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Anomalously Warm Sea Surface Temperatures in the Western Tasman Sea, their Causes and Effects Upon the Southern Bluefin Tuna Catch, 1966–1977

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ANOMALOUSLY WARM SEA SURFACE TEMPERATURES IN THE WESTERN TASMAN SEA, THEIR CAUSES AND EFFECTS UPON THE SOUTHERN BLUEFIN TUNA CATCH, 1966-1977

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Abstract

The abnormally warm SST experienced in the south western Tasman Sea in the winter of 1973 are claimed to be the end result of a warming event originating in the north eastern Coral Sea in 1970-1971.

This major warming event was preceded by a smaller one in the south western Tasman Sea in 1970 and followed by an even smaller one in 1976. These warming events are also claimed to be the end result of anomalously high SST in the north eastern Coral Sea in preceding years.

A possible source of the waters responsible for the 1970-1971 winter SST anomaly in the north eastern Coral Sea has been postulated but needs confirmation.

In the western Tasman Sea large cumulative trends in winter SST of around 3°C have been found. A mechanism involving trapping of warm water at sub-surface depths in anticyclonic eddies of the East Australian Current has been suggested.

The winter long line SBF tuna fishery of the central Tasman Sea has declined in catch per unit effort since 1966. Most of the decline is attributed to the effects of cumulative winter increases in the SST in the fishing area.

INTRODUCTION

A causal relationship between the El Niño warming event off Peru and the earlier accumulation and subsequent eastward flow of above normal quantities of warm surface waters in the western Equatorial Pacific has been claimed by Wyrtki (1977). He was able to show that there were rises and falls in sea level associated with above and below normal wind patterns in the western Equatorial Pacific, consistent with such an explanation of an El Niño year.

Hynd (1974) reported on the failing in winter-spring 1973 of the southern bluefin (SBF) tuna fishery in the coastal waters off southern NSW. He attributed this failure to abnormally warm sea surface temperatures (SST) in the fishing area. SST from the CSIRO ships-of-opportunity programme (Piip 1974) indicated that this warming event off southern NSW in 1973 was only part of a more widespread increase in SST in the Tasman and Coral Seas in that same year.

This paper examines the time and spatial changes in SST of the Tasman and Coral Seas. SST of the Tasman and Coral Seas have been measured since 1966 by CSIRO ships-of-opportunity and these provide the basic data for this examination.

The association in time between the changes in circulation of the western Equatorial region preceding the 1972 El Niño and the 1973 warm winter event in the southern Tasman Sea, suggested a common initial cause might be responsible for both. This possibility is also examined in this paper.

If such an origin could be found, Tasman Sea warming events such as the one in 1973 might be predictable on the basis of preceding information from the western Equatorial region.

DATA AND METHODS

The SST in this paper have been lodged with World Data Center A. For details of the routes, sampling depths, and instrumentation in the CSIRO ships-of-opportunity programme see Piip (1974). The situation he described was representative of the coverage to about 1977 only. After 1977 the number of merchant ships available and the adequacy of their coverage of the Tasman and Coral Seas became progressively limited. The data presented in this report are therefore likely to be the best available for an examination of temporal and spatial trends in the SST of the Tasman and Coral Seas.

Surface temperatures from this programme are usually collected some 3-5 m beneath the sea surface. Despite this, these "surface" values can be subject to the effects of localized weather at the time of the temperature observations. These localized effects are more pronounced in summer when the vertical mixing is minimal, than in winter when such effects are mixed to greater depths and smoothed out in the "surface" temperature.

Winter values of SST, therefore, are considered better indicators of major displacements of warm water anomalies than summer values.

The temperature values in this paper are the means of all surface temperatures within 1° squares of latitude and longitude in the month of minimum surface water temperature for the year (this month is subsequently referred to as "winter"). This "winter" value is representative of the period of greatest vertical mixing either by wind or by convective overturn. The minimum surface temperature occurred between July and September of each year.

During 1966-1977 ships-of-opportunity traversed most of the Tasman and Coral Seas (Edwards 1979). For this paper, however, only those 1° squares were selected in which there was an uninterrupted sequence of values from 1966 to 1977 from the month preceding to that following the month of minimum surface temperature. The 45 such squares available provided sufficient geographic coverage of the Tasman and Coral Seas to trace the distribution in time and space of high temperature sea surface anomalies particularly in the western parts of these seas.

The mean temperature within these selected 1° squares was based upon a variable number of temperature values per month. Table 1 shows the number of such values within a group of 1° squares. The number of temperature values per 1° square was greatest in the areas off the NSW coast and was considerably less to the north and to the east. The table also shows the year to year variability within a square in the number of temperature values, caused by the alteration in the observing ships routing and schedules.

In each of the 45 selected 1° squares, those years were selected in which the mean winter temperature was above the 1966-1977 mean. Years and squares were then sorted into warm water events covering the Tasman and Coral Seas (such as 1970-1973, Fig. 1) on the basis that:

Table 1. Number of surface temperature observations in representative 1°squares.

Square bounded by	Month	1966	1967	1968	1969	1970	1971	Year 1972	1973	1974	1975	1976	1977	1978
	July	-	5	2	2	1	1	1	-	-	6	1	-	2
13°- 13°59'S	Aug.	-	3	2	6	-	9	1	-	1	-	-	1	-
161°-161°59'E	Sept.	2	1	1	3	3	3	4	-	1	4	-	1	-
25°- 25°59'S	July	10	-	2	5	5	21	17	6	4	4	11	6	3
153°-153°59'E	Aug.	11	-	-	11	2	16	24	6	14	7	11	9	5
	Sept.	12	1	-	9	-	24	18	2	6	5	10	7	2
29°- 29°59'S	July	10	4	24	11	6	16	2	2	7	4	9	3	-
153°-153°59'E	Aug.	22	22	19	12	4	15	7	7	5	-	7	3	4
	Sept.	15	30	24	10	5	21	5	1	4	6	5	2	2
32°- 32°59'S	July	5	4	3	2	-	4	-	1	-	2	-	-	11
154°-154°59'E	Aug.	5	4	2	4	4	6	2	4	2	4	-	-	7
	Sept.													
36°- 36°59'S	July	15	14	20	7	5	19	6	14	11	10	2	1	-
150°-150°59'E	Aug.	19	19	16	10	15	19	8	20	15	11	4	1	-
	Sept.	15	18	16	9	18	11	10	17	15	14	1	-	15

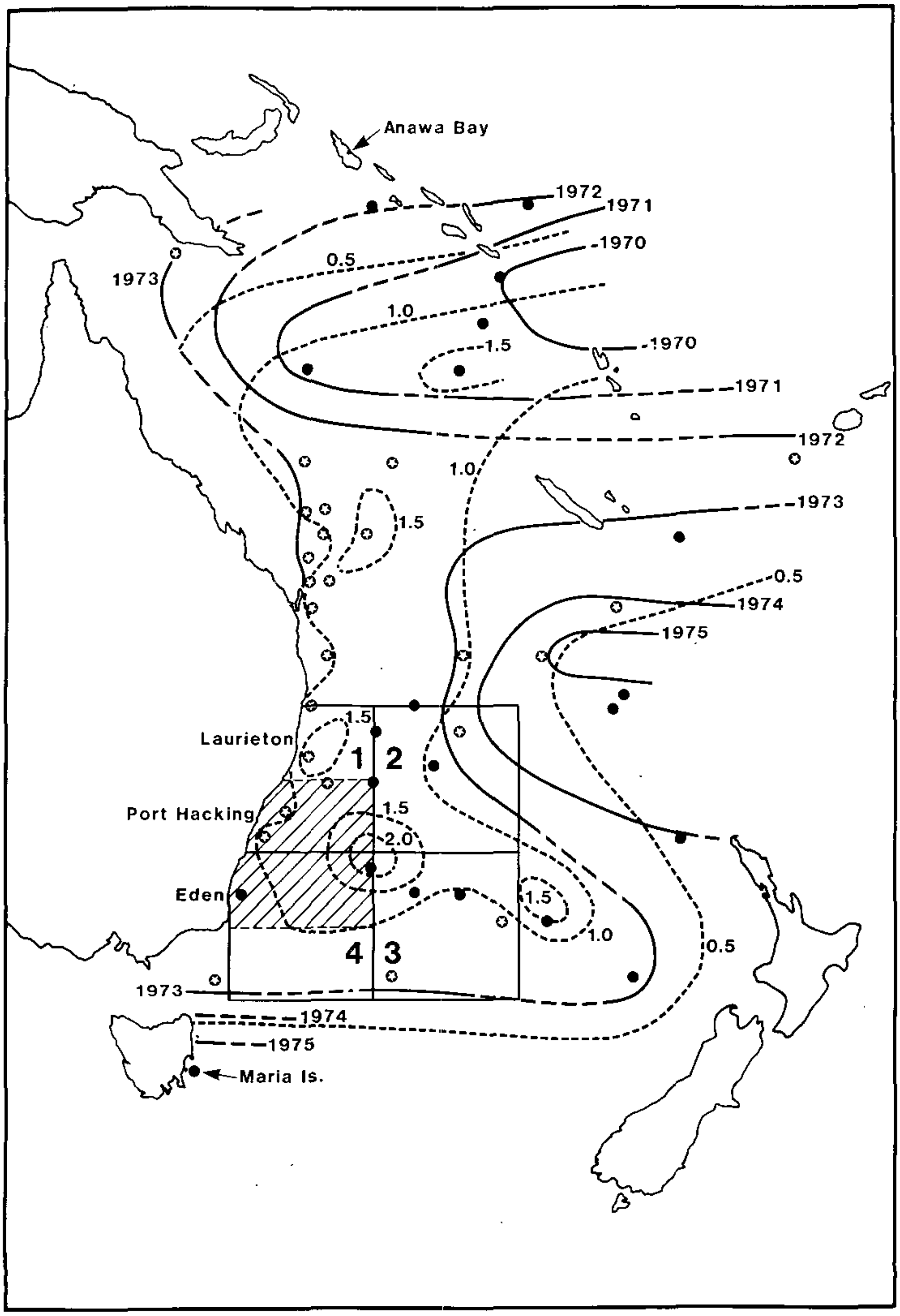

Fig. 1. The year by year progression to the south of a winter high sea temperature anomaly originating in the northern Coral Sea in 1970-1971 and the resulting increases in temperature above the 1966-1978 average. Departure from average (°C) - - -. • Anomaly detected in this region in the year indicated by the isolines ——. ✪ Anomaly detected in this region in the year indicated superimposed on a 1966-1977 trend to higher temperatures. The four areas marked 1 to 4 in this figure and in Figs 3 and 4 refer to areas in the western Tasman Sea in which catch per unit effort data have been calculated for the SBF tuna longline fishery. The area fished by the NSW pole fishery is shown ▨

(a) Warm water anomalies must originate from the north and therefore occur progressively earlier towards the north.

(b) Spatial and temporal connections between these anomalies, implying a direction of drift, must agree with the salient features of the surface circulation (Wyrtki 1962).

(c) Rates of drift implied in (b) above must not exceed acceptable limits (Hamon 1965).

CHANGES IN THE SST OF TASMAN AND CORAL SEA WATERS 1966-1977

(i) Inter-yearly Changes in Mean Annual Winter Temperatures 1966-1977

The mean annual winter temperatures in some areas of the Tasman and Coral Seas, although varying considerably from year to year, do not exhibit a trend towards high or low temperatures between 1966 and 1977. This was the case in the northern Coral Sea (Fig. 2*a*) and in the southern Tasman Sea (Fig. 2*e*). In other areas, however, a trend of varying magnitude towards consistently higher temperatures was found with inter-yearly fluctuations about this trend (Figs 2*b*, *c*, *d*).

(ii) Major Warming Events 1966-1977

(a) 1970-1973 Event

This warming event was the most pronounced in its effect on SST and the area influenced originated in the north eastern Coral Sea in 1970 (Fig. 1). The anomalously warm waters then spread westward and southward and finally eastward in good conformity with the circulatory features of the East Australian Current (Hamon 1965). An average spreading rate of 3 km/day would transport the warm anomaly from its origin to the region off Sydney in the observed time of three years, a rate which is within acceptable limits for residual open ocean currents in the western Tasman Sea (Hamon 1965). SST within the centre of spreading of these anomalously warm waters were between 1° and 2°C above the 1966-1977 average (Fig. 1). South of 40°S and in the vicinity of Norfolk Island the southward and eastward spreading rate and the extent of warming were much reduced.

(b) 1967-1970 Event

This warming event originated in 1967 in the north eastern Coral Sea also (Fig. 3). The chronology and direction of spreading of the anomalously warm water were very similar to the 1970-1973 event (cf. Figs 1, 3).

The magnitude of the initial temperature anomaly in the eastern Coral Sea was much smaller in 1967 than in 1970 (cf. Figs 1, 3). The overall warming effect in the 1967-1970 event was less (0.5°C or less) than that in the 1970-1973 event (1°-2°C).

(c) 1973-1976 Event

As in the case of the two previous events the origin of the anomalously warm water was in the north eastern Coral Sea (Fig. 4). Commencing in 1973 this anomaly created temperatures generally less than 1°C above average in the region of its westward and southward spreading. The extent of eastward spreading was much reduced relative to the 1970-1973 event.

CUMULATIVE WARMING TRENDS 1966-1977

Fig. 2*d* shows that in the north western region of the Tasman Sea mean surface winter temperatures between 1966 and 1977 have increased by as much as 3°C.

Fig. 1 shows that areas exhibiting cumulative trends to warmer temperatures of between 2°-3°C occurred predominently in the western Coral and Tasman Seas off the central margin of eastern Australia. There were other areas exhibiting trends to higher temperatures (1966-1977) in the central Tasman Sea but the magnitude of the trend was only 1°-2°C.

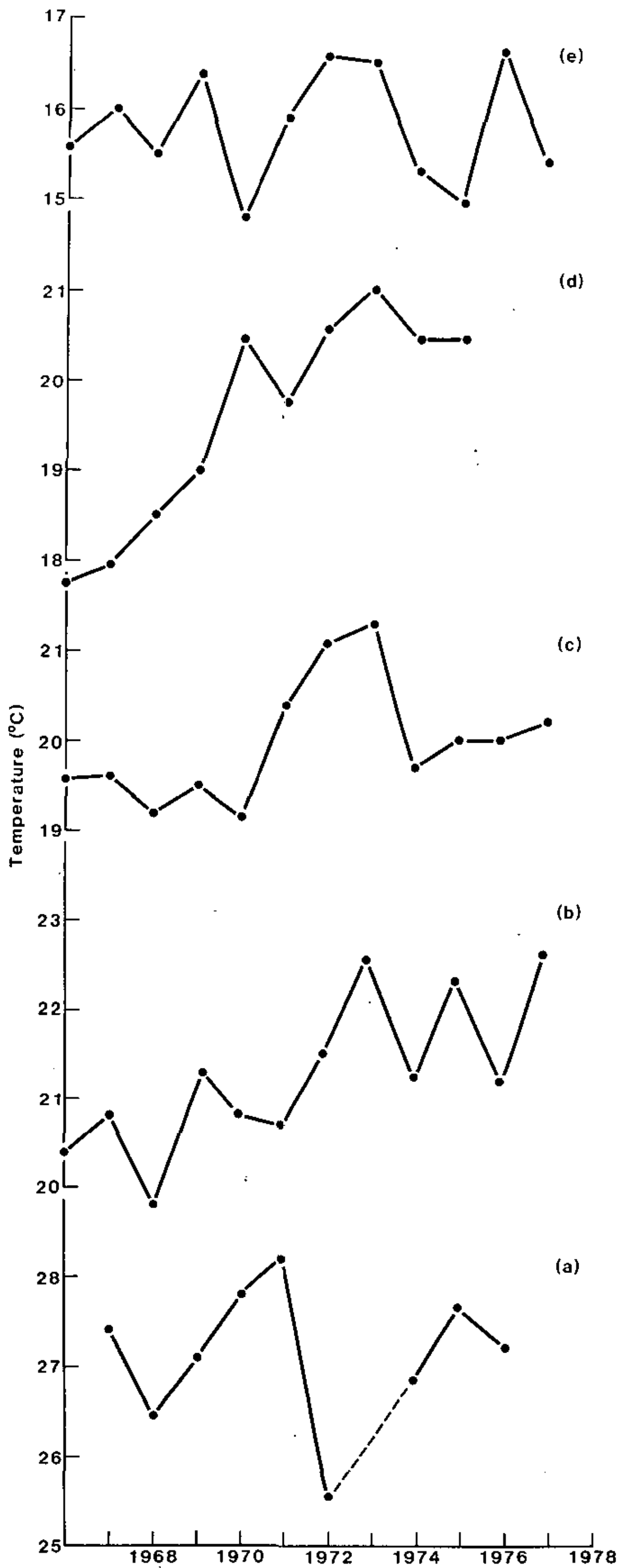

Fig. 2. The changes in mean winter surface temperature 1966-1977 at the following locations: (a) Area bounded by 13-14°S and 161-162°E. (b) Area bounded by 25-26°S and 153-154°E. (c) Area bounded by 29-30°S and 153-154°E. (d) Area bounded by 32-33°S and 154-155°E. (e) Area bounded by 36-37°S and 150-151°E.

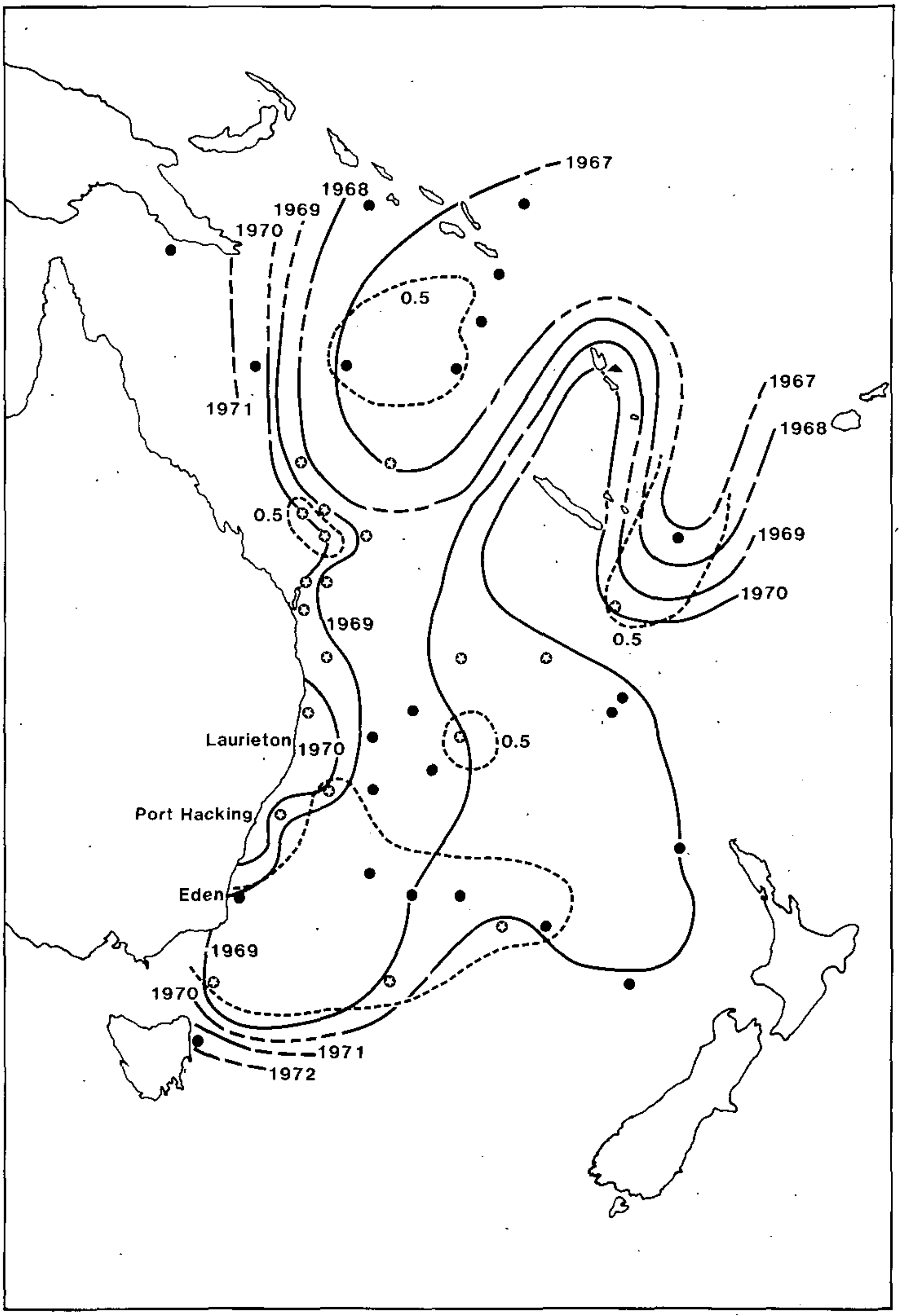

Fig. 3. The year by year progression to the south of a winter high temperature anomaly originating in the northern Coral Sea in 1967 and the increase in temperature above the 1966-1978 average for this anomaly. For symbols see Fig.1.

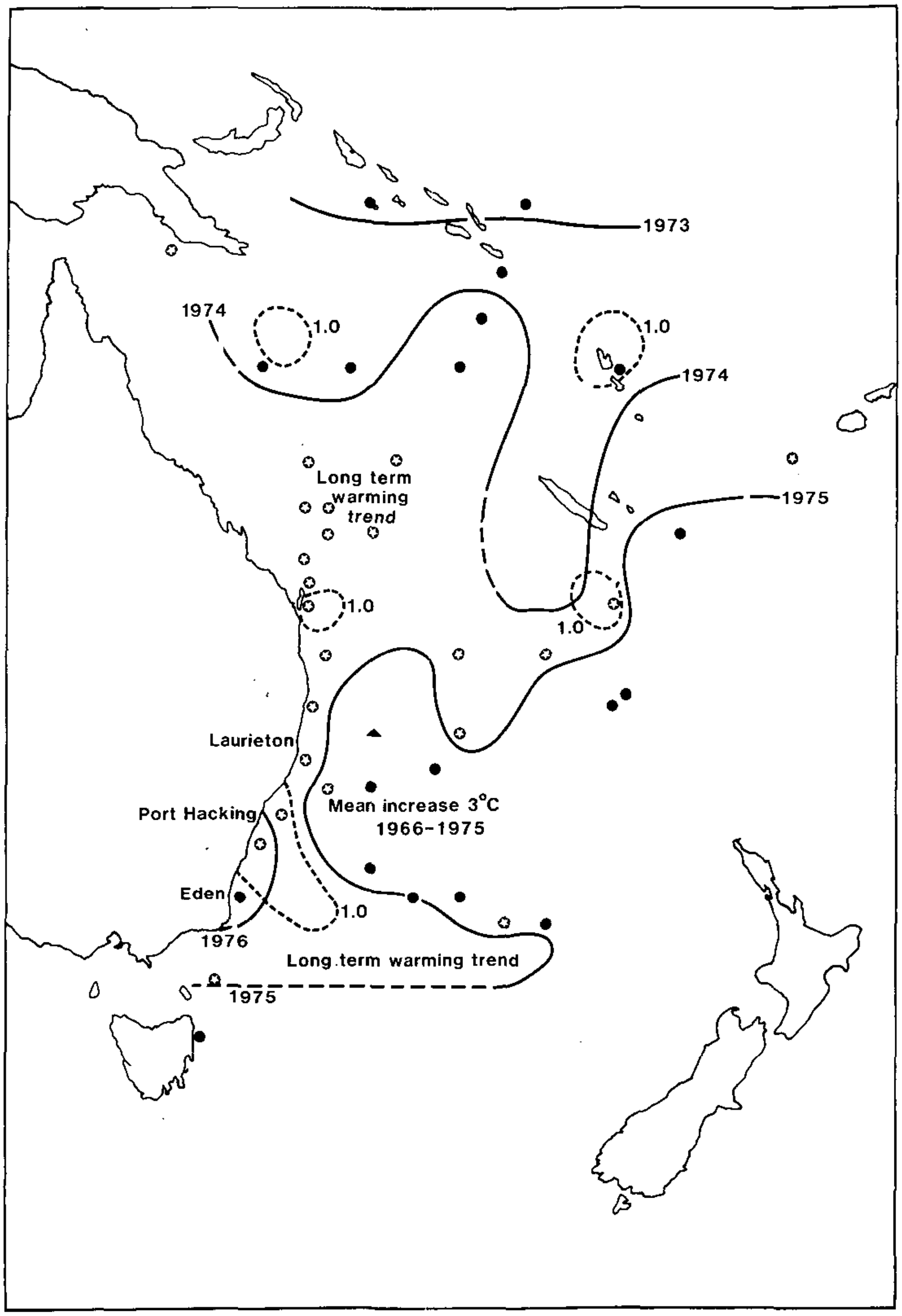

Fig. 4. The year by year progression to the south of a winter high temperature anomaly originating the northern Coral Sea in 1973 and the increases in temperature above the 1966-1978 average of this anomaly. For symbols see Fig. 1.

LONG-TERM CHANGES IN TEMPERATURE AND SALINITY OF COASTAL WATERS

(a) Maria Island Station
Lat. 43°36'S, Long. 148°16'E

The mean annual near surface (20 m depth) sea temperatures at this station (Fig. 1) have increased by around 1°-1.5°C in the period 1946-1978 (Fig. 5). In that same period salinities have also increased by between 0.2 to 0.3‰ (Fig. 5). A combination of increased temperature and salinity identifies waters from the north as the only advective source for this long-term trend.

In 1974 there was a peak in the temperature and salinity, following the 1970-1973 warming event in the Tasman Sea. It is probable that there was a connection between the two events. No such connection was apparent for the 1967-1970 or the 1973-1976 events. Despite this lack of reconciliation between individual warming events in the north and the warming trend off Maria Island, the overall cause of the latter seems to be an increase with time of the warmer and relatively more saline waters from the north in the composition of these Maria Island waters. It is significant also that in these waters nitrates increase during years of lowered temperatures and salinity, and decrease in other years, consistent with the above explanation.

(b) Eden Station
Lat. 37°04'S, Long. 150°05'E

There is not a complete set of data at this station (Fig. 1) with values of temperature and salinity from 1954-1960 and from 1966 to the present only (Fig. 6). However, the mean annual temperatures from 1966 onward do show a trend towards higher values. This trend becomes even more apparent if the below 16°C mean temperatures in 1956 and 1957 are taken into account.

Salinities from 1966 onwards show a trend towards lower values (Fig. 6) with values lower than observed in 1954 to 1960. A trend towards higher temperatures and lower salinities indicates an increasing contribution by tropical waters characterised by higher temperatures and lower salinities, to these Eden coastal values in the period 1954 to the present. The various warming events in the south western Tasman Sea seem to have had limited effect on the year by year fluctuations in these Eden coastal temperatures. The single exception could be the very warm temperature in 1974 arising out of the 1970-1973 warming event.

(c) Port Hacking Stations
Lat. 34°05'S, Long. 151°12'E and
Lat. 34°05'S, Long. 151°15'E

At the near shore station (Fig. 1) there was no evidence of a long-term trend towards higher or lower temperatures during the period 1943 to the present (Fig. 7*a*). There was however some peaking of SST in 1973 and 1976 associated with the two warming events.

Some three miles further offshore, SST exhibited only small inter-annual changes between 1955 and 1968 (Fig. 7*b*). Following a decline in 1971, SST progressively increased to peaks in 1973 and 1976 during the 1970-1973 and 1973-1976 warming events.

(d) Laurieton Station
Lat. 31°39'S, Long. 152°54'E

SST were observed at this mid northern NSW coastal station (Fig. 1) during 1969-1973. The mean monthly SST (Fig. 8) are based upon some 15-20 values each month. At this station the 1973 warming event climaxed in late spring although the warming was discernable in June and persisted through to October. The 1973 mean summer SST were not above previous summer SST, despite some high values in January 1973 reflected in the s.d. for the month (Fig. 8).

Fig. 5. Changes in the mean annual sea temperature (°C) and salinity (‰) at 20 m off Maria Is. Tasmania (42°36'S-148°16'E, Fig. 1) since 1946.
● Based upon fortnightly values. ▲ Based upon monthly values.

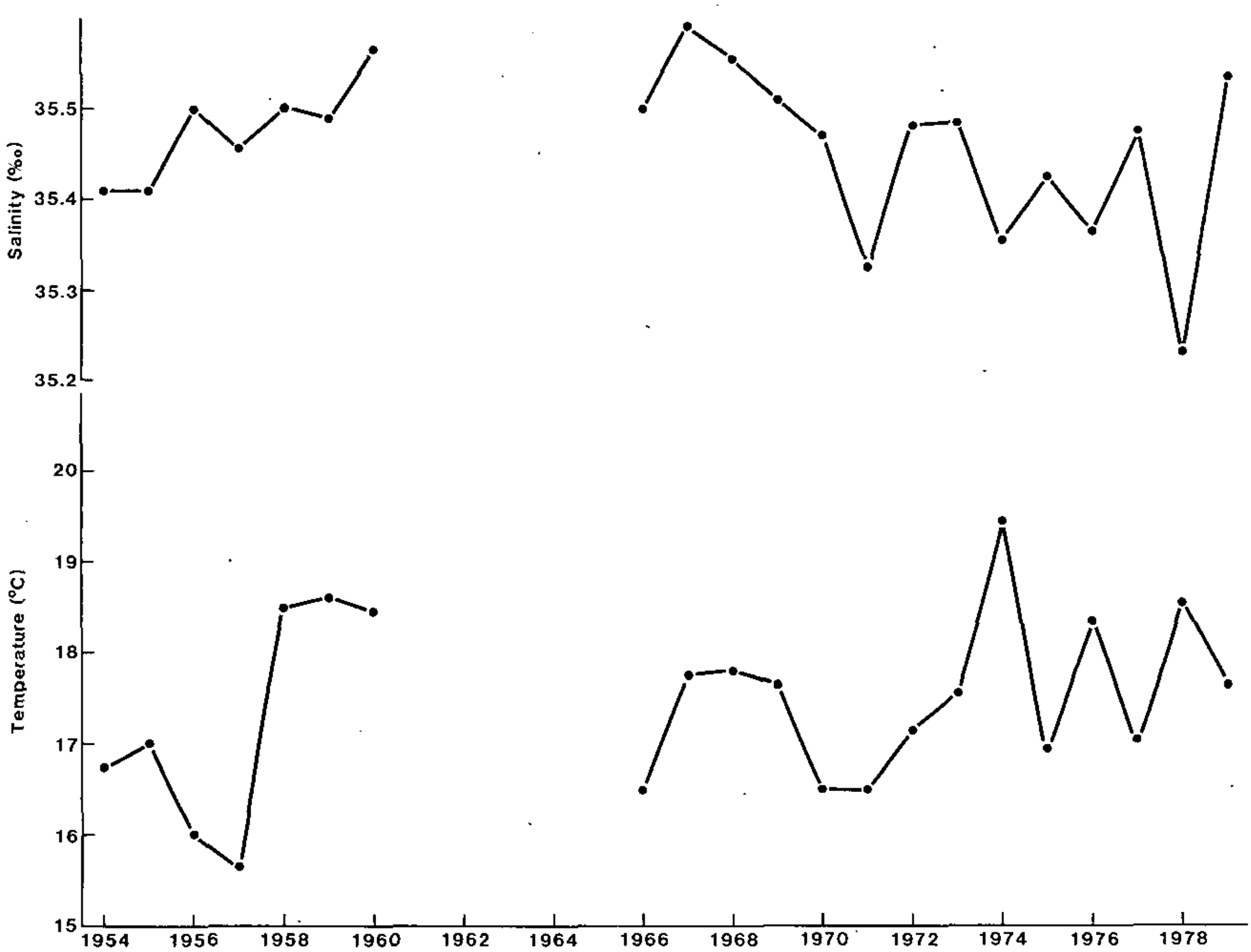

Fig. 6. Changes in the mean annual SST (°C) and salinity (‰) at the Eden coastal station (lat. 37°04'S long. 150°05'E, Fig. 1) since 1954.

Fig. 7. Changes in the mean annual SST (°C) at the Port Hacking coastal station (Fig. 1). (a) Lat. 34°05'S - long. 151°12'E since 1942.
(b) Lat. 34°05'S - long. 151°15'E since 1955.

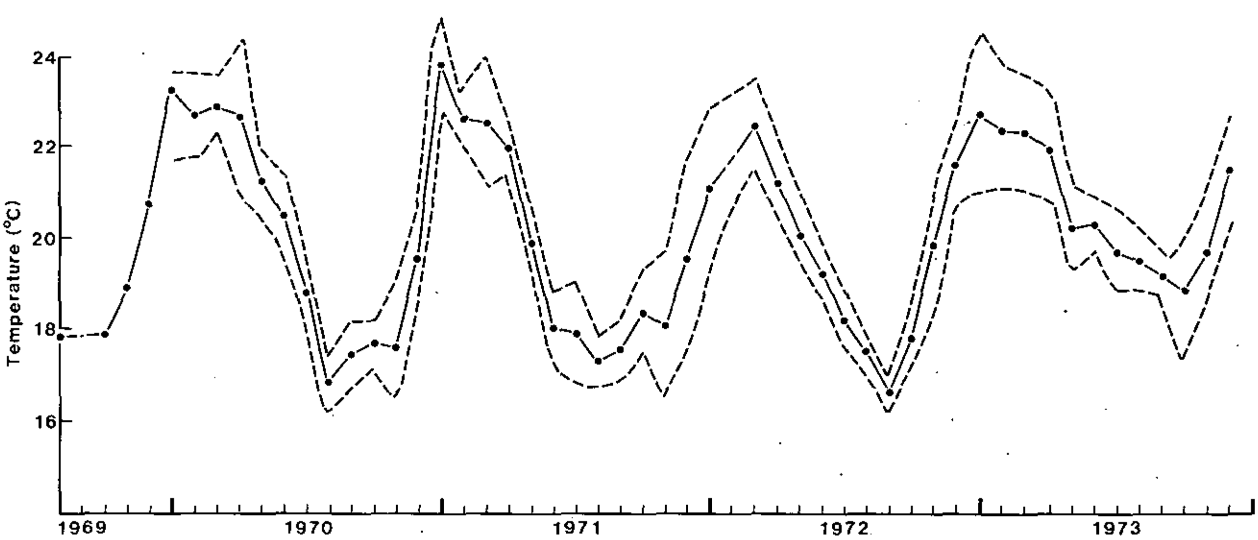

Fig. 8. Changes in the monthly mean and standard deviation of SST (°C) at the Laurieton coastal station (lat. 31°30'S - long. 152°54'E, Fig. 1) between 1969 and 1973.

POSSIBLE ORIGINS OF THE ANOMALIES IN SST AND SALINITY IN THE NORTH EASTERN CORAL SEA

Fig. 9 shows a close correspondence between the inter-yearly rise and fall in MSL at Anawa Bay and the increases and decreases in both SST and salinity in the north eastern Coral Sea. It could be claimed that during the increase in SE Trades during 1970-1971 (Wyrtki 1977) warmer and lower salinity waters were driven into the north eastern Coral Sea and at the same time raised MSL at Anawa Bay further to the north. The MSL at Noumea in the south eastern Coral Sea (Fig. 10) exhibits a large annual swing associated with the NW Monsoon in summer and the SE Trades in winter. In 1971 there was an exceptional lowering of MSL, indicating above normal SE Trades in the winter of that year. This corresponded to the peak in MSL at Anawa Bay and the peak in temperatures in the north eastern Coral Sea in the same year (Fig. 9). However, the peak in SST in the vicinity of Noumea didn't occur until 1973 (Fig. 1) several years after the marked increase in Trade Winds in 1971 (Fig. 10) which had very weak SE Trade Winds.

It is difficult also from the general distribution of SST and salinity in the western Equatorial Pacific (Fig. 11) to determine a possible origin of high enough temperature and low enough salinity water along the path of the SE Trades to account for the origin of the 1970 warm water low salinity anomaly in the north eastern Coral Sea. Wyrtki (1977) argues that the increased SE Trade Wind activity in the western Equatorial Pacific during 1970-1971 piled up equatorial water in the western end of the equatorial belt. These waters could contain warm and low salinity waters from an easterly region to the north of the Equator (Fig. 11) mixed with waters of similar characteristics from the extreme western region in the vicinity of the Equator (Fig.11). These waters could then flow eastward during the 1971 slump in the SE Trades (Fig. 9) along the Equator and to the south in the vicinity of the Solomon Islands. When the SE Trades increased in strength again in 1971-1972 (Fig. 10) these waters would be driven as above normal temperature below normal salinity waters into the western Coral Sea (Fig. 1).

CHANGES IN THE SBF TUNA FISHERY OF THE SOUTH WESTERN TASMAN SEA DURING THE PERIOD 1963-1977

The southern bluefin (SBF) tuna fished in the colder SST months in the western Tasman Sea are part of a migrating southern ocean stock that moves northward, in the southern winter, towards warmer waters (Shingu 1978). The SBF tuna in the Tasman Sea are intolerant of waters warmer than 21.1°C (Hynd 1968) but do not bite well above 20°C. The extent of their northward distribution pattern and their accessibility to fishing by pole and jig in any year therefore, is largely conditioned by oceanographic, particularly sea temperature, conditions.

The SBF tuna long line fishery by Japanese boats in the central Tasman Sea is concentrated in an area 30°-40°S, 150°-160°E (Fig. 1) and is largely a winter fishery. Within this area the yearly changes in catch per unit of effort in four sub-areas (1-4, Fig. 1) have been examined (Fig. 12).

The three warming events in the western Tasman Sea had some immediate response to all sub-areas but the major changes in the SBF tuna catches occurred over a longer time scale. These were most probably attributable to the longer term warming trends experienced particularly in sub-area 1 but to a lesser extent in sub-areas 2 and 3 also. In sub-area 1 for example (Fig. 2*d*) surface winter temperatures have increased in the 1966-1977 period by at least 3°C.

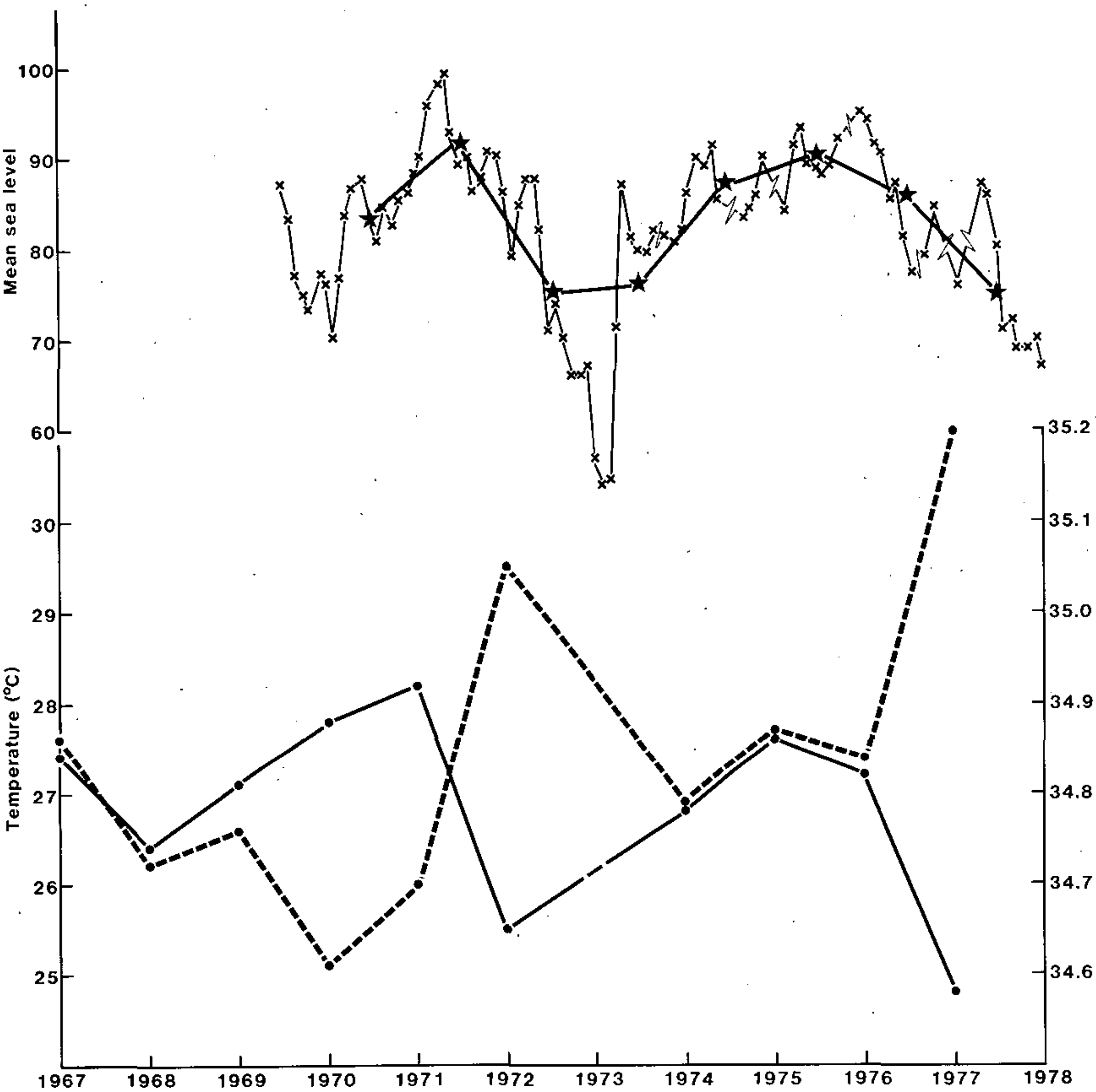

Fig. 9. Monthly changes in MSL from 1969-1977 at Anawa Bay (lat. 6°13'S - long. 155°38'E) X —— X (Wyrtki, pers. comm.) and mean annual changes ★——★. Mean winter SST •——• and salinity •---•, within the 1° square 13°-14°S, 161°-162°E, from 1967 to 1977.

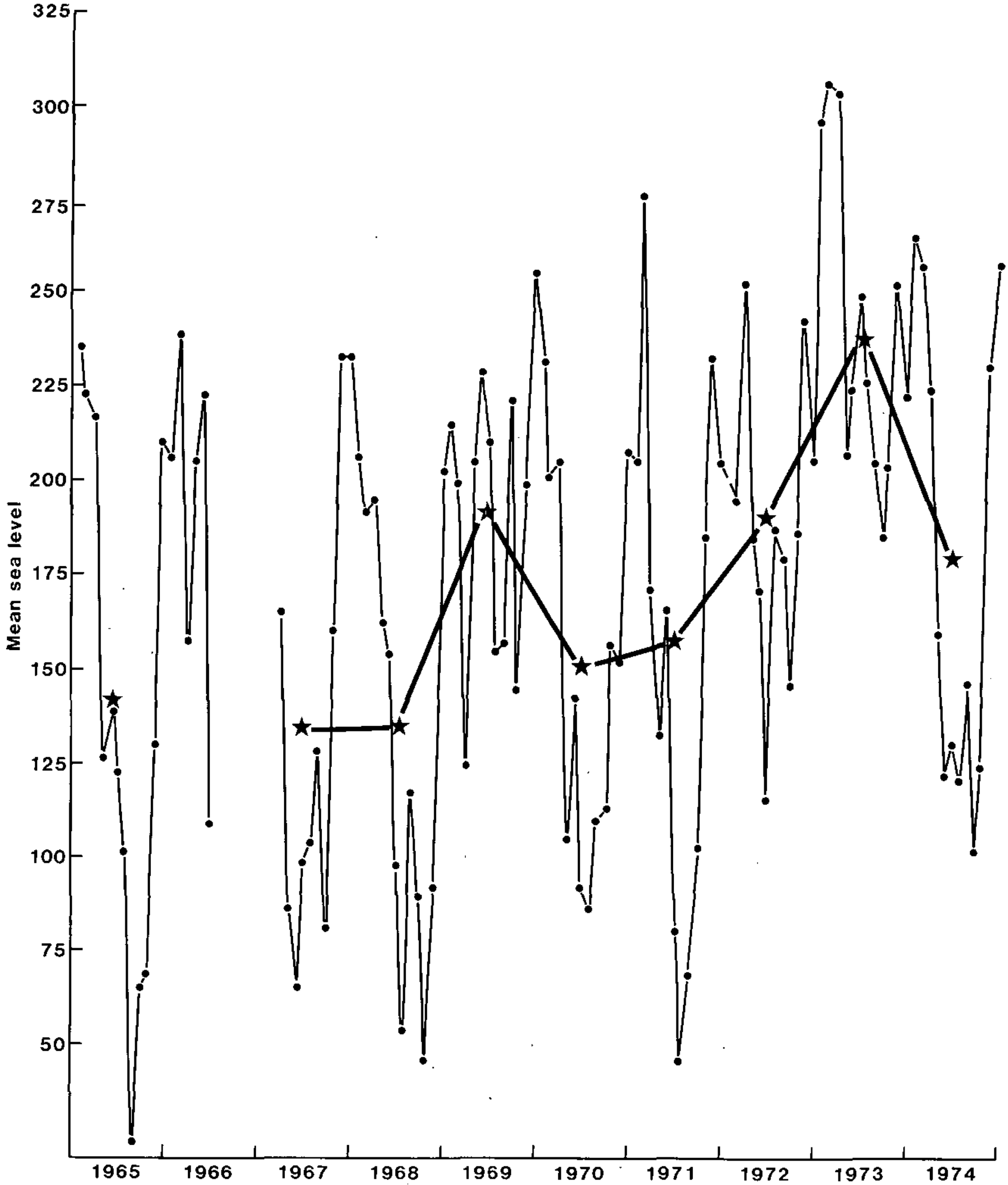

Fig. 10. Monthly MSL off Noumea, New Caledonia (lat. 22°18'S - long. 166°26'E) •——• and the annual means ★——★, 1965-1974.

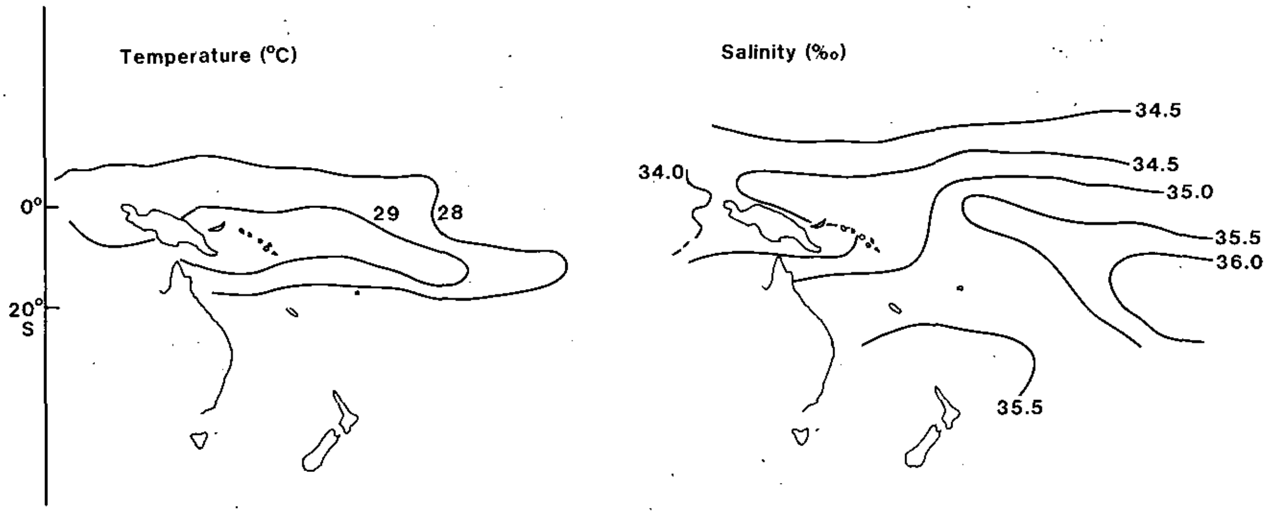

Fig. 11. The distribution of SST (°C) (January) and surface salinity (‰) (February) in the western Equatorial region of the Pacific (Gorshkov 1974).

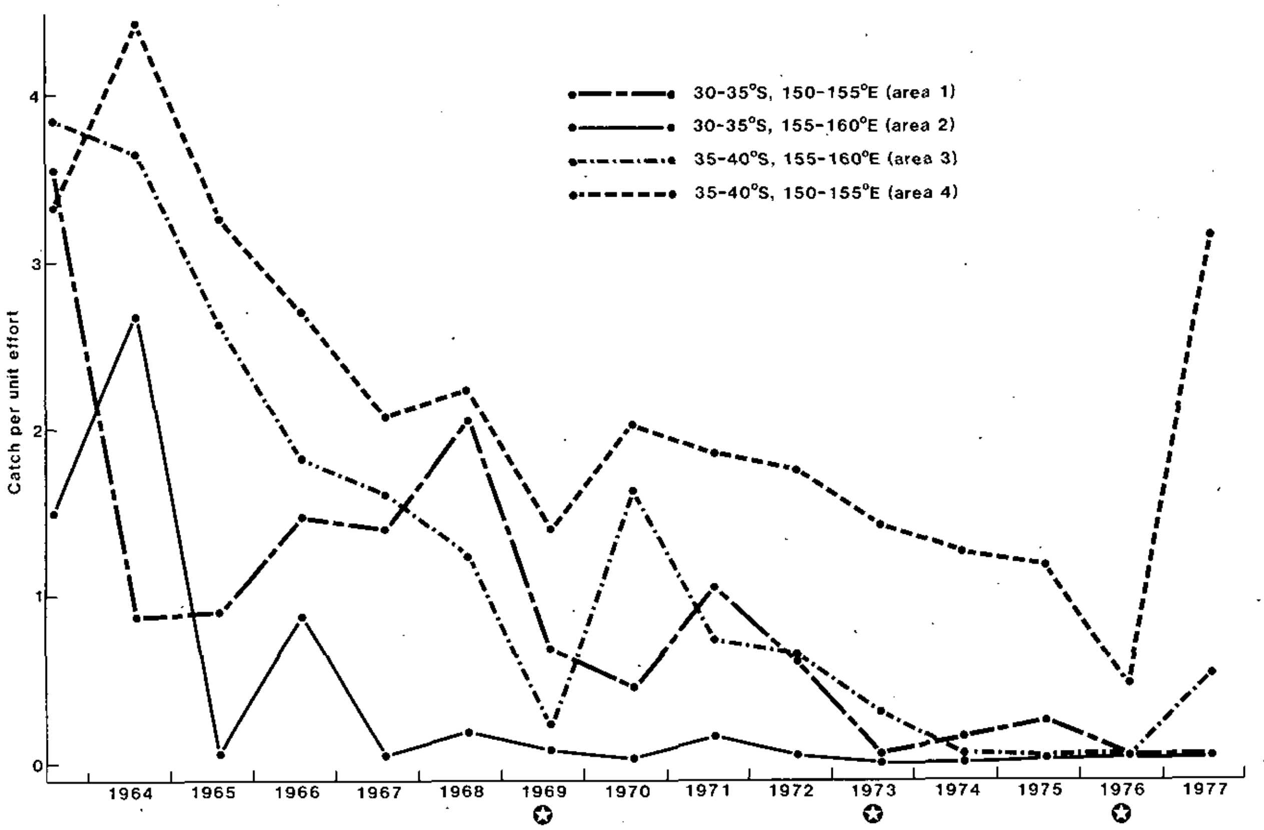

Fig. 12. Catch per unit effort (number of fish/100 hooks) of SBF tuna in the western Tasman Sea (areas 1-4, Fig. 1) 1963-1977. Data from Murphy (pers. comm.). ✪ Years of above normal winter SST in the western Tasman Sea.

In sub-areas 2 and 3 trends to higher temperatures have been in evidence from 1966 to 1977, but the overall increase in temperature has been of the order of 1°-2°C rather than the 3°C in sub-area 1. Sub-area 2 has had very poor SBF tuna catches from 1967 to 1977. Sub-area 4 whilst maintaining a significant fishery between 1963 and 1975 certainly suffered continued reduction in catch until 1977 when the catch increased considerably. The catch in sub-area 3 also increased in 1977. It is not considered likely therefore that the decline in the SBF tuna fishery during this period is solely attributable to fishing, as evidenced by the fact that the ocean wide catch in numbers has only declined by about one third in the period 1964-1977 (Murphy, pers. comm.). The decline is more likely to be caused by changes in the SST of the Tasman Sea affecting that part of the population of SBF tuna that migrates into the Tasman Sea during the winter and become largely inaccessible to fishing in sea areas of SST greater than 20°C (Hynd 1968). This temperature has been exceeded since 1970 in north western Tasman Sea waters (see Fig.2*d*).

The NSW pole fishery for SBF tuna is mainly confined to the southern and northern halves of sub-areas 1 and 4 respectively (Fig. 1) during the winter and spring. This fishery catches smaller size tuna than the Japanese long line fishery and only when the SBF tuna are responsive to catching at the surface. The amount of tuna caught per boat in this fishery appears to be largely a function of the local oceanographic conditions particularly SST and the presence of temperature fronts along which the tuna congregate (Hynd 1968). It is not possible in this fishery to calculate catch per unit effort since the number of boats is a function of the availability of tuna. Under these circumstances the total annual catch of SBF tuna in this fishery is considered a reasonable indication of the size of the stocks in the fishing area. (Murphy, pers. comm.).

The total annual catch of SBF tuna by this fishery has consistently declined in years of above normal winter SST in the western Tasman Sea between 1966 and 1977 (Fig. 13). In addition there has been an overall trend towards a lower annual catch since 1969, paralleling the cumulative increases in winter SST in the western Tasman Sea (Fig. 13).

Despite such associations however, the changes in the NSW catch can only provide supplemental evidence of the trends exhibited by the long line fishery in the same period (Fig. 12). It is considered significant however that the two sets of evidence do not disagree.

DISCUSSION AND CONCLUSION

The transport of a warm SST anomaly from the western Equatorial Pacific to the Tasman Sea necessitates the persistence of such an anomaly on a large scale for 2-3 years. Anomalies of SST have been traced in the northern Pacific to upward of 2 years (Namias 1970). Gentilli (1972) claims that SST anomalies in the eastern Indian Ocean off Australia are the result of transport over a two year period of SST anomalies from the Pacific. Wyrtki (1977) claimed at the most a two year interval between the increased eastward transport of the SST anomaly in the western Equatorial Pacific in 1970-1971 and the onset of the 1972 El Niño.

There doesn't appear therefore to be evidence for the persistence of SST anomalies for the longer time span (upward of three years) that is demanded in the case of the 1970-1973 warming event of this paper.

There are however special features associated with this SST anomaly in the western Equatorial Pacific, which lend support for its persistence during the longer three year time span required to explain the 1973 warming anomaly in the SST of the Tasman Sea.

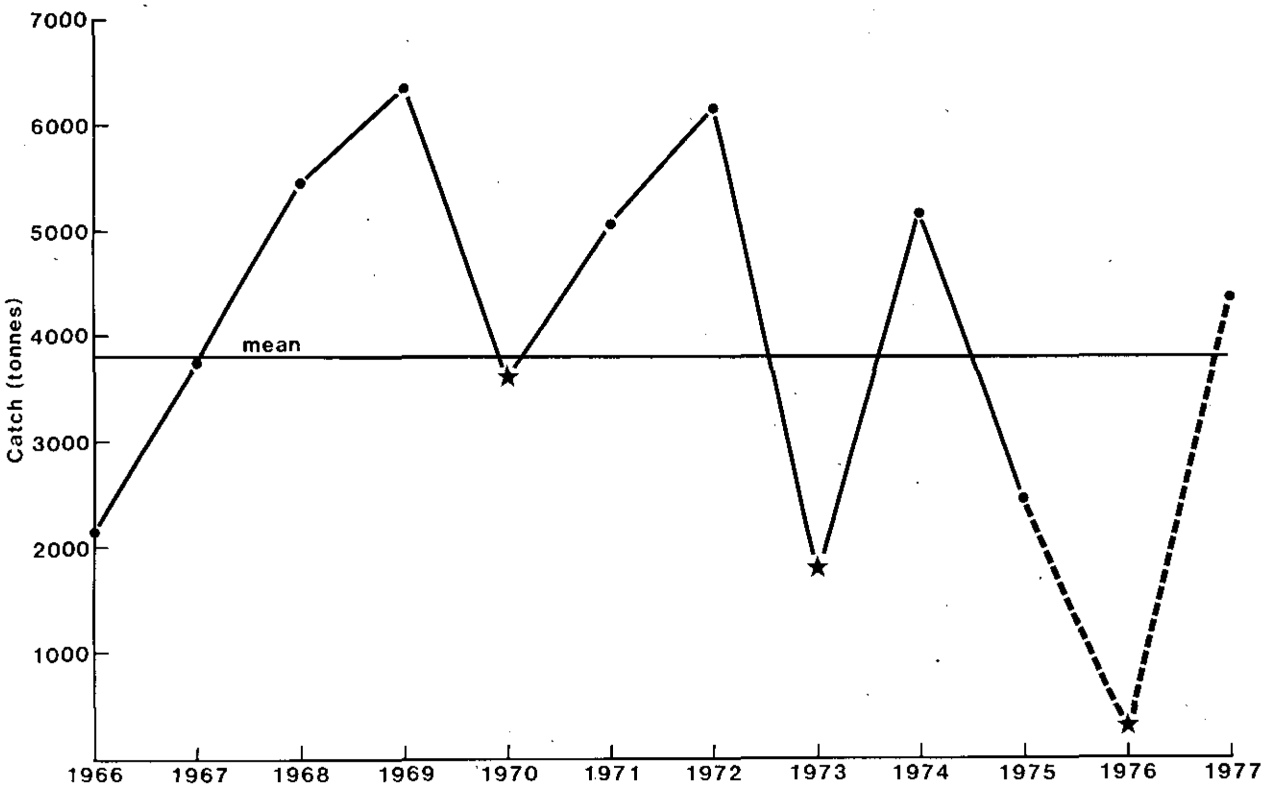

Fig. 13. The changes in total annual catch of SBF tuna by the NSW pole fishery 1966-1977. N.B. The 1976 catch was so poor that only an approximate value was recorded. ★ Years of anomalously warm winter SST.

These are:

(a) The temperatures associated with this anomaly were some 3°-4°C above normal (Hickey 1975).

(b) The increased temperatures in this anomaly were not restricted to the surface waters but extended to the depth of the thermocline (Hickey 1975).

(c) The area of ocean involved in this anomaly was considerable, creating in conjunction with (b) above a very large volume of anomalously warm water.

Trenberth (1975) claims that SST anomalies off eastern Australia are created by local weather patterns. This is most likely the explanation for small scale isolated occurrences but in the case of the 1970-1973 warming event the area involved and the magnitude of the increase in SST together with cumulative longer term increases in SST of 3°-4°C off northern NSW are considered beyond the scope of localised weather to generate.

Two other important issues are still unresolved. The first concerns the origin of waters of the requisite high temperature and low salinity to account for the observed changes in winter SST and salinity of the north eastern Coral Sea. Although it is possible to rule out an origin in a direction downwind of the SE Trades, the alternative origin in the western Equatorial Pacific cannot be substantiated. Information about SST and salinity in the western equatorial region during the 1970-1971 build up in MSL and of the currents to the north of Papua-New Guinea to transport such waters into the region off the north eastern Coral Sea is generally unavailable. This would be required to substantiate such an origin.

The second concerns the mechanism whereby periodic injection of more tropical waters into the north western Tasman Sea can lead to cumulative increases in SST by as much as 3°C in the period 1966-1977. One would expect that in between the three distinct warming events during that period there would have been dissipation of these warm waters by the East Australian Current. The most likely mechanism is provided by the warm core anticyclonic eddies that are a persistent feature of the East Australian Current system (Nilsson and Cresswell 1981). These have life cycles of one year or more and drift only slowly southward from an origin in the Coral Sea. These eddies could retain at subsurface depths, warmer waters trapped during a warming event, for some at least of the cooler dissipative years between such warming events. There is, however, insufficient information about the thermal history of these warm core eddies to decide how effictive they might be in this cumulative temperature effect.

Within these limitations evidence of this Report demonstrates:

(a) A major warming event in 1973 in the Tasman Sea was preceded by a warming event in the Coral Sea during 1970-1972. Other warming events of reduced magnitude occurred in the Tasman Sea in 1969-1970 and 1975-1976. There is limited evidence of minor warming events occurring in the Coral Sea prior to these years.

(b) The 1970-1972 warming event in the Coral Sea appeared to begin in 1970-1971 in the north eastern Coral Sea at the same time as the mean sea levels at Anawa Bay indicated an eastward flow during 1971 along the Equator of warm waters leading to the 1972 El Niño. There is insuffient knowledge of the currents of the north eastern Coral Sea and their connection with this eastward flow to conclusively link these two events together. However the possibility that they are connected must be considered highly probable.

(c) The large cumulative increases in SST of the western Tasman Sea between 1966 and 1977 and longer term (1946 to the present) off south eastern Tasmania (although of much smaller magnitude), indicates that the 1966-1977 data might span only part of a longer term trend in SST of the Tasman Sea.

(d) The observed decrease in the catch per unit effort in the long line SBF tuna fishery of the western Tasman Sea in the period 1963-1977 appears to be the result of cumulative rises in winter SST, creating an unfavourable temperature regime for their northward winter migration.

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