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Division of Fisheries and Oceanography

REPORT 13

# THE COASTAL CIRCULATION OF NEW SOUTH WALES FROM DRIFT CARD RESULTS 1953-56

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# CONTENTS

## SUMMARY

The results of the drift card programme from 1953-56 carried out by the C.S.I.R.O. Division of Fisheries and Oceanography are summarized and statistically analysed in an attempt to correlate them with the coastal circulation in New South Wales.

Over the period of four years (1953-56) a total of 15,696 drift cards was released at eight stations along the New South Wales coast. 2,480 cards (about 15.8 per cent.) were recovered in regions north, south, and adjacent to the stations of liberation.

The circulation of the coastal waters is influenced by that of the oceanic water masses, particularly in the summer period.

It was found that the use of drift cards alone in this region has often provided very contradictory evidence of coastal circulation and this must be interpreted or supplemented by a study of the associated changes in coastal hydrological structure. In this paper hydrological evidence has been furnished in support of the general winter offshore drifts and to interpret the onshore and southerly drifts in summer.

Recommendations about the limitations of the present programme and suggestions for supplementary studies are discussed.

# THE COASTAL CIRCULATION OF NEW SOUTH WALES, FROM DRIFT CARD RESULTS 1953-56

By Y. K. Chau*

## INTRODUCTION

The use of drift cards or drift bottles provides direct information, which supports hydrological data in the charting of ocean currents. The method is an old one but it is still widely used. Carruthers (1930) successfully used drift bottles to study water movements in the English Channel. Tait (1930) was able to use drift bottle results to locate an eddy in the eastern North Sea region. Both of these investigations were concerned with surface currents in an enclosed sea, but Tibby (1939), working off southern California, found the use of drift bottles less successful on an open coast because of poor recoveries.

The coastal hydrology programme of this Laboratory has been carried out since 1942, but a regular survey, with liberations of drift cards to study coastal circulation, was not commenced until November 1952. The eastern coast of Australia is entirely exposed to the South Pacific Ocean, and coastal circulation is directly influenced by oceanic water masses. As the coastline of New South Wales is a populated area, with some frequented beaches and holiday resorts, it may be assumed that many of the drift cards stranded on the coast have been found and returned to the Division. Batches of cards may have been swept offshore or lost by other means but the returns to date indicate that such losses do not debar the successful use of drift cards in this area.

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* This is a part of the study programme of a UNESCO Fellowship under which the work has been carried out at the Division of Fisheries and Oceanography, C.S.I.R.O. Cronulla, New South Wales, Australia.

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## II. METHODS

The drift card, sealed hermetically in a polythene envelope has advantages over the drift bottle. It is light in weight and compact so that the transport of sufficient cards to liberate upwards of 50 cards at each coastal station becomes a simple task compared with the weight and bulk of a similar number of drift bottles. It is easier and quicker to manufacture than a drift bottle. In any case, non recoveries of either bottles or cards will be numerous on an exposed coastline; the greater the number of releases, the more representative will be the recoveries. In the present programme, drift cards were liberated in sufficient numbers to assess the significance of isolated or contrary recoveries.

### (a) Type of Drift Card

The drift cards used were similar to those described by Olsen (1951). They are 5 in. x 3 in. in size, blue in colour, to avoid being discovered and carried off by fish and birds. Each is enclosed in a polythene envelope 4 in. x 6 in., sealed at both ends. The small amount of air sealed in is just sufficient to keep the card afloat. Figure 1A shows a sealed envelope ready for release and Figure 1B shows the questions that the finder is asked to complete before returning the card. Between 1953 and 1956, 15,696 drift cards were liberated at the eight coastal stations listed below.

### (b) Regions of Liberation

Eight stations approximately 70-80 miles apart on the New South Wales coast were chosen for liberation of the drift cards: Evans Head, Coff's Harbour, Port Macquarie, Port Stephens, Port Hacking (50 m and 100 m stations), Ulladulla, and Eden (Table 1; Fig. 2). These stations are about 3-6 miles from shore so that the drift of the cards was not masked by the local movements of tidal effects.

**POST CARD**

*Commonwealth Scientific and Industrial Research Organization,*

*Division of Fisheries,*

*P.O. Box 21, Cronulla,*

*N.S.W., Australia*

Fig. 1A. Drift card sealed in polythene envelope ready for release.

DRIFT CARD No. ....................

**DRIFT CARD No.** ..................

*Where was this card found?* ..................................... ....................................

*Amount of growth on card - None, Slight or Heavy*
*Condition of growth on card - Alive or Dead*

*On what date?* ....................................

*Name and Address of finder* ..................................... ..................................... .....................................

**Please fill in the above particulars and mail this card.**
**A Reward is given for its return.**

(*Commonwealth Scientific and Industrial Research Organization, Australia– Hydrographic Investigation*)

Fig. 1B. Questions appearing on drift card.

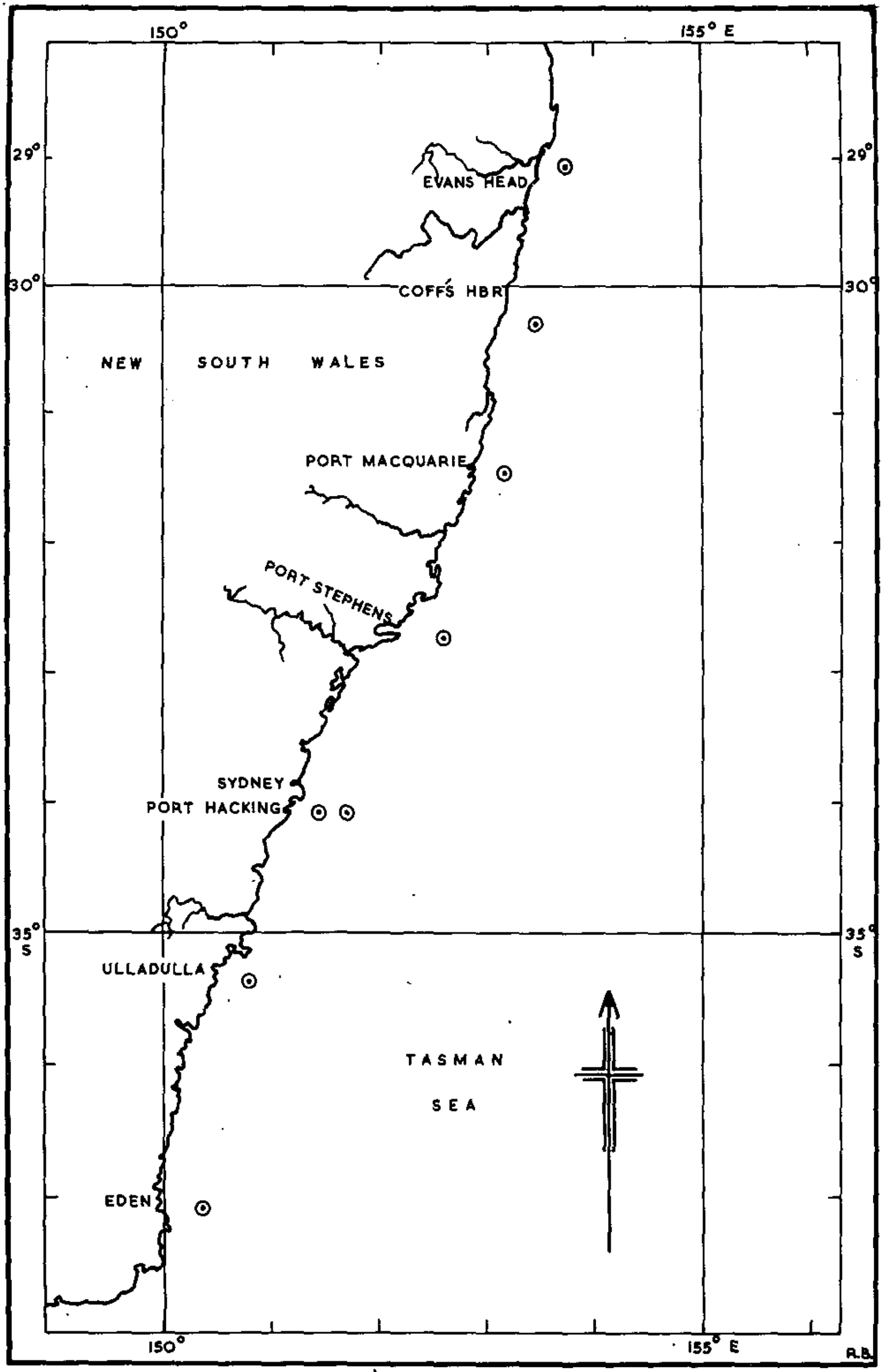


Fig. 2. Stations of liberation along the coast of New South Wales. (Latitudes correct but longitudes displaced for clarity).

TABLE 1

POSITIONS OF NEW SOUTH WALES COASTAL STATIONS

| Station | Position | |
|---|---|---|
| Evans Head | 29°07'30"S: | 153°38'E |
| Coff's Harbour | 30°17'S : | 153°16'E |
| Port Macquarie | 31°30'S : | 153°10'E |
| Port Stephens | 32°43'S : | 152°18'E |
| Port Hacking 50 m | 34°05'S : | 151°13'E |
| Port Hacking 100 m | 34°05'30"S: | 151°15'30"E |
| Ulladulla | 35°22'S : | 150°35'E |
| Eden | 37°04'S : | 150°05'E |

(c) Data

The data on the releases and recoveries of drift cards for the period 1953-56 are filed and are available at this Laboratory.

The hydrological data used in this report have been extracted from Oceanographical Station Lists for the period under review.

## III. STATISTICAL ANALYSIS OF DRIFT CARD DATA (1953-56)

### (a) Interpretation of Results

Drift cards were usually recovered from beaches along the coast. When cards are returned to this Laboratory the finder is notified of the point and date of release and paid a reward of two shillings. In the laboratory the position of recovery is located and the distance and direction of the drift are recorded.

(1) Local Recoveries.- Those cards recovered within a radius of 15 miles from the point of release have been classified as local returns, denoting an onshore movement. Among local returns there were results which appeared to be contradictory, probably due to wind stresses and weak local currents developed at that point.

(2) Zero Returns.- From certain sets of released cards no returns were received. This zero return may denote

an offshore movement into the oceanic circulation of the Tasman Sea, or the disintegration of the cards after a long period of immersion. Unless zero returns occurred frequently and consistently, offshore movement has not been assumed. If one card out of a set of 25 was recovered after a period of drift, this confirmative and definite information from this one recovery has been accepted as evidence.

(3) Drifts.- Cards recovered beyond the 15 miles radius were recorded as drifts. The period between the dates of liberation and recovery was expressed in days, and the drift as the shortest distance between the points of liberation and recovery.

Cards recovered after 30 days from date of release have been disregarded in this paper to eliminate the possibilities that they had been drifting to and fro or that they had been stranded long before being discovered.

## (b) Frequencies of Liberations and Recoveries

Table 2 shows the number of cards released and recovered at each station during 1953-56. This indicates that 15,696 cards were released and 2,480 (about 15.8 per cent.) were recovered.

(1) Liberations.- From November 1952 to December 1953 a set of 50 cards was released at monthly intervals from each station except Port Hacking, where weekly releases were made. From January 1954 the releases were reduced to 25 cards.

(2) Recoveries.- Over the period of four years 2480 cards, about 15.8 per cent. of the releases, were recovered. The maximum distance of drift was 130 miles southward in 3 days by a card released on December 17, 1953 at Coff's Harbour. This is equivalent to an average speed of 43 miles a day. The maximum percentage of recovery of a single set of cards was 88 per cent. recoveries from a set released at Port Hacking 50 m station on December 19, 1956. These all drifted in a southerly direction.

Recoveries here mean the absolute number of cards recovered. Part of the zero return cards bearing significant information of offshore drift are not included in the percentage of recoveries. The actual number of cards that bear information would be more than 15.8 per cent.

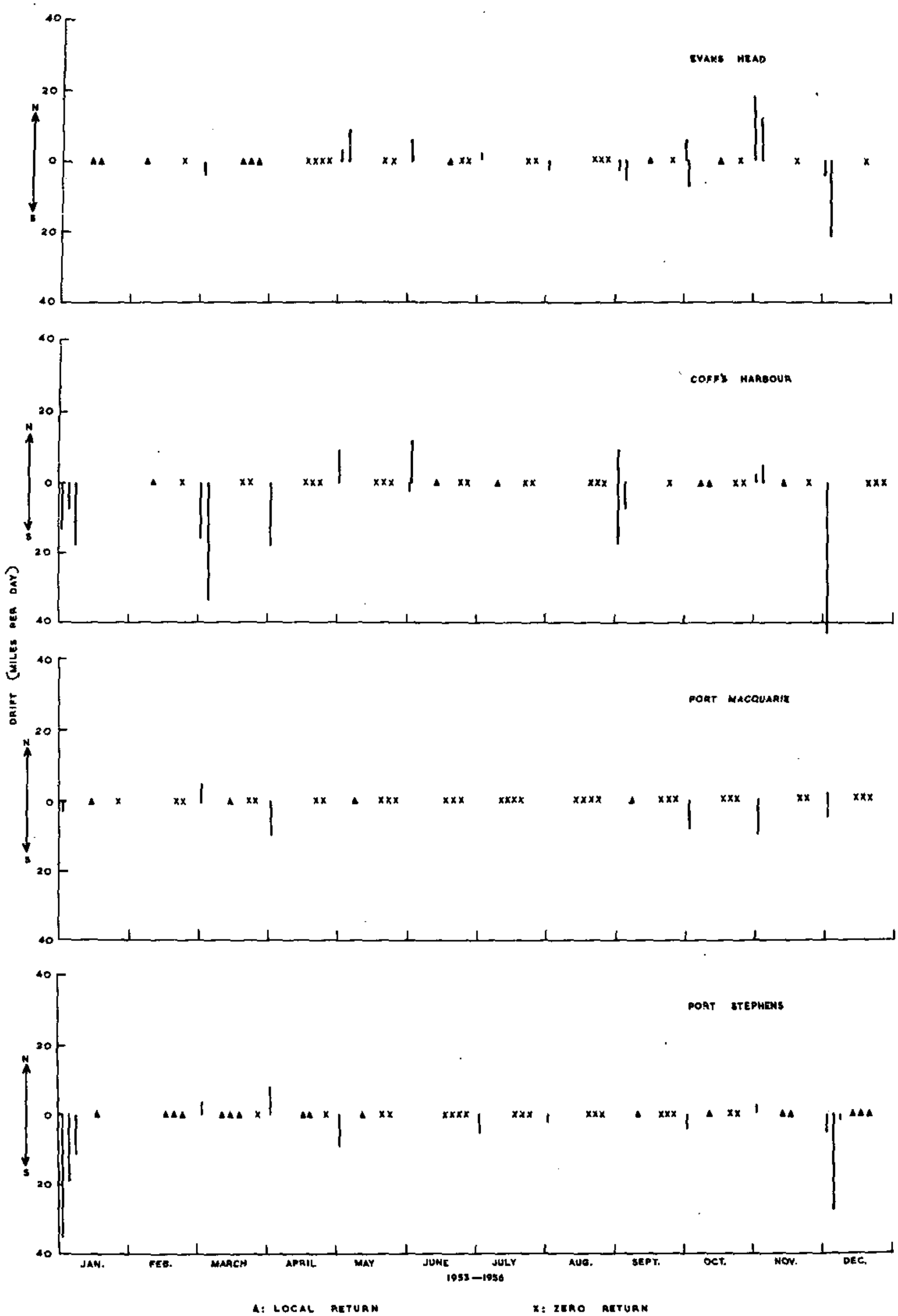


Fig. 3. Directions of drifts at each station (1953-56).

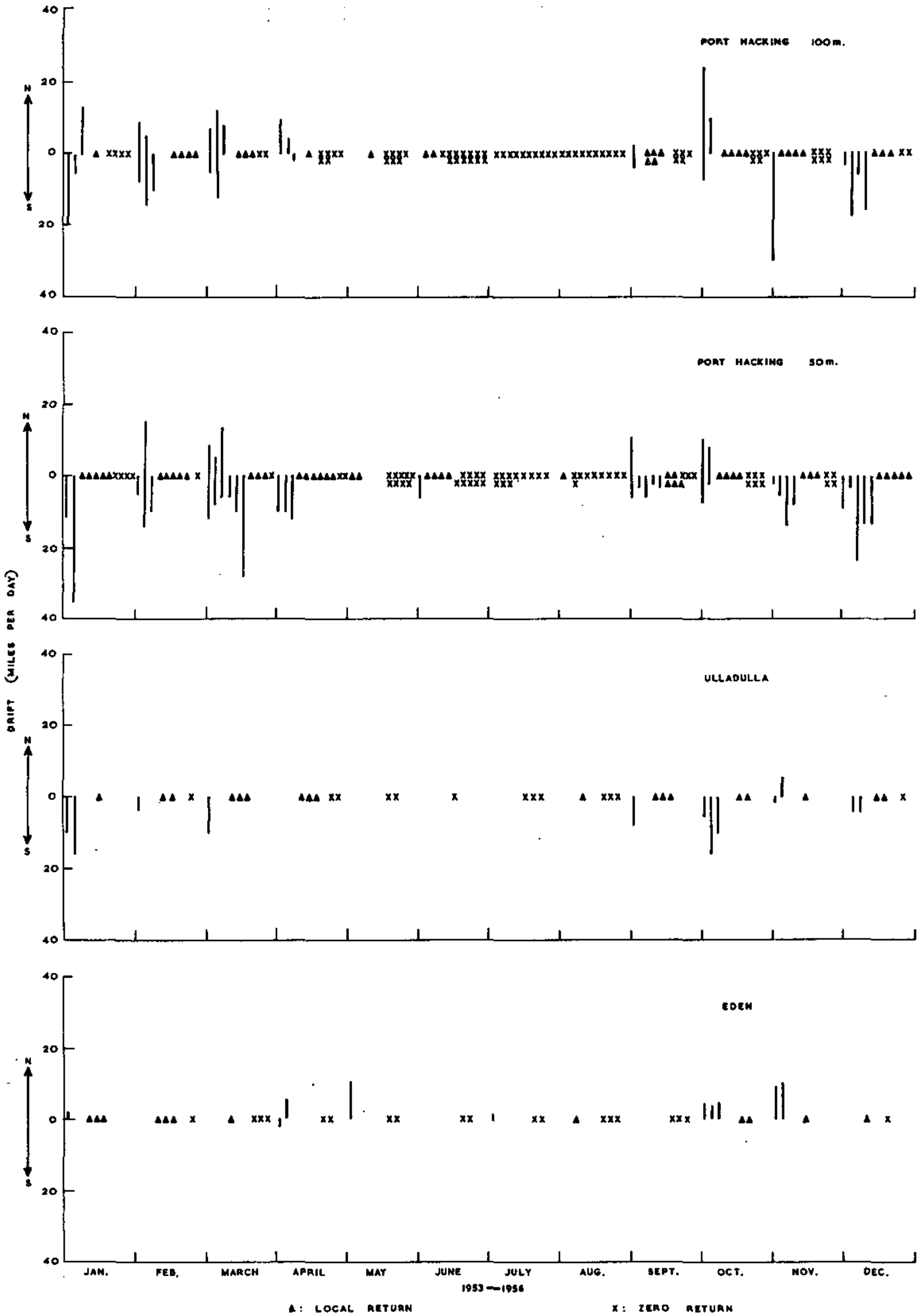


Fig. 3. Directions of drifts at each station (1953-56).

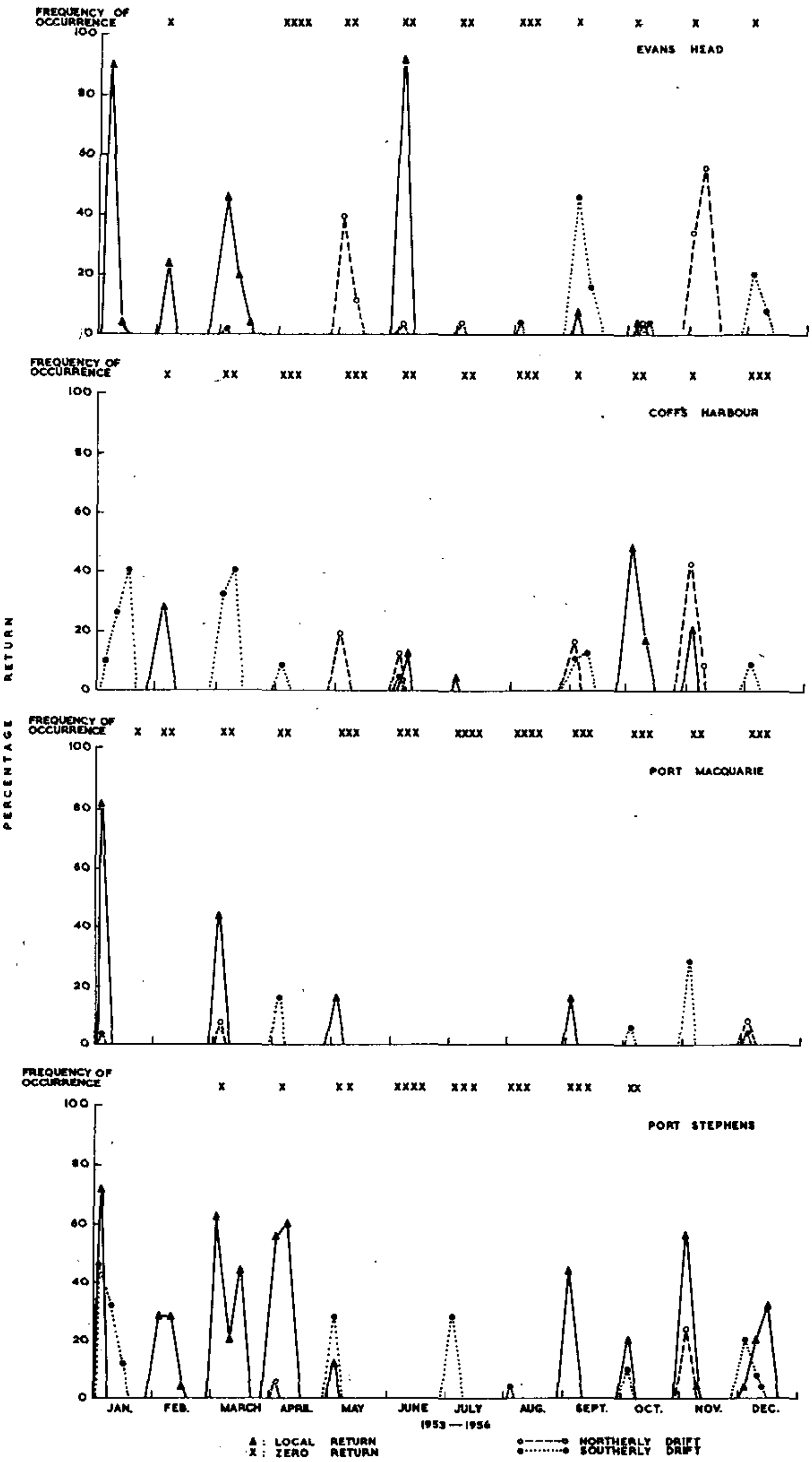


Fig. 4. Percentage of recoveries at each station (1953-56).

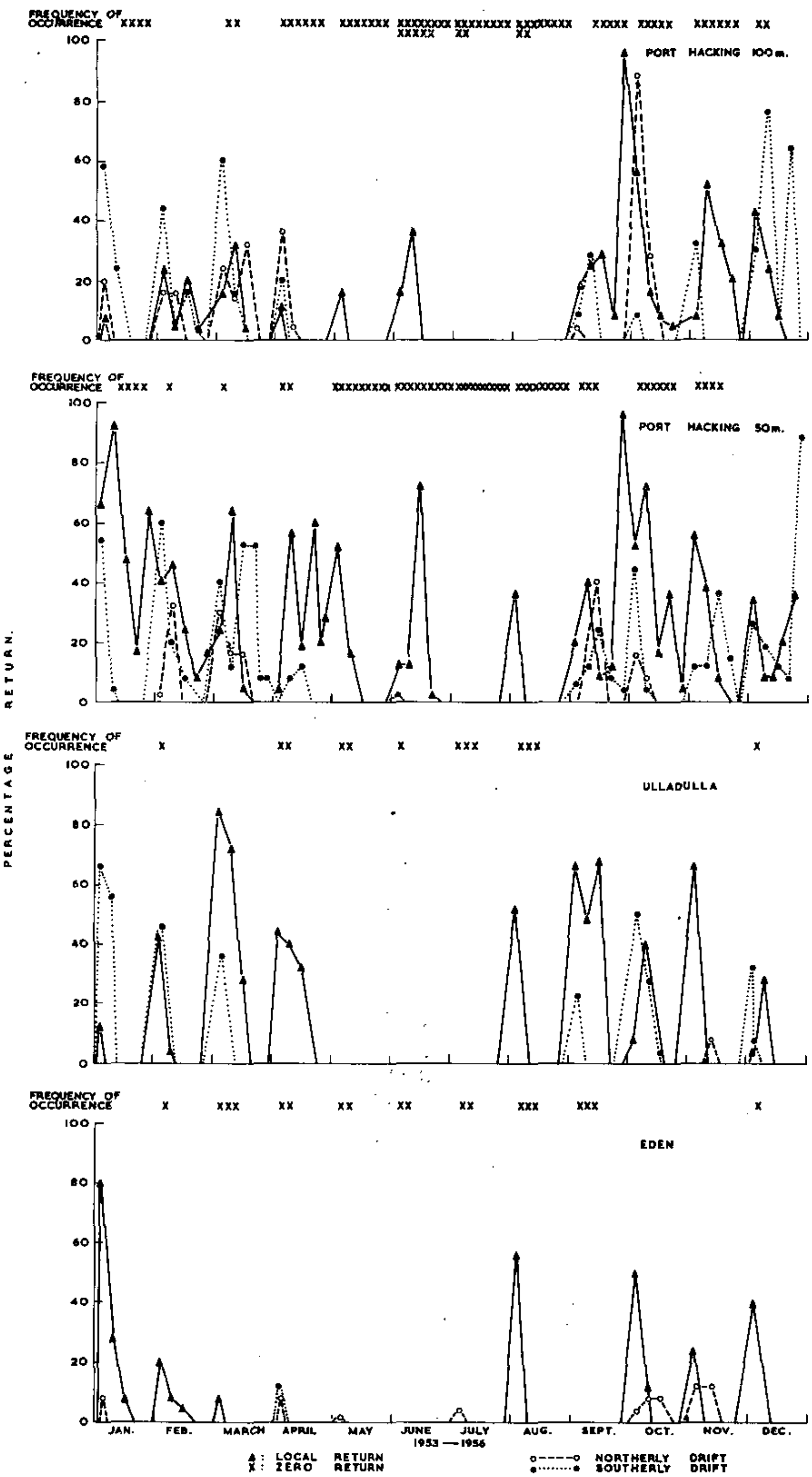


Fig. 4. Percentage of recoveries at each station (1953-56)

TABLE 2

FREQUENCIES OF LIBERATION AND RECOVERY (1953-56)

| Station | Total Release | Recovery | Percentage Recovery |
|---|---|---|---|
| Evans Head | 1250 | 171 | 13.7 |
| Coff's Harbour | 1350 | 142 | 10.5 |
| Port Macquarie | 1275 | 87 | 6.8 |
| Port Stephens | 1450 | 280 | 19.3 |
| Port Hacking 50 m | 4100 | 812 | 19.8 |
| Port Hacking 100 m | 3650 | 432 | 11.8 |
| Ulladulla | 1297 | 374 | 28.8 |
| Eden | 1324 | 182 | 13.7 |
| Total | 15696 | 2480 | 15.8 |

### (c) Summary of Drift Direction at Each Station

Figure 3 gives a statistical summation of all the drift information for each station over the period 1953-56. The drift record is expressed in miles per day in scales upward and downward showing directions north and south, respectively. The graphs represent all of the drift results in each of the months of 1953-56. From these figures, it is found that southerly drifts are more frequent in the mid coast region. Only one southerly drift was recorded at Eden on the south coast. At Port Macquarie, where cards were mostly zero returns, very few drifts have been recorded.

Figure 4 indicates the percentage of recoveries from each drift at all stations. Zero returns are recorded separately in frequency of occurrence as the actual percentage of such cards could not be ascertained. Each occurrence of zero returns denotes a complete disappearance of a set of cards. Poorest recovery was recorded at Port Macquarie and an offshore movement has been frequently assumed in this area.

A summary of the directions and strength of drift and percentage recovery of the cards in each month at a station gives the average mean direction of drift in that area. Although some results indicate isolated movements of water which depart entirely from the evidence of other stations, most results are consistent over a period of the year. The water movements deduced from the drifts of cards released at each station do fit into the offshore circulation pattern. Figure 5 is a summation of the monthly mean drift made from the recovery data of drift cards released in 1953-56 (Fig. 3 and Fig. 4). In some cases northerly and southerly drifts have been revealed from the same set of cards. In those cases, the drift periods, distances travelled and percentages of recoveries have been carefully considered in the selection of the dominant drift listed in Figure 5.

From Figure 5 it can be seen that from May to August there was a zero return of cards and consistent offshore movement can therefore be assumed. This is the winter period of the year when a westerly wind system predominates. From December to January the drift card returns from the coastal waters of most stations show a southerly movement, possibly due to the strong influence of the tropical water masses circulating in the Tasman Sea (Rochford 1957. See section IV (b)).

The intervening periods September to November, February to April are the intermediate periods between the offshore circulation in winter and southerly circulation in summer. Various movements were recorded in these transitional periods. For example, in the period of September to November there are found the only occurrences of northerly movements at the extreme stations in November and at the Eden station in October.

## IV. DISCUSSION - NEW SOUTH WALES COASTAL CIRCULATION

From the statistical analysis of the drift card records, certain periods of the year appear to have characteristic coastal circulations.

### (a) April to August - Period of Westerly Wind System

During this period a consistent westerly wind system is characteristic and it is presumed to be responsible for generating an offshore movement.

Wind systems have a direct effect on current movements. Ekman (1902) has shown that, in the Southern Hemisphere, wind stress produces a current which, at the surface, is directed 45° to the left of the direction of the wind. Such a wind system that generated a surface current would be a directing factor of coastal circulation. Drift cards reveal such surface currents.

| STATION NORTH TO SOUTH | JAN. | FEB. | MAR. | APR. | MAY | JUNE | JULY | AUG. | SEPT. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVANS HEAD | ← | ← | ← | → | → | → | → | → | ↓ | ? | ↑ | ↓ |
| COFF'S HARBOUR | ↓ | ← | ↓ | → | → | → | → | → | ↓ | ← | ↑ | ↓ |
| PORT MACQUARIE | ← | → | → | → | → | → | → | → | → | → | → | → |
| PORT STEPHENS | ↓ | ← | ← | ← | → | → | → | → | → | → | ← | ↓ |
| PORT HACKING 50m. | ← | ← | ↓ | ← | → | → | → | → | ← | → | ↓ | ↓ |
| PORT HACKING 100m. | ↓ | ↓ | ↓ | → | → | → | → | → | ← | → | → | ↓ |
| ULLADULLA | ↓ | ← | ← | ← | → | → | → | → | ← | ↓ | ← | ↓ |
| EDEN | ← | ← | → | → | → | → | → | → | → | ↑ | ↑ | ← |

Fig. 5. Average direction of monthly coastal movements (1953-56).

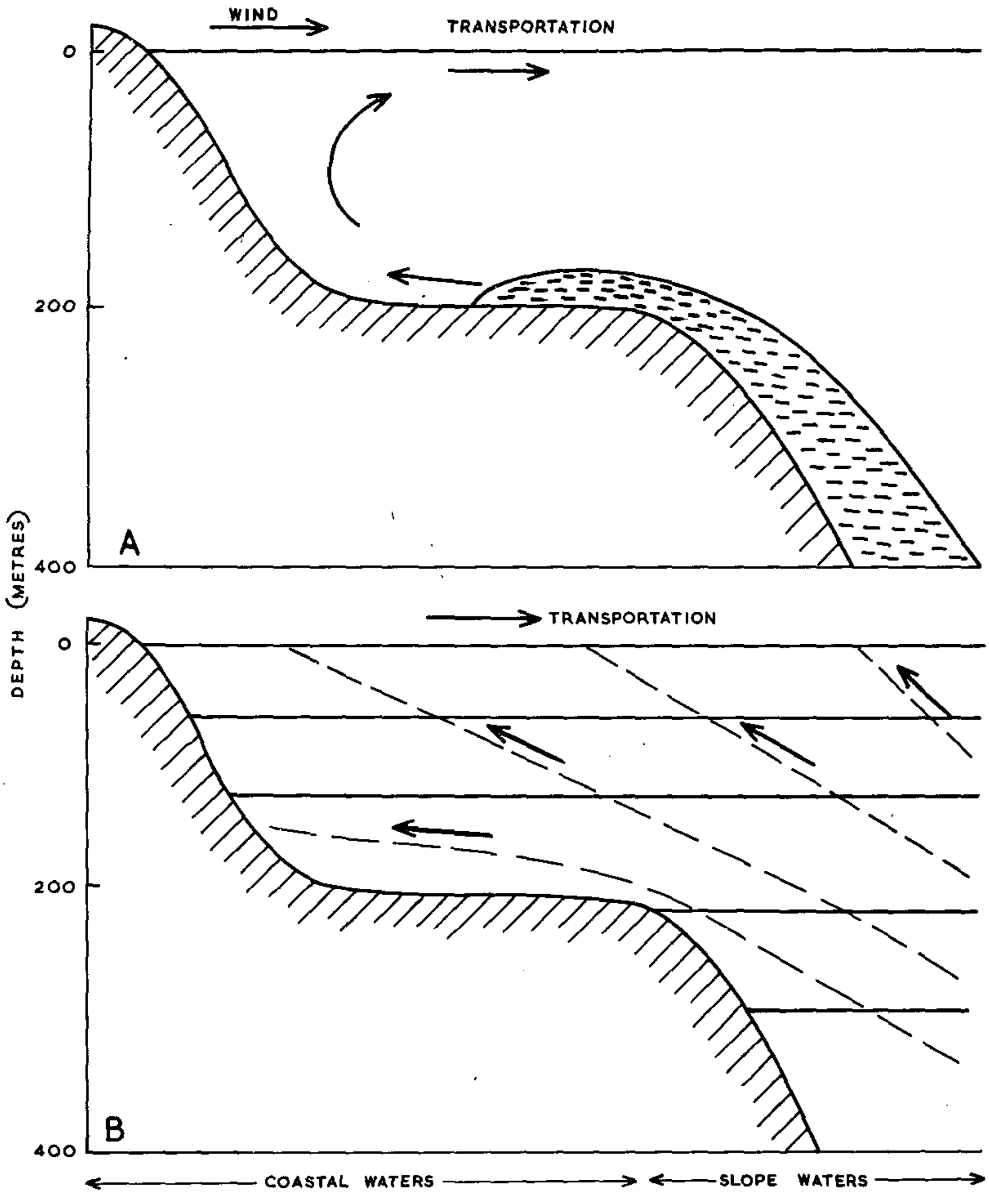


Fig. 6A. Probable source of upwelled waters during winter period.

Fig. 6B. Tilting of σ t surfaces at Coastal Region due to upwelling.

TABLE 3

DOMINANT MONTHLY WIND DIRECTIONS OFF PORT HACKING DURING 1952-56*

| | 1952 | 1953 | 1954 | 1955 | 1956 | Average Direction |
|---|---|---|---|---|---|---|
| Jan | NE | S | NE | NE | NE | NE |
| Feb | SE | NE | E | S | E | NEE |
| Mar | NE | S | NE | S | N | NE |
| Apr | W | W | W | E | W | W |
| May | W | W | W | W | SW | W |
| Jun | W | W | W | W | W | W |
| Jul | W | W | W | W | W | W |
| Aug | W | W | W | W | SW | W |
| Sep | W | W | S | W | SW | W |
| Oct | W | NE | NE | W | W | W |
| Nov | W | W | W | W | SW | W |
| Dec | W | NE | SE | NE | NE | NE |

*Extracted from records of the Sydney Weather Bureau.

Table 3 is a summary from the records of the Sydney Weather Bureau for 1952-56 indicating the dominant winds in the Port Hacking area. In the period April to August the wind of maximum force and persistance is from the west. This would certainly produce an effective current running away from the coast. Drift cards released in such a current would be carried away offshore.

While the circulation in the coastal region is moving consistently offshore, the coastal hydrological pattern, under such influence, shows an appreciable deformation. As the wind keeps blowing for a long period of time, the surface water is continuously transported away, and as a result, a counter current movement is induced at the bottom. Near the coast, the subsurface water rises to the surface to replace the offshore transportation. This is the process of upwelling which gives rise to a hydrological structure deviating from the normal pattern. Coastal waters at this time possess lower chlorinity, higher nutrients as indicated by phosphorus and nitrate, and comparatively low dissolved oxygen content and low temperature characteristic of mid slope waters. Temperature alone may not always be a suitable identifying property because of the heat exchanges between the water and atmosphere in shallow coastal regions.

Ideally, the general hydrological pattern during a coastal upwelling induced by continuous surface offshore movements should be that illustrated by Figures 6A and 6B. Figure 6A shows the probable hydrological mechanism of coastal upwelling. As the sea is a continuous system, subsurface waters move up along the continental shelf to replace the surface waters being transported away. Figure 6B shows the distribution of densities during upwelling. The tilting of $\sigma_t$ surfaces near the coast is due to the onshore transport of the heavier bottom waters.

In actual practice, however, turbulent mixing in these shallow coastal waters often obscures and greatly modifies this idealized picture. At coastal stations, it is a matter of chance whether sampling has been carried out during the stage of maximum development of this coastal upwelling, which often only exists for several days before mixing destroys its characteristics. To verify this offshore movement hydrologically, an example is chosen from the data at the two Port Hacking stations in July 1956 (July 23, 1956) when the hydrological structures had the patterns as a result of coastal upwelling shown in Figure 7.

The tilting of $\sigma_t$ surfaces in the coastal region is a pronounced evidence of upwelling. The undersaturation of dissolved oxygen in association with the relatively high inorganic phosphate in the upper layers is brought about by the movement of mid slope waters to the surface. Figure 8 shows a near linear relationship between the distribution of phosphate and $\sigma_t$ surfaces indicating that the high phosphate at the surface can be completely explained by the transportation of bottom waters along isopycnal surfaces by an upwelling process without any secondary local effects. Another set of hydrological patterns of the same month at Port Hacking in 1955 (July 11, 1955) is introduced here to show that some secondary effects have taken place subsequent to the original upwelling (Fig. 9). $\sigma_t$ surfaces indicate strong upwelling. Deficiency of oxygen and richness in phosphate in the upper layers are caused by this upwelling. The relationship between phosphate and $\sigma_t$ (Fig. 10) is linear except for some scattered high phosphate anomalies between $\sigma_t$ surfaces (25.70 - 25.90). These anomalies are believed to have been caused by various secondary effects involving the breaking down of planktonic organisms and their sinking down in this density stratum. These anomalies are often encountered if the hydrological

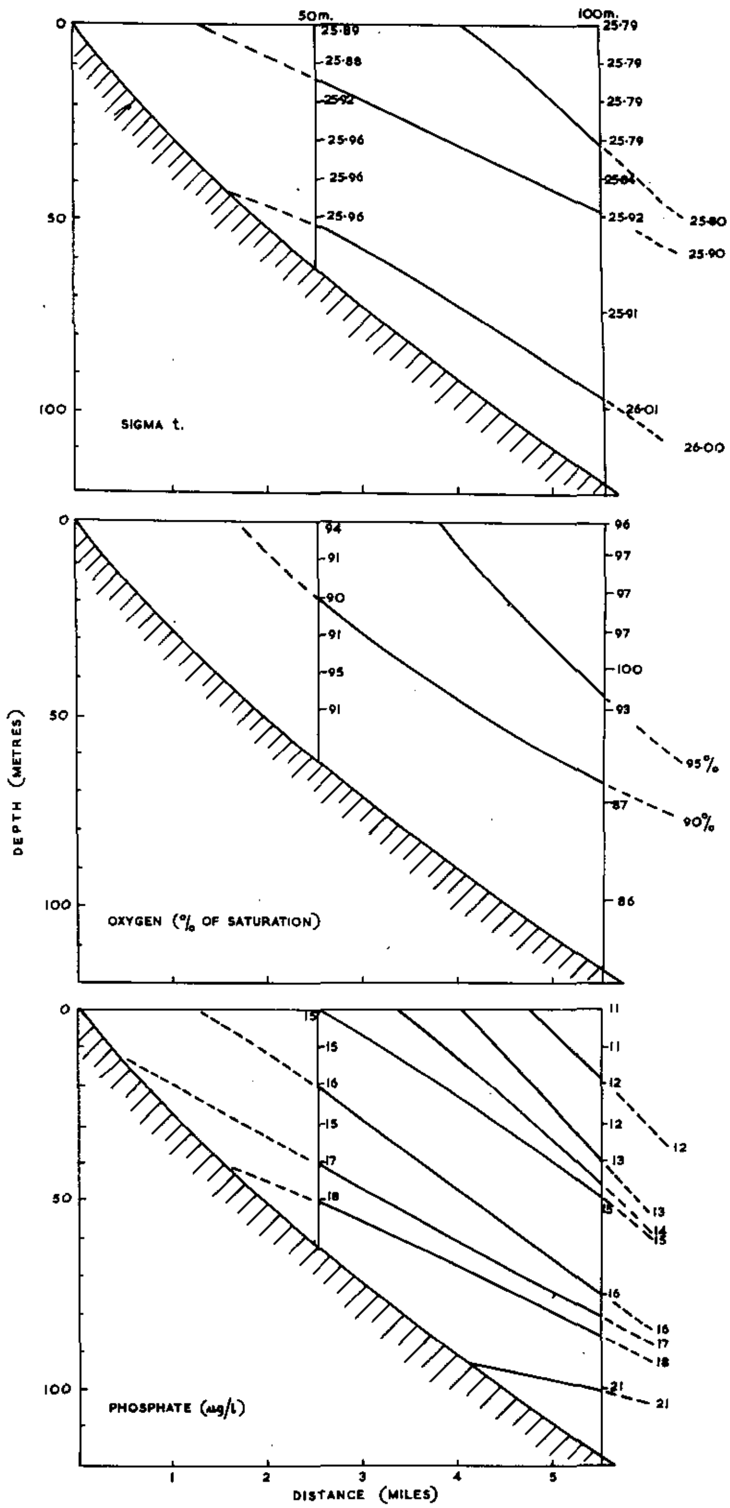


Fig. 7. Relationship of hydrological structure at Port Hacking 50 m, 100 m stations on the 23 July, 1956.

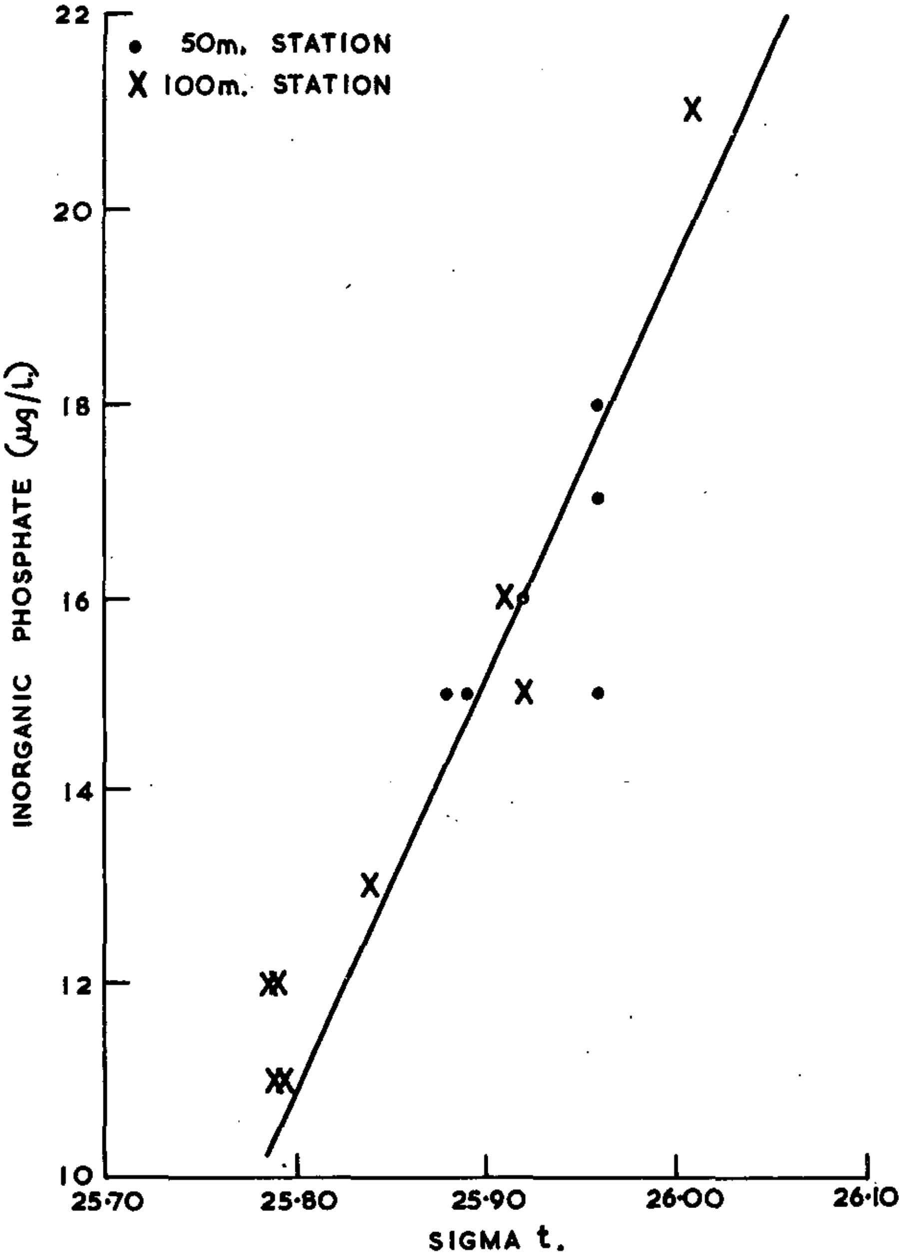


Fig. 8. Inorganic phosphates in relation to $\sigma$ t at the Port Hacking 50 m, 100 m stations on the 23 July, 1956.

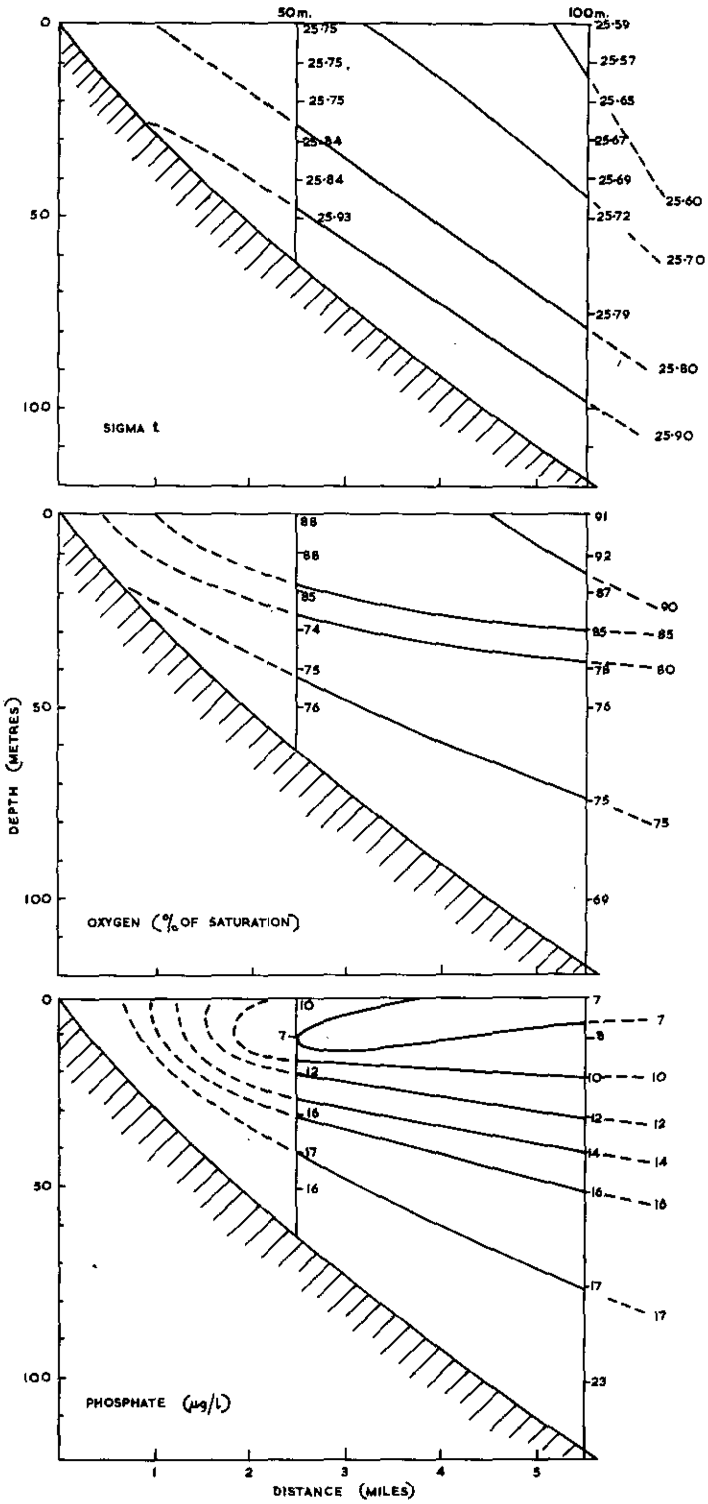


Fig. 9. Relationship of hydrological structure at Port Hacking 50 m, 100 m stations on the 11 July, 1955.

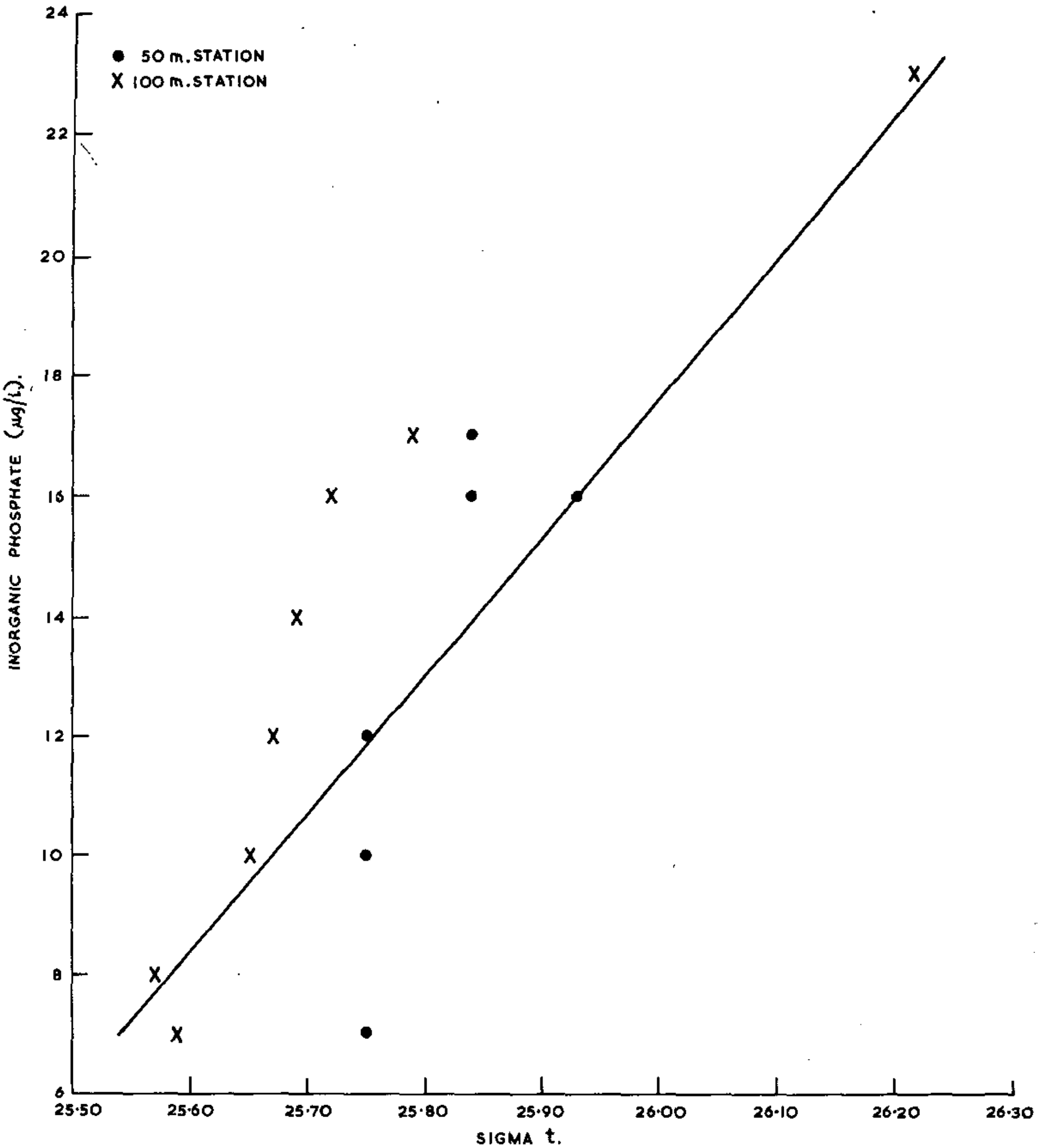


Fig. 10. Inorganic phosphates in relation to σ t at the Port Hacking 50 m, 100 m stations on the 11 July, 1955.

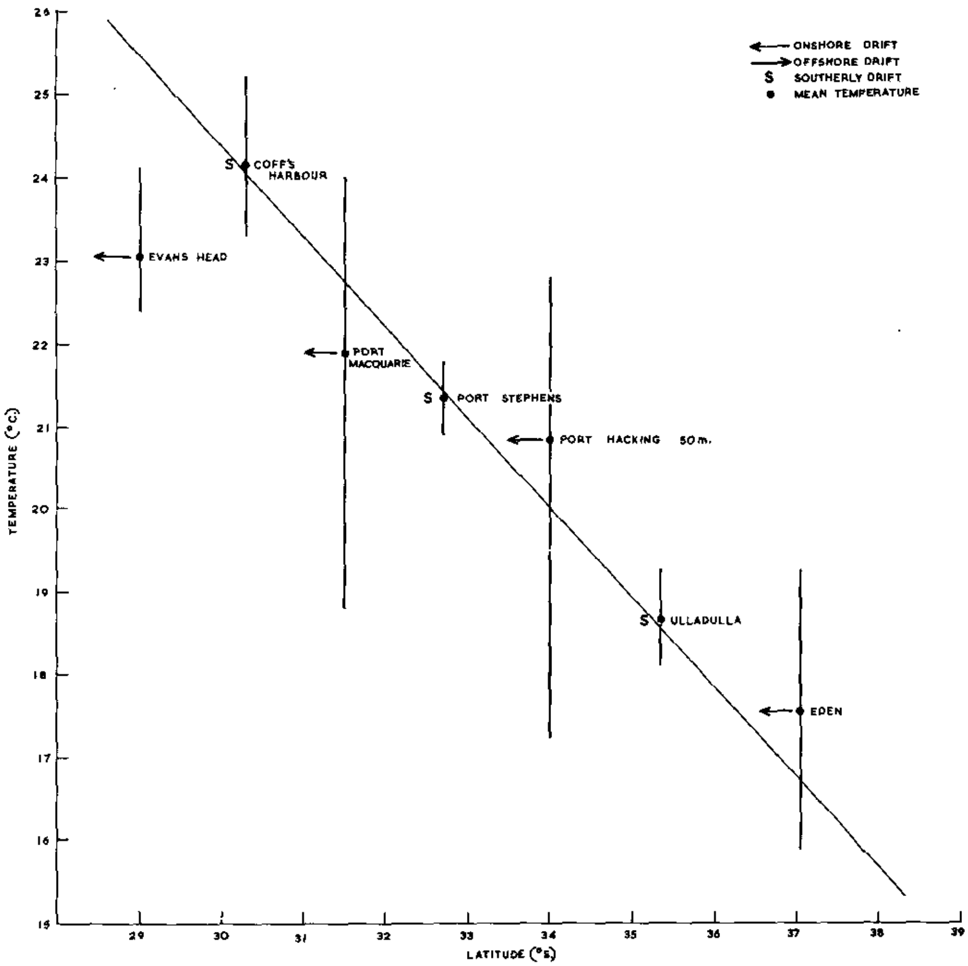


Fig. 11. Monthly range of temperature in the upper 10 m of New South Wales coastal waters. (January data 1953-56).

sampling is not carried out at the right moment when the water is brought up from the bottom and the original characteristics still remain.

### (b) December to January - Period of Summer Circulation of Tropical Waters

In December the southerly flow commences at most of the stations except at Port Macquarie and Eden where off-shore and onshore movements have been recorded. This strong southerly flow dominates the coastal area and persists until January. During this period two tropical water masses, as reported by Rochford (1957) are circulating in the Tasman Sea, sweeping the eastern coast from north to south. The first one is the Coral Sea water mass which reaches its maximum velocity in December and the second one is the South Equatorial water mass, which appears in this region during late summer. The drift card results during this period revealed a general pattern of southerly circulation.

If the mean and range of all water temperatures in the upper 10 metres for each of the coastal stations in January 1953-56 are plotted against the latitudes (Fig. 11), certain features are apparent. Stations at Coff's Harbour, Port Stephens, and Ulladulla where southerly drifts were recorded showed the minimum of variability in temperature and their means lay upon a line with a change of about 1°C per degree of latitude. Those stations at Evans Head, Port Macquarie, and Port Hacking at which drift returns were consistently onshore exhibited much higher variability in temperature. It is apparent that those stations continuously affected by the invasion of the southerly drifting tropical current would not vary much in temperature. At Evans Head, Port Macquarie, and Port Hacking, it is suggested that these onshore movements are caused by the formation and dispersion of eddies breaking away from the main flow of the tropical water and that these eddies have very variable temperatures depending upon their mixing characteristics. The great range of temperature variation at Port Macquarie is believed to be caused by such an eddy system. The exact mechanism behind these features is still unknown, however, and further investigation in these regions is necessary.

January is the most convenient month to examine these temperature ranges in the summer period because in earlier months the tropical influence is confined to the north coast only and in February there is considerable discharge of warm river water into the northern coastal waters.

In December the general circulation is very strongly to the south (Fig. 5) but it is considered that the influence of tropical waters does not extend beyond about latitude 34°S and that even in the north coast area the warm tropical waters are not in any quantity in coastal waters (Fig. 12). The surface temperatures of most stations vary tremendously, which show no sign of tropical water invasion. The Coff's Harbour and Port Stephens stations are probably most influenced by these tropical waters and exhibit minimum temperature variability, but it is impossible to generalize about the others.

The station at Eden, the most southerly on the New South Wales coast, has onshore movements mostly in the summer period. The conditions here are complicated as this region is under the influence of another circulatory system of east Bass Strait waters. Data are insufficient to explain conditions at this station.

The summer period of tropical water movements along the coast can be visualized by a diagram (Fig. 13). Eddy regions have been marked to explain the onshore movements. The boundary of the flow is hypothetical because there are no data to fix its position, and the positions of the stations are exaggerated.

<u>(c) September to November - Spring Transitional Period</u>

This is the most uncertain period of the year when all stations exhibit various directions of drift which do not appear to be connected. It is possible that local effects such as regional topographical features, river drainage could be responsible for the differing circulation systems. While the influence of oceanic circulation is weak, these local circulatory systems appear to be dominant. This period is between the maximum offshore circulation of winter and the summer southerly circulation of tropical waters. In this period offshore movements were still recorded at some of the mid coast stations, which are believed to be due to the weakening but still dominating westerly wind system. In November, northerly drifts have been recorded at the extreme stations. Further investigations will have to be made to interpret the significance of the drift card information for this period.

<u>(d) February to April - Autumn Transitional Period</u>

This is another transitional period when the southerly circulation of tropical waters in summer is replaced by an offshore circulation in winter caused by a consistent westerly wind system. At some of the coastal stations,

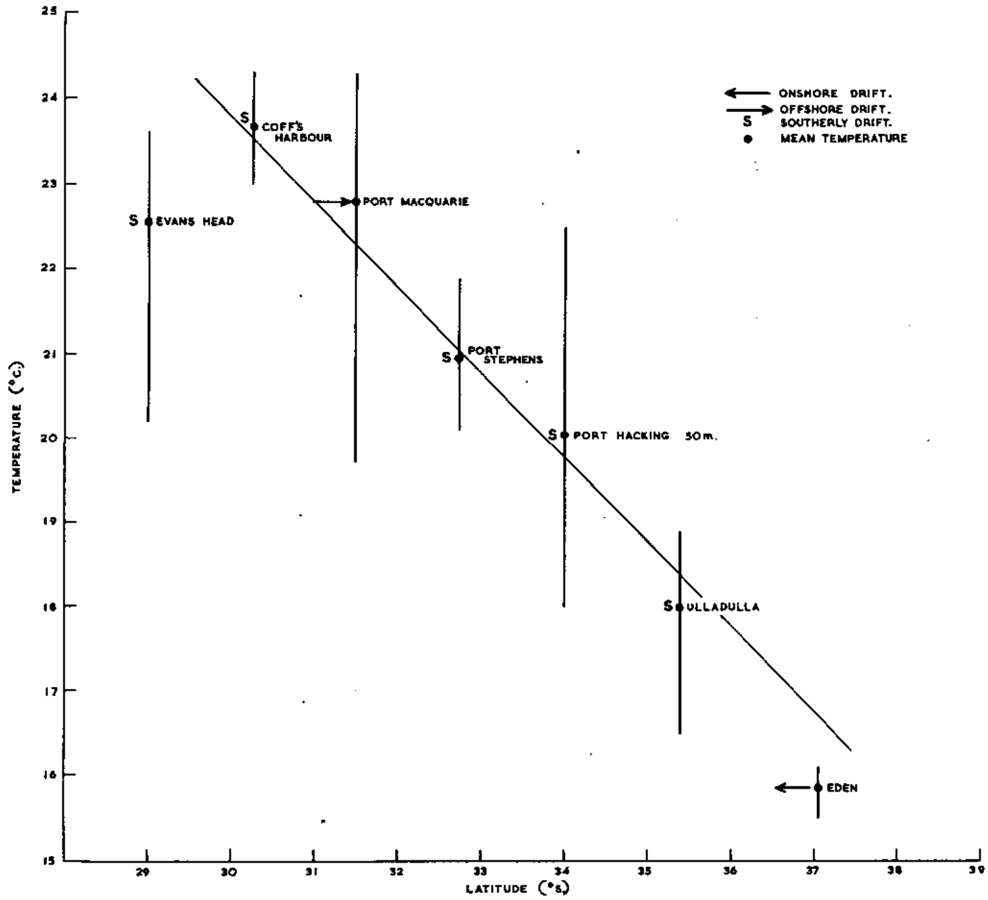


Fig. 12. Monthly range of temperature in the upper 10 m of New South Wales coastal waters. (December data 1953-56).

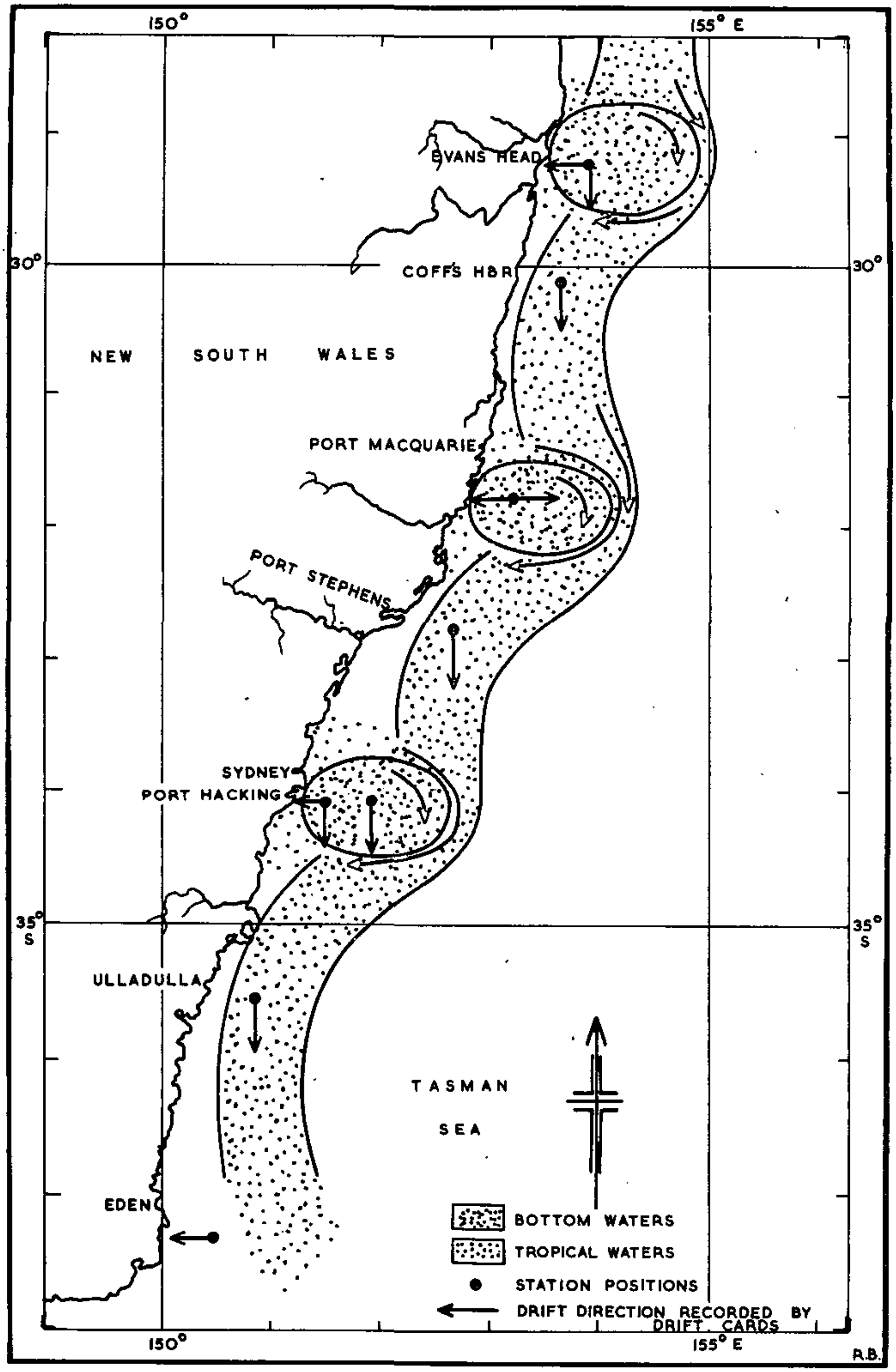


Fig. 13. Probable coastal circulation of New South Wales coastal waters during the summer tropical invasion.

(Longitudes of station positions exaggerated).

scattered southerly movements, which are presumably due to the residual tropical flows in that area, were still recorded. No definite circulation pattern could be generalized for this period.

## V. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been deduced from the 1953-56 drift card results.

(i) The New South Wales coastal circulation can be divided into four periods in each year when particular types of circulation occur.

(ii) In May to August the circulation is consistently offshore under the effect of a strong westerly wind system.

(iii) In December to January, the coastal circulation is influenced by the tropical water masses. A southerly circulation is exhibited along the coast.

(iv) In September to November the only northerly drifts occur at extreme stations. This is a transitional period between the two major patterns of circulation in summer and winter.

(v) February to April is the autumn transitional period when the coastal circulation is gradually influenced by the developing westerly winds.

(vi) There is a good deal of direct hydrological evidence in support of (iii), but only indirect for (ii).

Arising out of these conclusions, the following recommendations for the future programme are offered. Firstly, a special programme should be developed to study the slope water movements along the coast of New South Wales. This would supply confirmative proof to verify the drift card movements during the period of maximum offshore circulation. To accomplish this, a series of special cruises, with almost continuous hydrological sampling and direct measurements of currents at various depths near the coastal regions would be desirable to ascertain the periods of slope water penetration into the coastal area. Secondly, a specific investigation should be designed at different localities where eddy systems have been assumed. This would ascertain the course of the tropical water masses and their mode of incorporation into the local coastal waters. When such questions have been answered, the interpretation of drift card results will be much simplified and the frequency and regions of liberation of these cards placed upon a more profitable basis.

## VI. ACKNOWLEDGMENTS

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