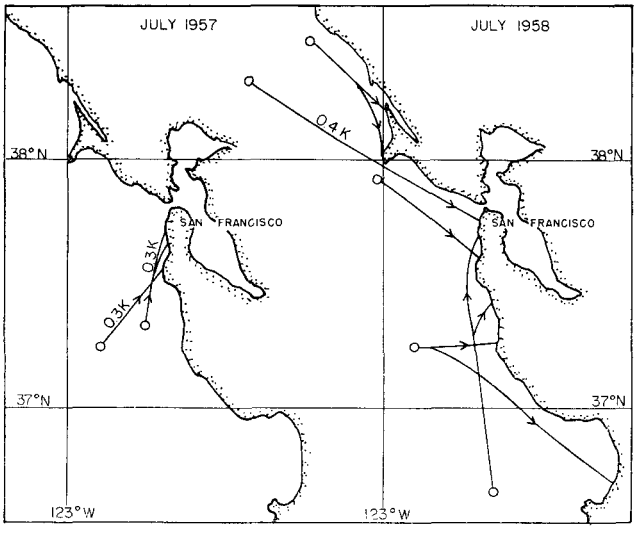

FIGURE 6. Examples to show movement of water to the north off central California during the summer. (July, 1957 and 1958.)

eddy is present. Examination of the returns of many months suggests that there is an eddy between Santa Rosa-Santa Cruz Islands and San Nicolas-Santa Catalina Islands. There may also be an eddy between San Clemente Island and the mainland. The amount of flow to the north from the area between Santa Catalina and the mainland is not known; the returns do indicate that there is movement at times into the northern part of the Channel Islands. The returns

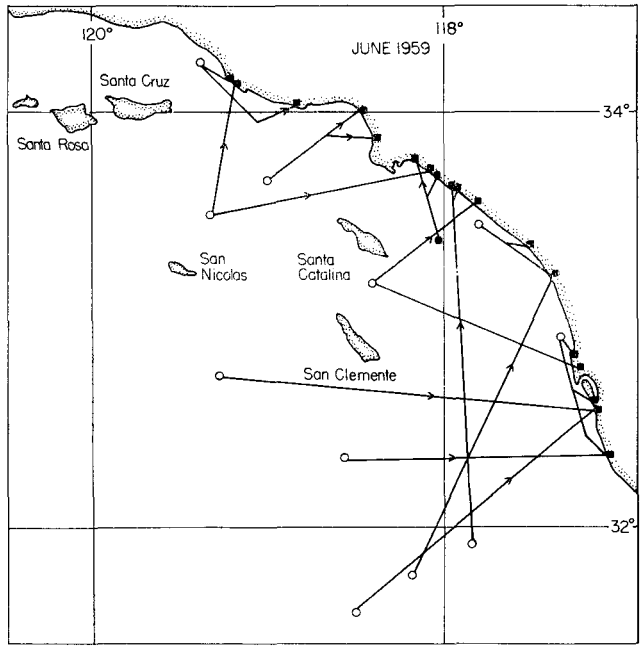

FIGURE 7. Drift bottle returns in June, 1959, indicating the eddies off southern California.

also indicate that there is a flow to the southeast very near shore at times when the eddy is present.

Other data that are available indicate a complex circulation off southern California. From direct current measurements made in October, 1958 (S10 Ref. 1962) there were indications of a counterclockwise eddy between Santa Catalina Island and the mainland, a small clockwise eddy east of San Clemente Island, and a counterclockwise eddy between Santa Cruz and San Nicolas Islands. More current measurements in May, 1961 (S10 Ref. 1962) indicated a counterclockwise eddy between San Nicolas and San Clemente Islands. The large counterclockwise eddy to the east of San Clemente Island is believed to be present at least part of the time as indicated from CalCOFI cruise data which shows a warmer body of water within that area for several months during summer.

Possibly the general circulation in the Channel Island area is a large counterclockwise gyre with some small eddies scattered within it. The data for the Channel Island region do not give a clear picture of the complexity of the eddies nor their duration.

Figure 8 best illustrates the pattern that was seen when the eddies do not exist in the southern California area. The returns are always from releases close to the coast. The months when this type of circulation was the strongest were March, April, and May. As seen in Table 2, there was no indication of the counterclockwise circulation in April during any of the years of drift bottle returns.

Very few of the drift bottles released off southern California moved north of Point Conception during the fall and winter countercurrent period (Reid, Roden and Wyllie, 1959; Reid, 1960; and Berner and Reid, 1961).

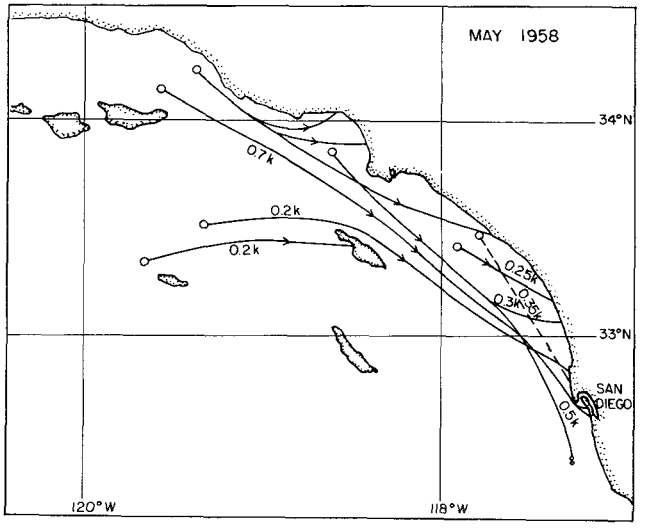

FIGURE 8. May, 1958, drift bottle returns indicating no eddies off southern California.

Figure 9 indicates how far offshore and how far south, surface water enters the southern California circulation. The maximum inshore movement of a drift bottle was from approximately 120 miles westward of the nearest island. The longest movements into the southern California area were primarily during the fall and winter months. Shown below are the number of returns by months when the drift bottles traveled more than 150 miles to reach the southern California coast.

J	F	M	A	M	J	J	A	S	O	N	D
8	3	5	4	3	0	1	1	2	6	3	5

The data from Table 3 indicate that there was a marked increase in the percentage of returns beginning in March and lasting until October when considering the 0-20 miles offshore releases. This same trend may appear from other distances offshore, but is not clear. From the range of 120-160 miles there

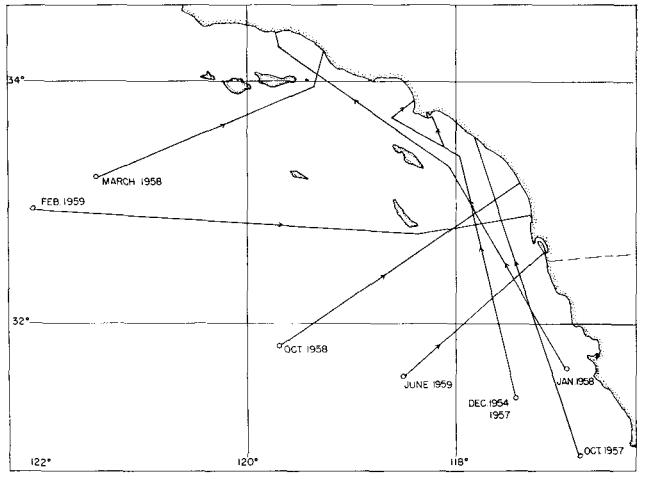

FIGURE 9 Indications from drift bottles as to how far west and south water enters the southern California eddy.

TABLE 3

RATIO OF RETURNS/RELEASES

Distance from shore	J	F	M	A	M	J	J	A	S	O	N	D
0-20	14.1	10.8	22.4	26.5	20.4	28.7	25.2	20.0	23.7	15.8	10.3	8.0
20-40	7.7	8.0	6.2	8.0	10.2	11.1	6.7	6.9	11.6	5.3	5.3	4.7
40-80	3.3	2.8	5.2	1.1	3.1	3.9	2.8	5.2	7.9	4.1	2.5	2.9
80-120	0	0.4	1.0	0	1.6	1.2	2.4	0	0	0	0.7	0.4

were only two returns, one from February and one from October. Some of the increases in returns from March through September may be a consequence of more beach visitors during that period.

Along the northern Baja California coast there are very few recoveries. Most of the coast is sparsely settled and rarely visited. From the small amount of information gleaned from the drift bottles it appears that a southeast current flows along most of the coast all year. The eddy off southern California extends south into the most northern part of Baja California (Figs. 7 and 9). Beyond the southern boundary of the southern California eddy, the data indicate that the current throughout the year is to the southeast. For example, figure 10 shows a southeasterly current in January, 1959, during the period of the countercurrent along the West Coast of the United States. In Sebastián Vizcaíno Bay, the circulation is generally a strong clockwise eddy as shown from current surveys in 1952 and 1960, and the few drift bottles returned from that area.

Along the southern Baja California coast there are so few returns that a pattern cannot be determined clearly from the drift bottles. However it would appear that the flow is southeast along the coast most of the year and that two short countercurrents or counterclockwise eddies appear during the winter between 27° N. and 28° N., just south of Punta Eugenia, and off the southern tip of Baja California, between 23° N. and 24° N.

There was a strong movement of water to the southeast from about 26° N. to 16° N. near the Mexican mainland during the summer of 1959 (Fig. 2). Also a bottle that was recovered from Tres Marias Island, near Cape Corrientes, Mexico, about 20° N., had been released 120 miles offshore from Magdalena Bay, Baja California, about 25° N. A bottle released in January, 1959, about 60 miles offshore from the southern end of Baja California, was recovered just south of Cape Corrientes.

SUMMARY

Drift bottle returns can give some useful indications of the near shore currents, but care must be taken when interpreting the returns since only the points of release and return are known. The unknowns are the route traveled and the amount of time the bottle has lain on a beach before being found.

Eighty two percent of the drift bottles recovered were released within 20 miles of shore, and 90 percent recovered were released within 40 miles of shore. In contrast the total releases were about equally di-

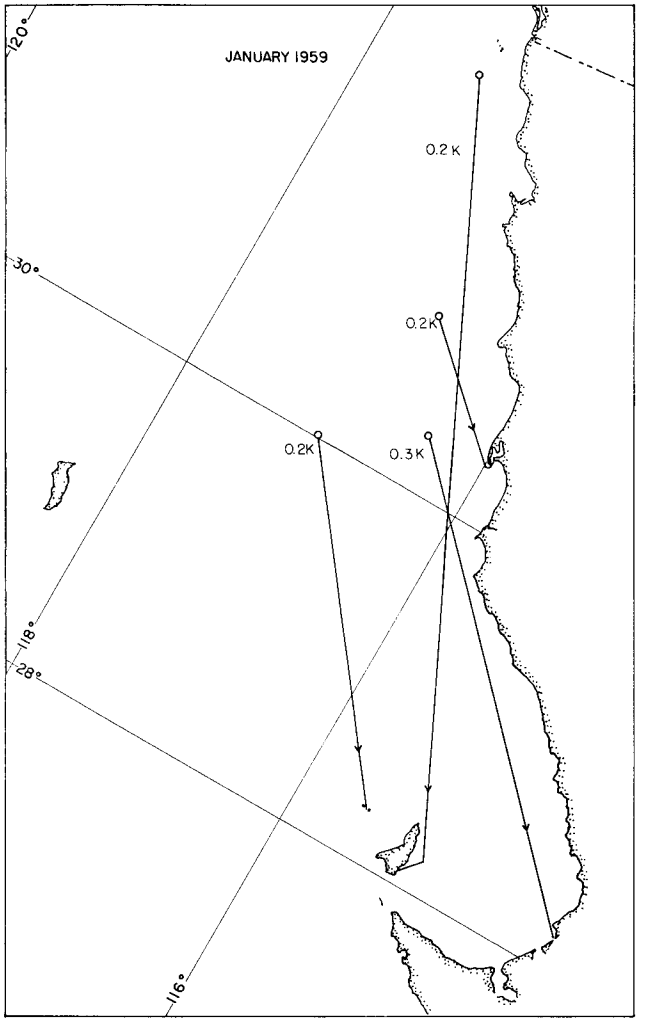

FIGURE 10. Flow to the southeast long the northern Baja California Coast during January, 1959.

vided between the coast to 40 miles and 40 to 160 miles.

The predominate feature exhibited by the drift bottle releases and returns is the countercurrent during the fall, winter, and early spring months from central California north to British Columbia. The countercurrent develops along the Washington and Oregon coasts in August or September, first close to shore, later widening. By October it appears as far south as Point Conception. The countercurrent appears to be at least fifty miles wide and with speeds of at least 0.5 to 0.9 knot for distances of several hundred miles (Fig. 4). For distances of more than seven hundred miles minimum average speeds of at least 0.3 knot have been shown by drift bottle returns (Fig. 11). In the spring the process is reversed. The countercurrent disappears in April off central California and in May off Oregon and Washington.

The important unique features of the countercurrent are its narrowness compared to its length (a ratio of about 1/20) and its ability to carry drift bottles at speeds over 0.5 knot for long distances before they come ashore. No other data have shown these features as clearly as the drift bottle returns.

South of Point Conception to the southern tip of Baja California there is little evidence of a countercurrent such as exists north of the Point. From southern California only a small amount of surface water passes to the north of Point Conception. The drift bottle returns indicate that when water is moved north of Point Conception there is a very strong countercurrent from central California northward (Fig. 2, 11, and Berner and Reid, 1961).

The Pilot Charts (U.S.N.H.O. 1950) show a northward movement along northern Baja California in November and January while the Atlas of Surface Currents (U.S.N.H.O. 1947) show southerly currents all winter. The few drift bottle returns from this area indicate a drift south along the coast all months of the year.

Off southern Baja California there are so few data that it is difficult to determine whether a counter-

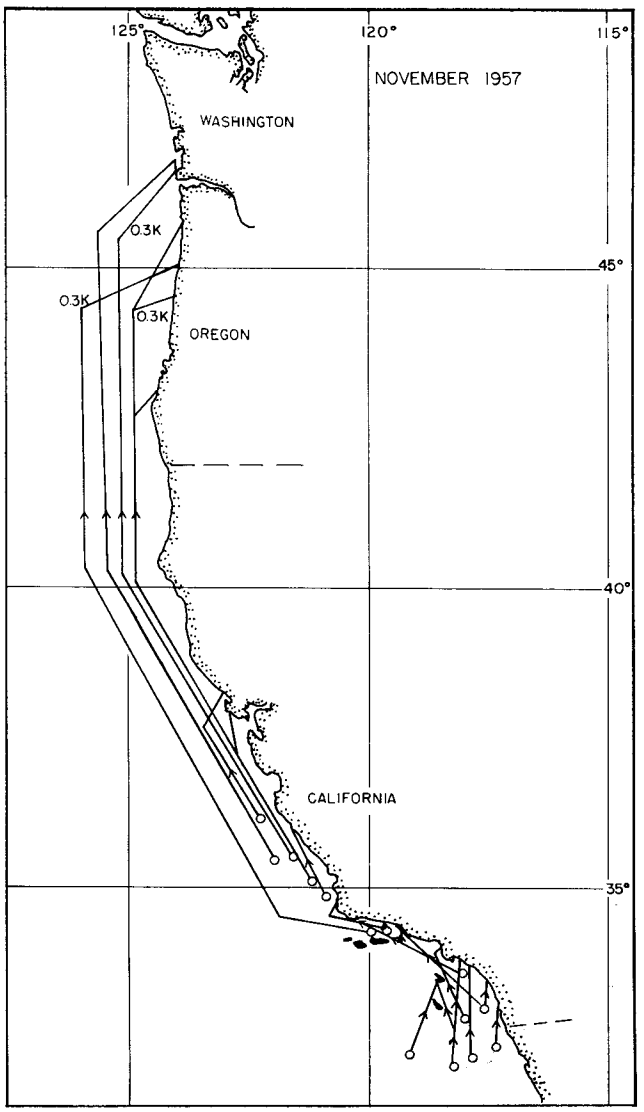

FIGURE 11. The countercurrent during November, 1957.

current exists in the winter. A few returns indicate that there may be several short countercurrents sometimes during the winter.

The current is south to southeast near the coast during the months when there is no countercurrent along the coast from Washington to Point Conception, off central California, and from northern Baja California to its southern tip. The relatively few returns are from near shore. They indicate flow at times of at least 0.4 knot. The few exceptions to the southeast flow have appeared between San Francisco and Monterey as small countercurrents or eddies, with shoreward movements of water from fifty miles offshore in May and July (Figs. 5 and 6).

The southern California circulation is different from the rest of the coast in that eddies predominate. Large and/or small eddies have been observed in every month of the year except April from the five and a half year's returns. Only during April has the current smoothly flowed to the southeast past southern California.

There are some months from which returns were numerically adequate, but the complex patterns of the returns, for example, recoveries both north and south of the release points cannot be resolved into a cohesive circulation. This suggests either a very complex or a changing circulation during these months.

ACKNOWLEDGMENTS

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