Nutrient Enrichment of East Australian Coastal Waters

I. Evans Head Upwelling

D. J. ROCHFORD

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CORRIGENDUM

DIVISION OF FISHERIES AND OCEANOGRAPHY TECHNICAL PAPER NO. 31
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Page 2. Delete the following:

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"Geopotential Topographies and Currents off West Australia, 1965–69." By B. V. Hamon.

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NUTRIENT ENRICHMENT OF EAST AUSTRALIAN COASTAL WATERS
I. EVANS HEAD UPWELLING

By D. J. ROCHFORD*

Abstract

Between July 1966 and June 1969 measurements of the hydrological characteristics of coastal waters off Evans Hd (29°08′S., 153°27′E.), have shown that upwelling commonly occurs in the spring and early summer (July–December) of each year. This upwelling is confined to the inner 10 miles of coastal water with the centre of upwelling travelling from north to south at around 2 miles per day at intervals of around 6 weeks. Peak concentration of nitrates during the upwelling never exceeds 5 μg-atom/l. but this value is some ten times the value (0.5 μg-atom/l.) at other times of the year. The upwelled water originates at around 150 m over the continental slope. Local winds are not important in its genesis. Most probably changes in the internal dynamics around 200 m over the continental slope cause this upwelling.

I. INTRODUCTION

Since 1966 the long established CSIRO coastal hydrological stations off Pt Hacking (34°05′S.) and Maria I. (42°36′S.) have been supplemented by east–west lines of stations off Evans Hd (29°S.), Eden (37°S.), and since 1968 off Laurieton (31°30′S.). This pattern of coastal stations was planned to ascertain the causes of nutrient enrichment of East Australian coastal waters. The observations off Evans Hd were discontinued in June 1969 because of lack of facilities to study the onshore currents of the region. This first paper of a series examines the characteristics of the upwelling off Evans Hd between July 1966 and June 1969.

II. DATA AND METHODS

Figure 1 shows the location of Evans Hd along the East Australian coast. Between July 1966 and the end of June 1968 stations off Evans Hd were worked, as weather permitted, at the positions shown in Table 1.

TABLE 1

STATIONS OFF EVANS HD, JULY 1966–JUNE 1968

Station position		Depth of water (m)	Depth of sampling (m)	Miles offshore
Lat. °S.	Long. °E.			
29°07′	153°38′	69	0–50	9
29°07′	153°43′	85	0–75	14
29°07′	153°49′	180	0–175	19
29°07′	153°55′	1646	0–1000	24
29°07′	154°06′	2195	0–1000	34
29°07′	154°18′	2195	0–1000	39

* Division of Fisheries and Oceanography, CSIRO, Cronulla, N.S.W. 2230.

Sampling was planned at monthly intervals between January and July of each year and twice weekly or sometimes more frequently during the upwelling season, August to December 1966 and 1967. Temperature, salinity, oxygen, and nitrate nitrogen were measured at all stations and times of year, but inorganic phosphate only during the intensive period August to December.

From July 1968 to June 1969 stations were worked, as weather permitted, at the positions shown in Table 2 (see also Fig. 1).

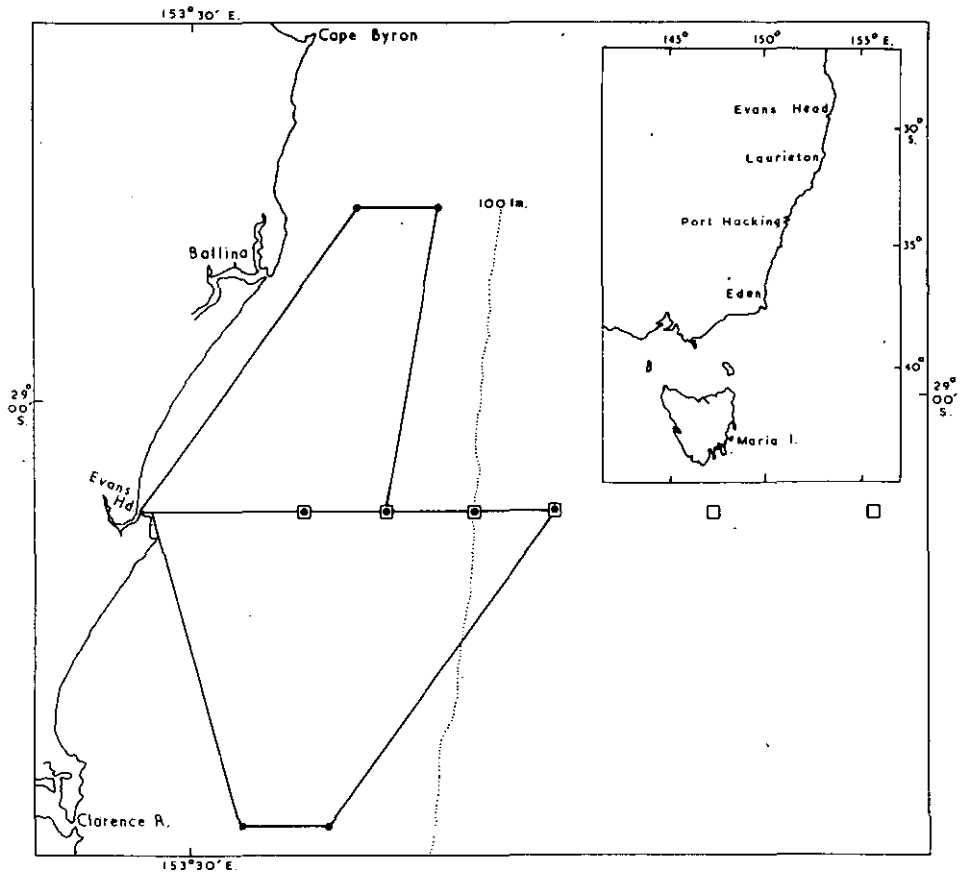

Fig. 1.—Chart showing the position of the Evans Head sampling stations. □ July 1966–June 1968. ● July 1968 onwards. Chart showing position of Evans Head in relation to other East Australian coastal stations.

Sampling was planned at weekly intervals between July and November 1968 and at monthly intervals from December 1968 to June 1969. Temperature, salinity, oxygen, and nitrate nitrogen were measured at all stations and times of the year, but inorganic phosphate only between July and November 1968. Hydrological data from all of these 1966-69 stations of the Evans Hd region are available from CSIRO and in due course will be deposited at World Data Centre A.

TABLE 2

STATIONS OFF EVANS HD, JULY 1968–JUNE 1969

Station position		Depth of water (m)	Depth of sampling (m)	Miles offshore
Lat. °S.	Long. °E.			
		(*a*) Off Evans Hd		
29°07′	153°38′	69	0–50	9
29°07′	153°43′	85	0–75	14
29°07′	153°49′	180	0–175	19
29°07′	153°55′	1646	1000	24
		(*b*) Off Lennox Hd		
28°49′	153°41′	59	0–50	4
28°49′	153°47′	86	0–75	9
		(*c*) Off Yamba		
29°26′	153°33′	60	0–50	10
29°26′	153°39′	82	0–75	15

III. NUTRIENT CHANGES 1966-69

Figure 2 shows the changes that occurred in surface nitrates and phosphates during 1966-69, and Figure 3 the accompanying changes in surface salinity and temperature. Taking nitrate values greater than 1.0 μg-atom/l. as evidence of enrichment in these subtropical waters, in general phosphates were at their highest (greater than 0.3 μg-atom/l.) and temperatures at their lowest (less than 19°C) during such enrichment. Salinities were consistently around 35.50% during these enrichment periods. Generally the increase in nitrates was much more pronounced at the shoreward western end of the Evans Hd section. The changes in surface nitrates at this shoreward station (Fig. 4) show that these periods of enrichment occurred only between August and September 1966, October and December 1967, and July and November 1968. Nitrate concentrations at the surface during these enrichment periods varied between 2 and 5 μg-atom/l., but in their absence nitrate values were consistently less than 0.5 μg-atom/l. and occasionally zero. Figure 4 also shows that the 1968 enrichment persisted longer, and judging by the nitrate concentration was of greater intensity than in 1966 or 1967.

IV. UPWELLING

Upwelling is a process of enrichment of surface waters whereby deeper waters are carried to the surface and transported away from the upwelling centre by compensatory currents. Verification of upwelling, in the absence of current measurements, is therefore difficult since enrichment of surface waters can also be the result of vertical mixing between surface and deeper waters, especially in regions of dynamic uplift of deeper waters. However, it is most probable that when a continuous band of deeper water extends to the surface with its original properties virtually unchanged and separated from adjoining waters by a sharp gradient in all

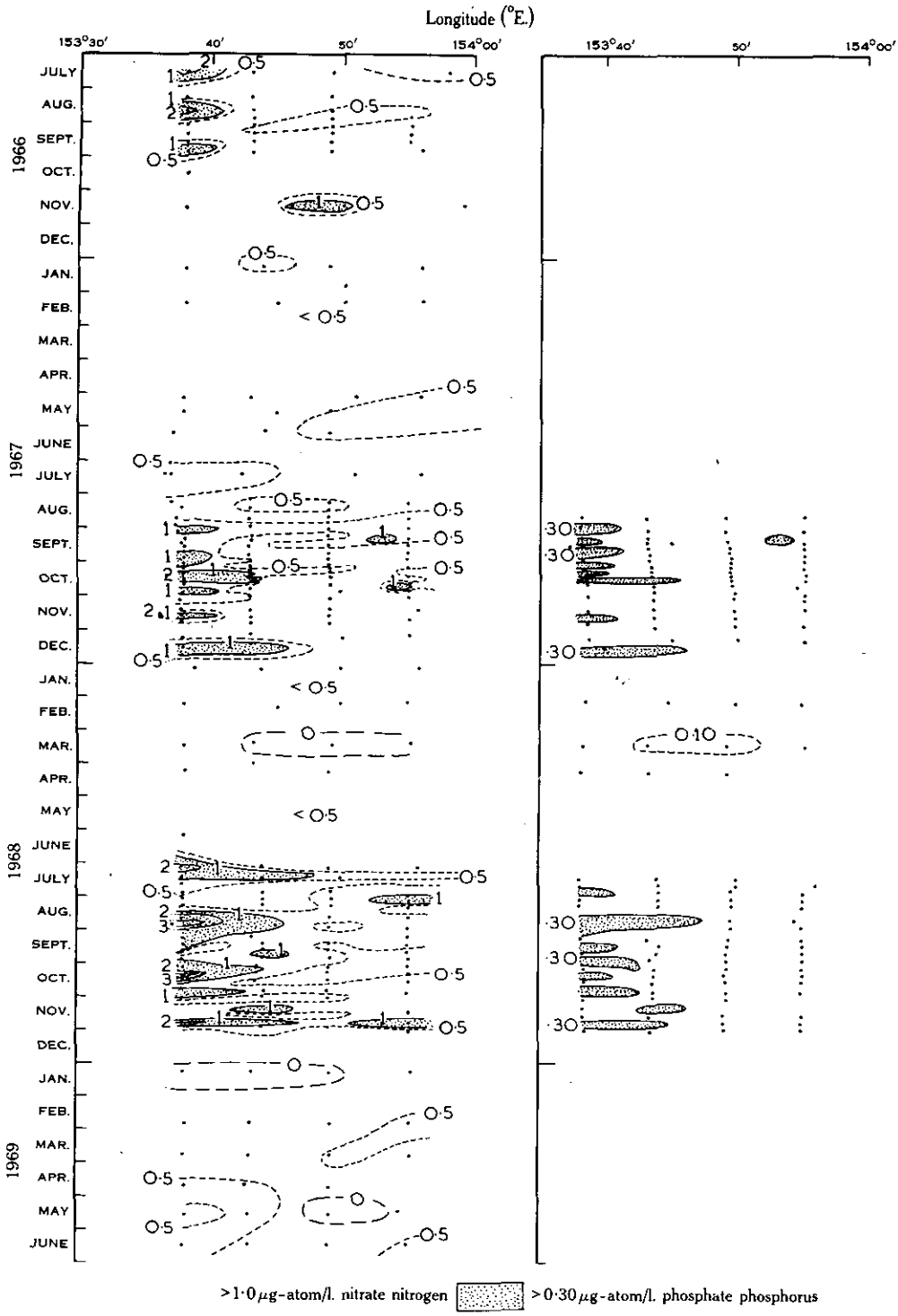

Fig. 2.–Changes in surface nitrate and phosphate along the Evans Head section (July 1966–June 1969 for nitrates; August 1967–April 1968, July 1968–November 1968 for phosphates).

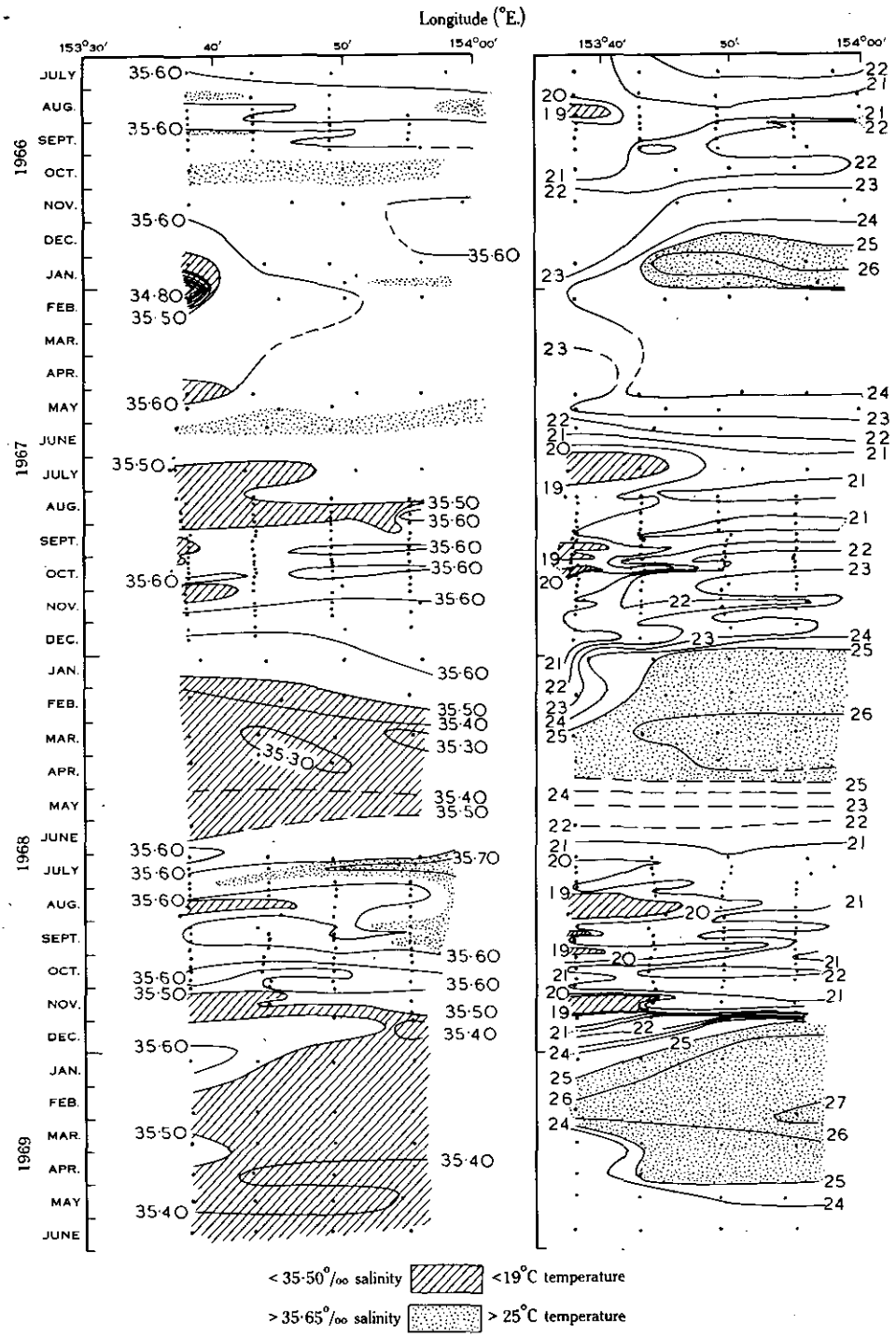

Fig. 3.–Changes in surface temperature and salinity along the Evans Head section (July 1966–June 1969).

properties (e.g. Fig. 5), upwelling has or is occurring. The accumulation of quite cold surface water along the coast in close proximity to warm offshore waters (gradient 0.5°C per mile) is also accepted as evidence of upwelling (e.g. Fig. 6).

(*a*) *Source of Upwelled Water*

The upwelled water originated at depths of 150-200 m within the continental slope region (Fig. 5) and during 1966-68 had much the same temperature (18-19°C), salinity (35.55-33.60%), and nitrate content (3-5 μg-atom/l.) (Fig. 7).

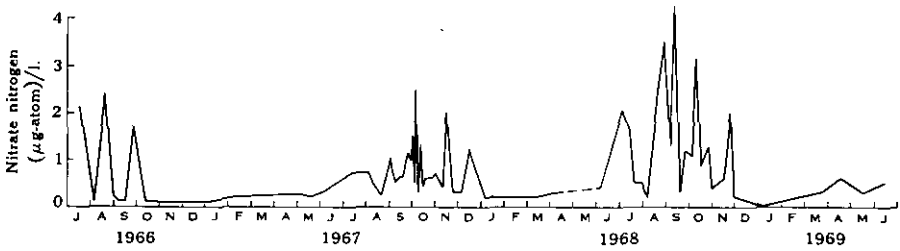

Fig. 4.—Changes in surface nitrates at the shallowest (50 m) station of the Evans Head section during July 1966–June 1969.

(*b*) *Time Sequence of Upwelling*

From August 1968 until June 1969 surface water temperatures were recorded by thermograph during the normal station sampling circuit. These records were used to plot the surface temperatures of the first 30 mile strip of coastal waters between Lennox Hd (20 miles north of Evans Hd) and Yamba (20 miles south of Evans Hd) (Fig. 1). Between August and November 1968 these thermograph records showed (Fig. 8) that the coldest water of this region was found north of Evans Hd on most occasions, very seldom to the south, and in most cases onshore of the shallowest station of the Evans Hd section (10 miles offshore).

The locations and times of occurrence of the coldest water of this region form three groupings (Fig. 9). These indicate a gradual spread southward of the cold water intrusions at around 2 miles per day. They also show an interval between major cold water intrusions of about 6 weeks.

(*c*) *Upwelling in Relation to Local Winds*

Coastal upwelling is generally found in regions where the wind has a strong component of flow seaward (Sverdrup, Johnson, and Fleming 1942). For the Evans Hd region such winds would be from the North-West quadrant. Using 0900 and 1500 hr winds recorded at Yamba (Fig. 1) as representative of the Evans Hd region, the relation between winds from the N.-W. quadrant and presence or absence of upwelling has been compiled (Table 3). These results show that upwelling can occur after a period of practically no winds from this N.-W. quadrant (*) and that upwelling does not always follow periods of consistent wind from this quadrant (▲). For the period August to November 1968 upwelling was associated with prior winds from the N.-W. quadrant on 50% of occasions, which was only slightly better than the 33% of occasions that upwelling did not follow prior winds from this quadrant. In 1966 and

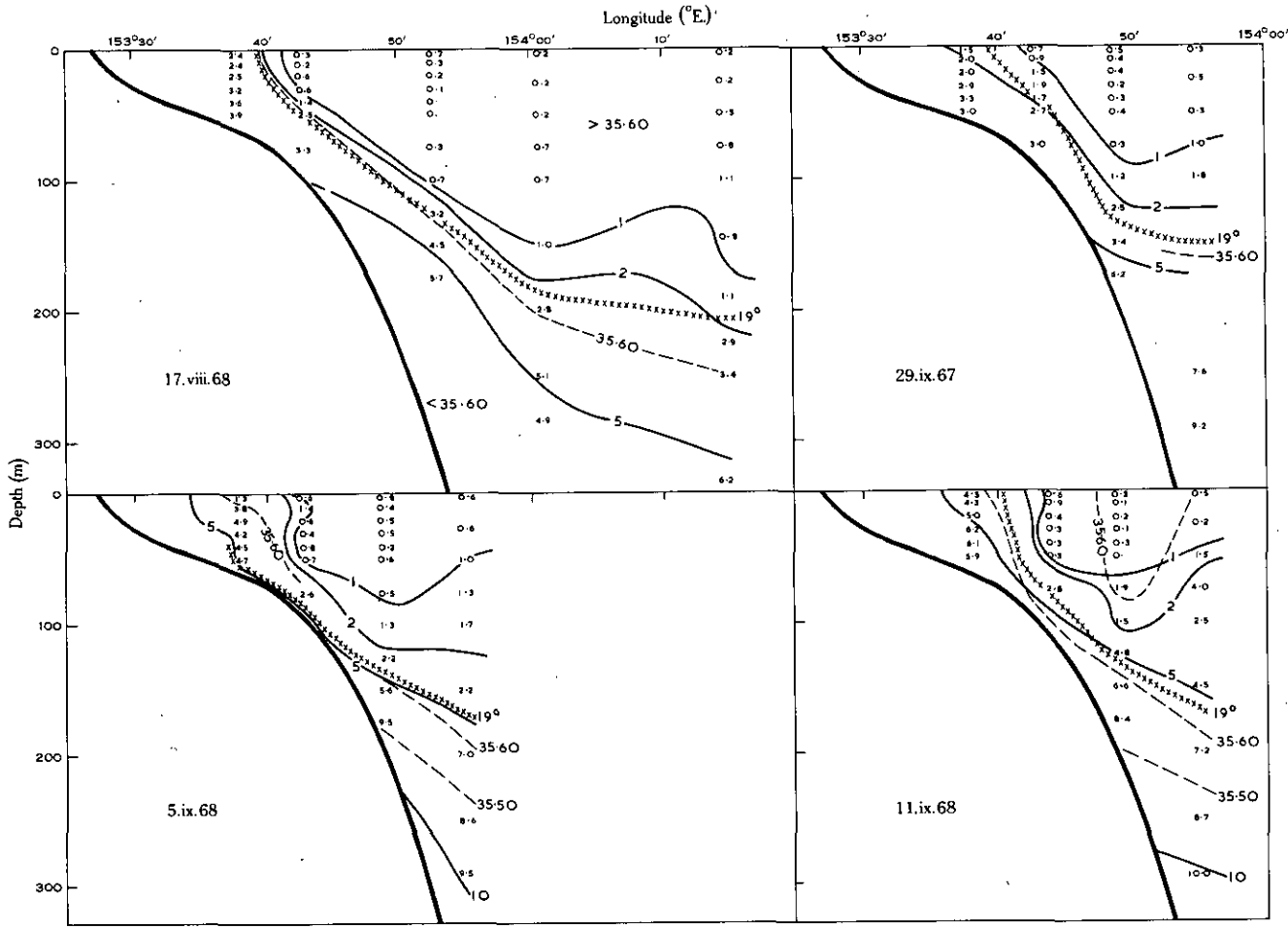

Fig. 5.—Distribution with depth of nitrates along the Evans Head section on various dates. Decimal point in values shows the station position. Contour intervals for nitrates 1, 2, 5, and 10 μg-atom/l. ----- Selected salinity contour. x x x Depth of 19°C isotherm.

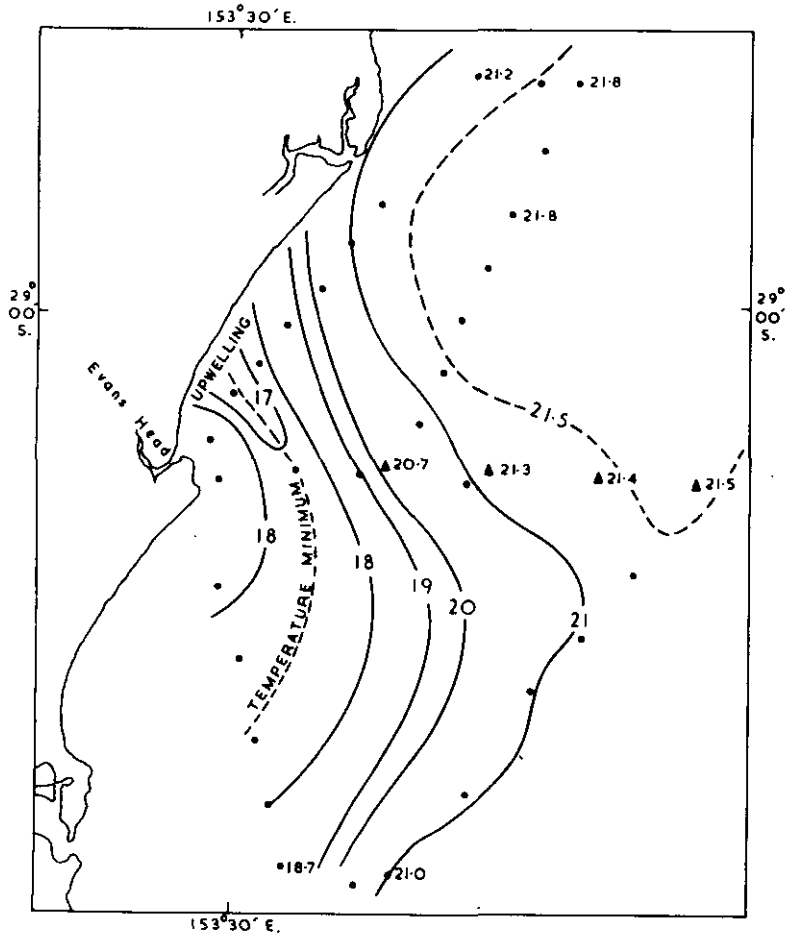

Fig. 6.—Surface temperature distribution in the vicinity of Evans Head (24–28.x.68). ▲ Evans Head section. ● Surface thermograph.

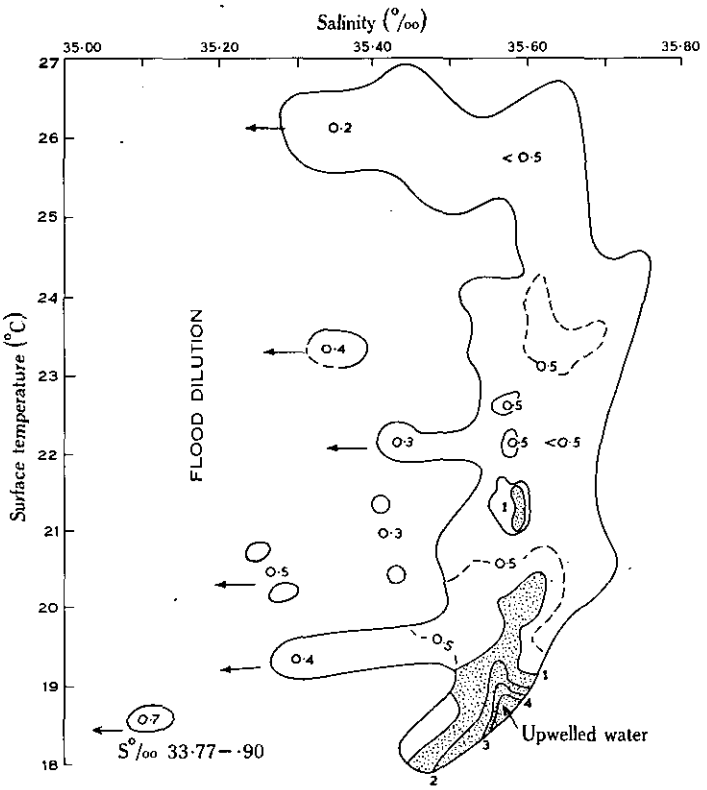

Fig. 7.—Envelope of surface temperature-salinity relations of all stations along Evans Head section July 1966–June 1969. The contoured values within this envelope are surface nitrate concentrations in μg-atom/l. of the temperature-salinity envelope.

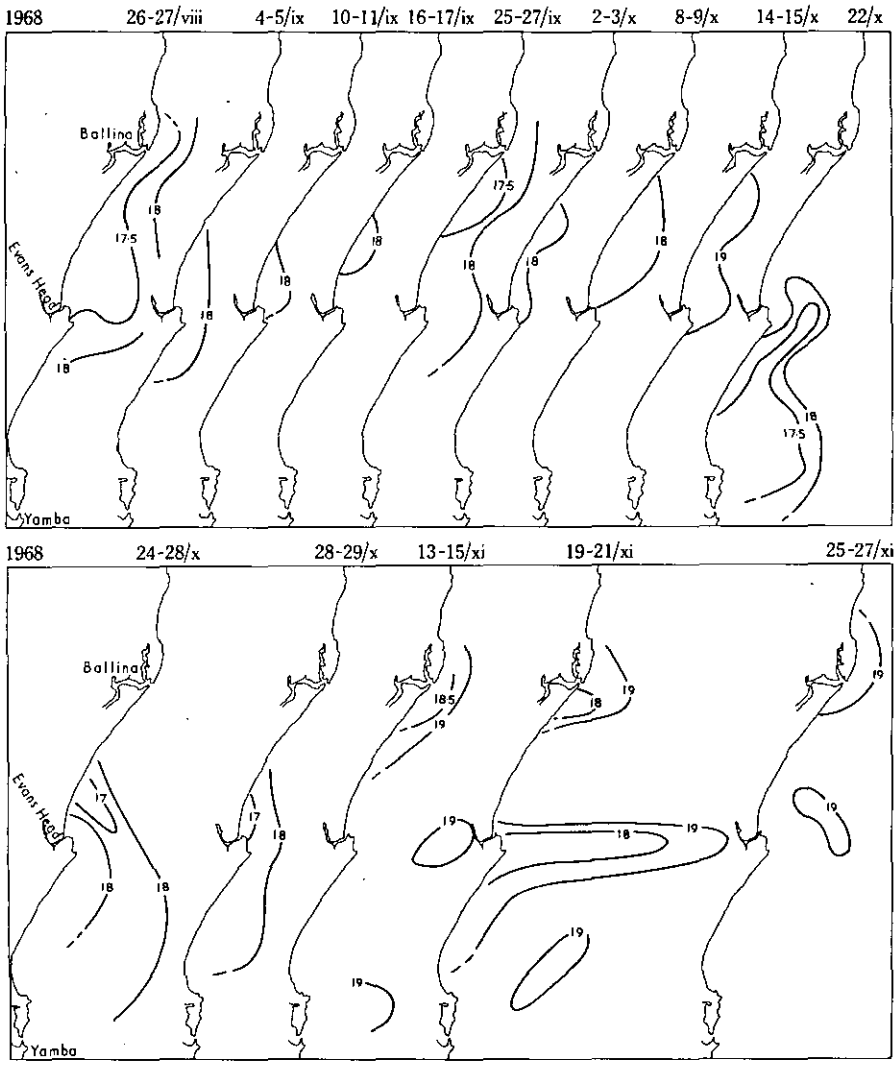

Fig. 8.—The location of the coldest water along the coast in the vicinity of Evans Head (August 1968–November 1968).

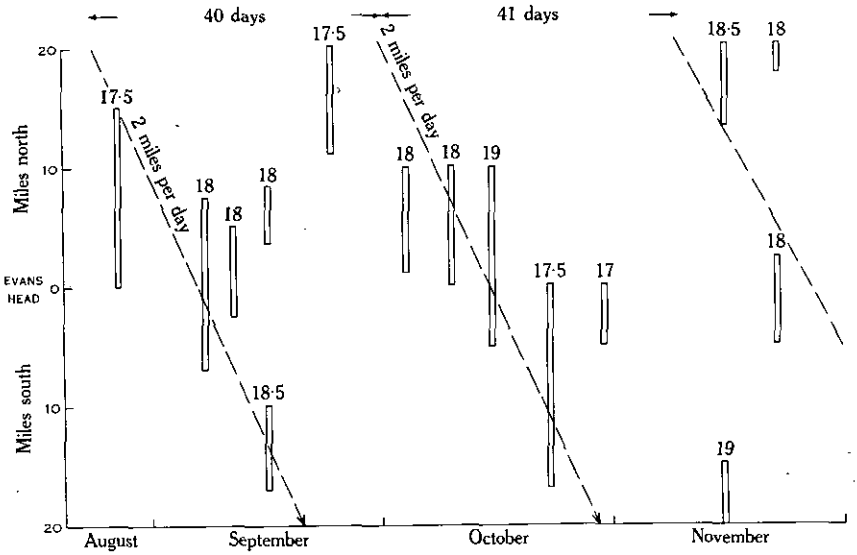

Fig. 9.–The grouping by time and position of cold water regions along the coast near Evans Head. Values of minimum temperature are shown in °C.

TABLE 3

WIND FREQUENCY AND VELOCITY FROM N.–W. QUADRANT AT YAMBA

For symbols, see text

Sampling date	Upwelling		No upwelling	
	% Winds from N.–W. preceding 5 days	Mean Velocity (kt) of N.–W. winds	% Winds from N.–W. preceding 5 days	Mean Velocity (kt) of N.–W. winds
7.viii.68			40	10
19.viii.68	20*	5		
27.viii.68	90	10		
3.ix.68	50	9		
11.ix.68	30	3		
17.ix.68			20	6
26.ix.68	55	7		
2.x.68	70	13		
9.x.68	20*	16		
15.x.68			0	–
23.x.68	10*	5		
28.x.68			60 ▲	14
9.xi.68	20*	13		
14.xi.68			30	7
21.xi.68	50	6		
27.xi.68			50 ▲	6
Number of upwellings = 10			No upwelling recorded = 6	
Winds from N.–W. for 50% or more of preceding 5 days = 5 (50%)			Winds from N.–W. for 50% or more of preceding 5 days = 2 (33%)	

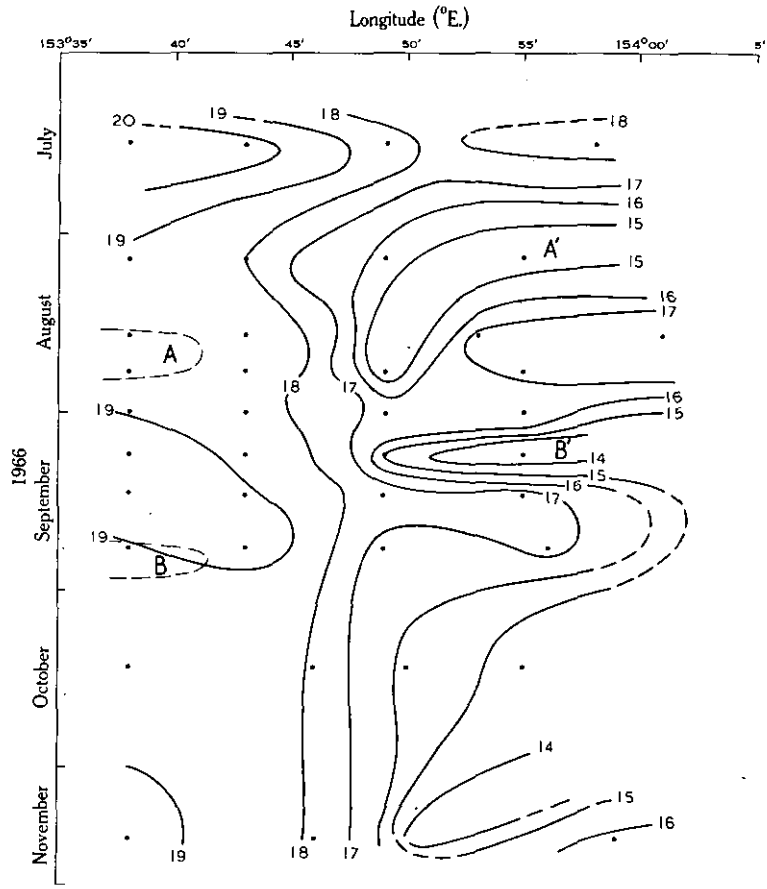

Fig. 10.–The change with time and longitude of temperatures at the bottom (eastward to 153°50′E.) and at 200 m (153°55′E.) along the Evans Head section (July–November 1966). Contours at 1 degC intervals. ----- Areas and times of upwelling along this section.

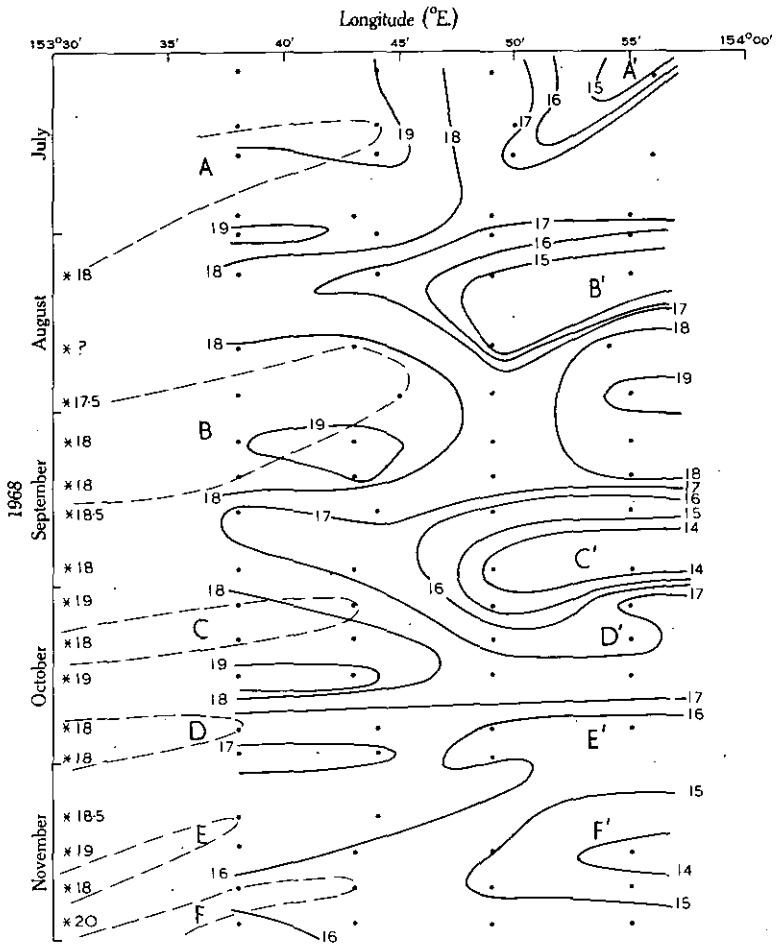

Fig. 11.–The change with time and longitude of temperatures at the bottom (eastward to 153°53′E.) and at 200 m (153°55′E.) along the Evans Head section (July–November 1968). Contours at 1 degC intervals. * Surface temperatures from thermograph. ----- Areas and times of upwelling along this section.

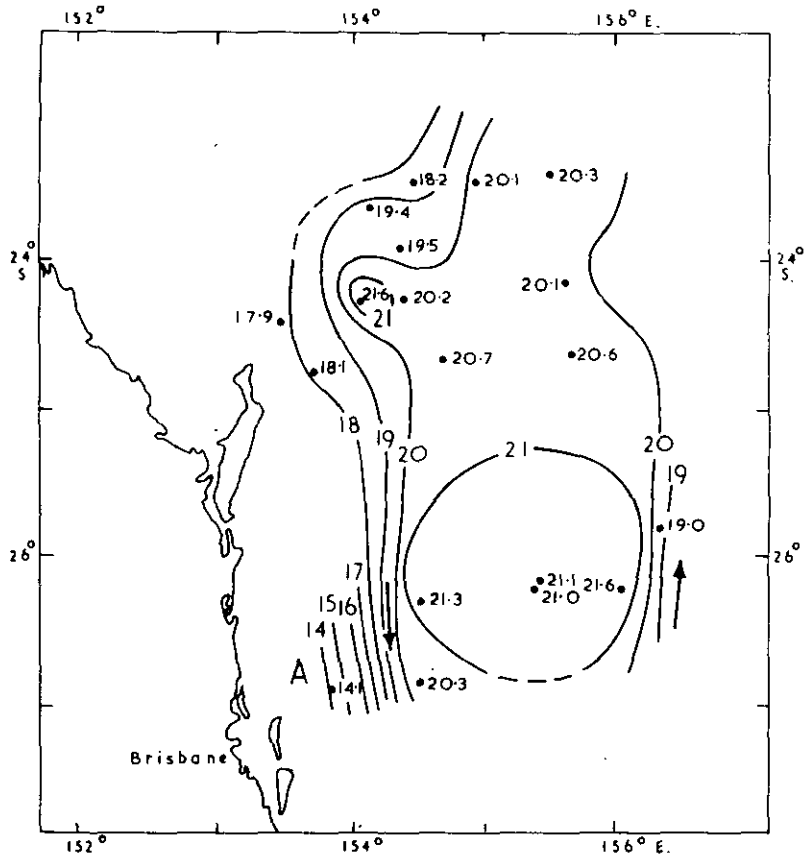

Fig. 12.—Temperatures at 200 m on *Kimbla* cruise 5/69 off southern Queensland. Arrows show direction of major currents. A, position of cold water intrusion.

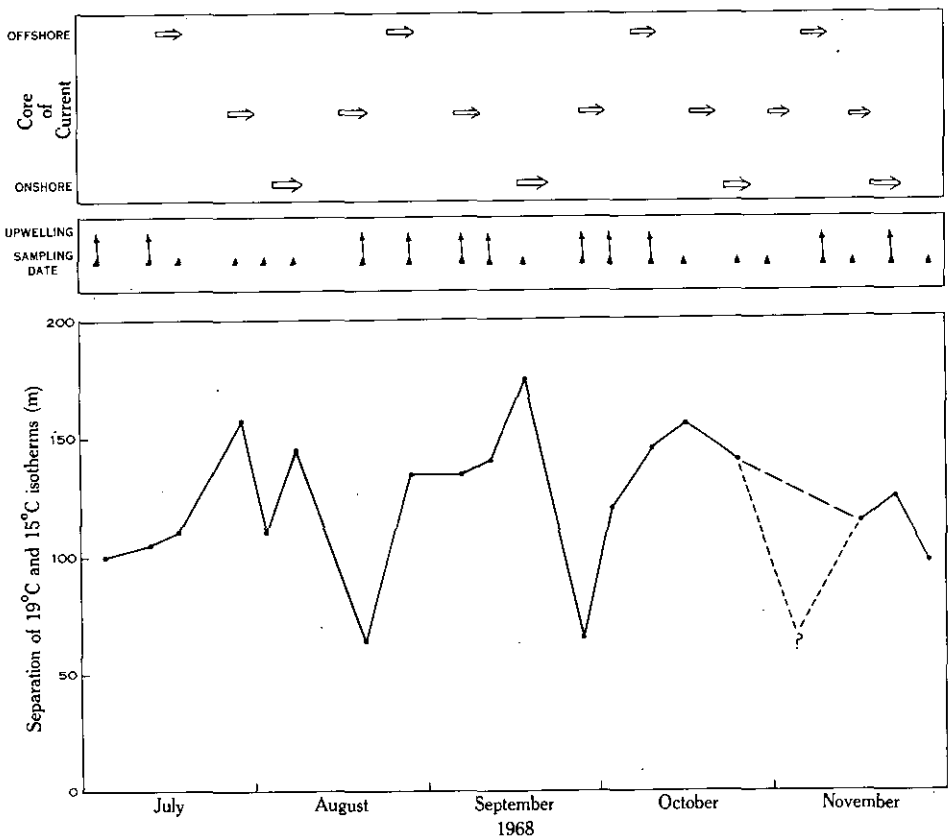

Fig. 13.–Changes in vertical separation (m) of the 15 and 19°C isotherms at the slope station (153°55′E., Fig. 1) of the Evans Head section between July and November 1968. The dates of sampling and of upwelling (*Table 3*) and the relative position of the current core based upon 200 m temperatures at the offshore station (Fig. 11) are shown for comparison.

1967 much the same relation between local winds and upwelling was found. The lack of persistence of winds from the N.–W. quadrant together with relatively weak wind velocities (Table 3) indicate that local winds are not a prime cause of upwelling off Evans Hd.

(d) Upwelling in Relation to Offshore Dynamics

During 1966 (Fig. 10) and 1968 (Fig. 11) periods of upwelling near the coast were preceded (A-A′, B-B′ etc., Fig. 11) by a decrease in temperatures of waters at 200 m over the continental slope. This relation was also found in 1967. Upwelling followed such a decrease in temperature some 10-15 days later. The mean time interval between these marked decreases in temperature at 200 m offshore was around 45 days, which is very similar to the interval between cold water occurrences near the coast at Evans Hd (Fig. 9).

When the core of a strong south-flowing current nears the continental slope, temperatures of mid-depth waters over the slope are much reduced (e.g. A, Fig. 12). Thus the reduction in 200 m temperature at the easternmost station off Evans Hd (Figs. 10 and 11) occurs when the core of the offshore current is nearest the coast. Contrariwise the increase in 200 m temperatures at this same station occurs when the core of the current moves away from the coast. The changes in nearshore circulation during these east-west meanders is not known but at the edge of the slope region the depth of water separating the 15° and 19°C isotherms changes considerably at these times (Fig. 13). Such volume changes can be the result of onshore flow or north-flowing subsurface counter current around the 200 m depth. Upwelling mostly occurred when this isothermal separation was increasing (Fig. 13). Upwelling off Evans Hd appears then to be the end result of onshore movements generated by these mid-depth currents.

V. Nutrient Enrichment during High River Discharge

Evans Hd is situated between two large rivers, the Richmond some 20 miles to the north and the Clarence some 20 miles to the south. On occasions therefore the surface waters off Evans Hd were diluted by the discharge from these rivers (Fig. 7). However, despite the high nitrate content of the waters of these rivers (Rochford 1951), the increase in surface nitrates of coastal waters during such discharge periods remained low (less than 0.5 μg-atom/l.). The direct effect of run-off from these rivers upon the nitrate economy of these coastal waters would seem therefore to be negligible.

VI. Discussion and Conclusions

The scale of upwelling off Evans Hd is very small by comparison with other coastal upwelling regions of the Southern Hemisphere such as the Benguella Current off W. Africa at 34°S., where surface nitrates exceed 20 μg-atom/l. and surface temperatures drop to around 9°C (Andrews and Cran 1969). Nevertheless, in terms of the very low nitrates that occur in its absence (0-0.5 μg-atom/l.), this upwelling is important to the nutrient economy of these East Australian coastal waters. Moreover, off Evans Hd there is no evidence that run-off or winter overturn increases nitrates in

surface waters. In this region therefore, upwelling albeit of a minor scale is the only mechanism for nutrient enrichment of surface waters.

The results to date support the following conclusions about this upwelling off Evans Hd.

(1) It occurs only in the period late July to mid December with fairly regular occurrences at intervals of 4–6 weeks.

(2) It develops near the coast and seldom has an effect on surface properties beyond 15 miles offshore.

(3) Its centre of intensity is often to the north of Evans Hd. These centres propagate southward at around 2 miles per day.

(4) Upwelling is generally preceded (10–15 days) by marked decrease in slope water temperatures at 200 m.

(5) During upwelling marked isothermal separation at around 200 m in slope waters is the result of onshore drift or northerly counter current at this depth.

(6) In the absence of any significant relation between upwelling and local winds it is probable that this mid-depth slope current is the final cause of upwelling.

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