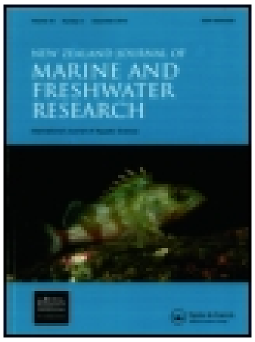

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Seasonal hydrological changes in continental shelf waters off the west coast, North Island, New Zealand, and comments on fish distributions

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ABSTRACT

Surface and subsurface temperature and salinity data were collected on eight trawling cruises along the west coast of the North Island of New Zealand, between January 1971 and March 1973.

Salinity ranges were more variable inshore than offshore, and geographical salinity variations were greater than seasonal changes. Temperature ranges were greater inshore than offshore, and at the surface compared with the bottom. Surface and bottom temperatures showed definite seasonal trends with maxima in January–March and a sharp drop between May and the minima in July. Bottom temperatures were more uniform in winter than in summer. Inshore bottom temperatures ranged from 17–20°c in late summer to autumn (March to May) to 12–13°c in winter (July to September). Summer maxima were similar along the entire coast, perhaps marginally higher in the north, while winter minima north of Cape Egmont were higher (14°c) than south of the Cape (12.5–13.5°c). Offshore, bottom temperatures at Ninety Mile Beach and Cape Farewell were similar to each other during summer and autumn at 14–16°c, but warmer at Ninety Mile Beach by 1–2°c during the rest of the year. Bottom temperatures at 100 m in North-west Trough (Cook Strait) were similar to those at adjacent inshore localities in winter and spring, but with a lower summer-autumn maximum.

Upwelling is regularly indicated along the coast, originating mainly in the top 100 m, but occasionally deeper. It may persist for 6-8 weeks in some areas.

Development of the summer thermocline is described; it occurred at 10–50 m in summer, 30–75 m in autumn. Variations in mixed layer depth, change of temperature, and rate of change of temperature through the thermocline are sufficiently large to preclude predictive equations.

The hydrological uniformity of this region, both in space and time, is reflected in the wide distribution of most demersal fish species. Annual variation in summer surface warming is associated with changes in distribution and abundance of juvenile albacore and southern bluefin tuna.

INTRODUCTION

There are few published data dealing with the hydrology of New Zealand's north-western shelf region, Cape Reinga to Cape Farewell, an area of considerable fisheries potential (Fig. 1). This area supports several local demersal trawl fisheries and has also been fished extensively by foreign longliners (both for bottom fish and tuna) and deep-sea trawlers. Since 1970 the area has also attracted a local fleet of albacore trolling vessels and a fleet of Japanese and Taiwanese squid boats. Since 1975 American and New Zealand purse-seiners have fished for skipjack (*Katsuwonus pelamis* L.) between Cape Reinga and Cape Egmont.

Because the hydrology of coastal waters is a factor influencing fluctuations in abundance, distribution and behaviour of commercial fishes, hydrological data were collected during a series of eight demersal trawling cruises off the north-west coast of New Zealand. Most of the cruises were in 1971, a year in which New Zealand experienced the highest summer temperatures in 110 y of climatological records (Gabites 1972). Although the data are not truly representative of "average" conditions, information collected in 1972 and 1973 cruises confirmed that a similar hydrological pattern existed in these latter summers but at lower temperatures.

In this paper we review the hydrological data collected on the cruises. These show seasonal changes in surface, midwater, and bottom temperatures, surface and bottom salinities, and in the depth and intensity of the summer thermocline. We also comment on fish distribution patterns. The hydrological data are presented more fully in Paul *et al.* (in press), together with the fish distribution data from the trawling survey.

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PREVIOUS STUDIES

Surface currents off the west coast of New Zealand are subtropical in origin and flow in a northerly direction (Heath 1974). There is drift-card evidence of the West Auckland Current carrying water southwards along the coast between Reef Point and Cape Egmont (Brodie 1960, Garner 1961) but conflicting data (Heath 1974) suggest that, at least sometimes, there is a northwards drift even in this area. Between Reef Point and Cape Reinga the predominant coastal current is north-westward in summer (Stanton 1973a). In Cook Strait, there is a persistent flow from north-west to south-east (the D'Urville Current). Stanton (1973b) showed that circulation off the west coast reflected variations in the East Australian Current, and its derivative, the Tasman Current.

Sea surface temperatures range between 22°c near Cape Reinga in summer and 13°c off Cape Farewell in winter; where the depth is about 100 m, bottom temperatures show little seasonal variation and range between 12°c and 14°c in both summer and winter (Garner 1961, 1969). In oceanic waters, typical sea surface salinities range from 35.8‰ in the north to 35.0‰ in the south, with lower salinities inshore associated with freshwater discharges from the land (Garner 1961, Stanton 1973a, b, Heath 1974). Bottom salinities show little seasonal variation within the range 35.1–35.6‰, with higher salinities in northern waters. Garner (1961) noted that near Cape Egmont salinity increased with depth to a maximum at the bottom. He suggested that low salinity surface water from northern Cook Strait was "flushed out past Cape Egmont" by the influx of D'Urville Current water in southern Cook Strait.

Several accounts of the hydrology and circulation of Tasman and Golden Bays (Heath 1969, 1971, 1973, Ridgway 1977) describe the movement of the D'Urville Current in this area, and the variable, wind-influenced circulation of water with basically subtropical characteristics in these bays.

Most previous hydrological studies have dealt with the Mid-Tasman Convergence north of New Zealand, the Subtropical Convergence to the south, and the oceanographic conditions along the west coast of the South Island and through Cook Strait. There is relatively little information on the shelf region between Reef Point and South Taranaki Bight.

Shuntov (1969) described movements of shelf fish species along this western coastline in response to seasonal hydrological changes. James (1975) described the distribution pattern of the jack mackerel *Trachurus declivis* Jenyns on the west coast of New Zealand, while Nosov & Shurunov (1975) related seasonal and annual variations to the hydrology of the shelf region between North and South Islands to the biology of this species. Roberts (1974a, b) has described the fishery for albacore *Thunnus alalunga* (Bonaterre) along New Zealand's west coast.

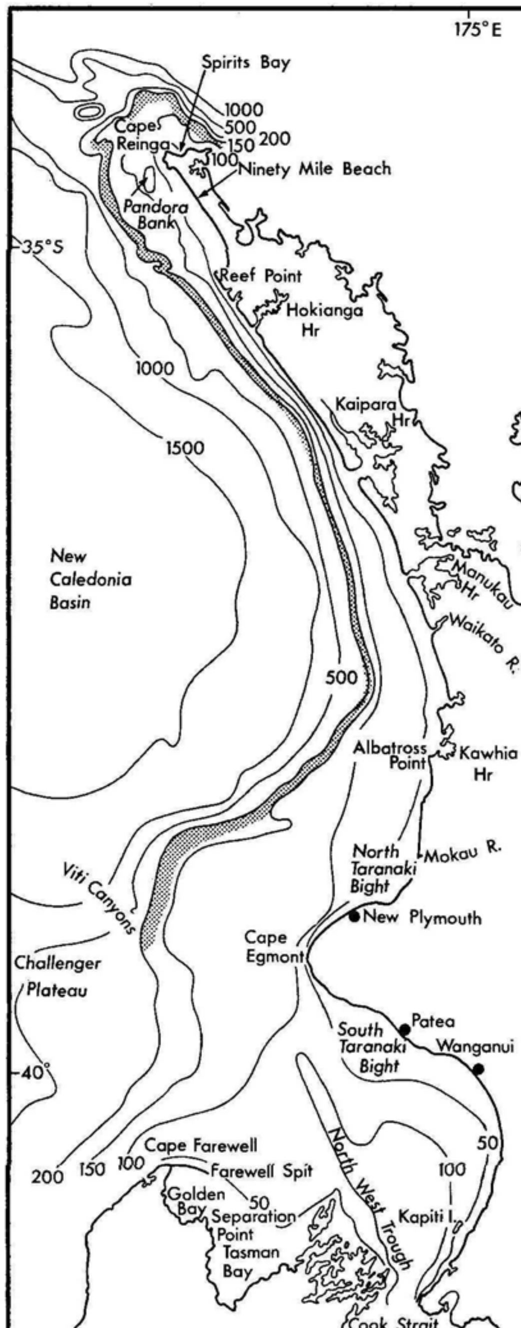


FIG. 1—Bathymetric map of the north-west coast of New Zealand (after Andrews & Eade 1973, McDougall & Brodie 1967, Summerhayes 1969). Depths in metres; approximate position of edge of continental shelf shaded.

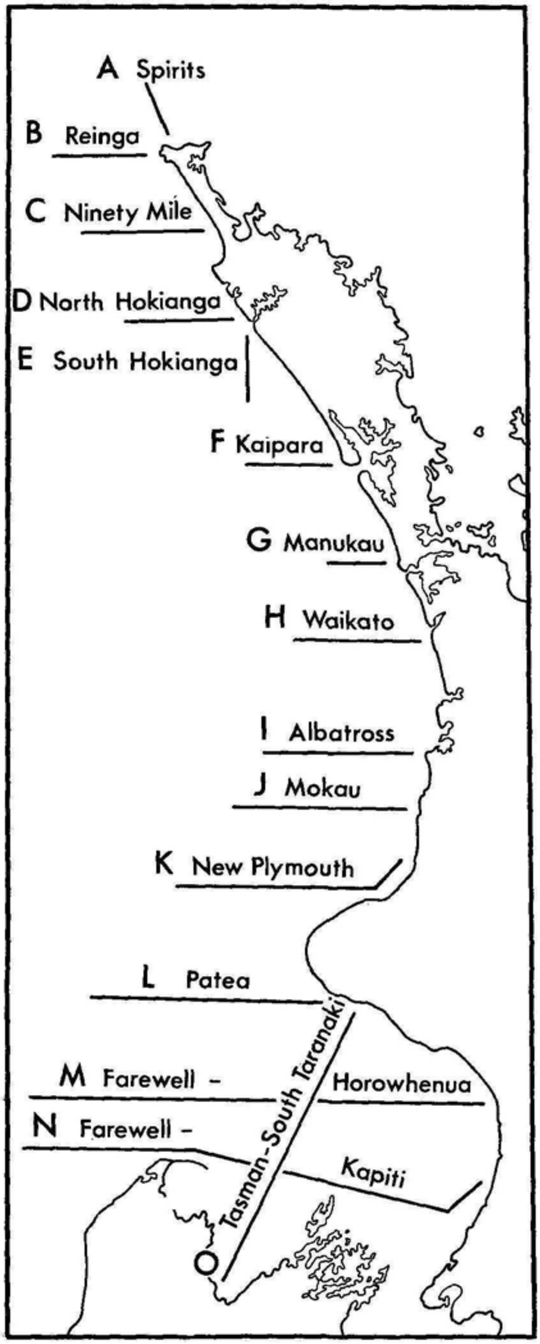


FIG. 2—Map of study area showing the lines along which hydrological stations were occupied, 1971–73. Not all transects were worked on each cruise; identifying letters (A–O) refer to Figs 7 and 10.

BATHYMETRY

The study area extends from Cape Reinga in the north to Cape Farewell in the south and from near shore depths of 10–20 m to the edge of the continental shelf. The shelf edge (Fig. 1) occurs at about 160 m off Cape Reinga (Summerhayes 1969). From Kaipara to Kawhia it lies between 130 and 145 m and is sharply defined, and towards Cape Egmont it is at 160–180 m and less distinct (McDougal & Brodie 1967). Between Cape Egmont and Cape Farewell the shelf edge is at 250–300 m and is poorly defined (Andrews & Eade 1973).

In the north the shelf is narrow and the outer portion is steeper than the inner; to the south it is wider (reaching almost 100 km from the coast at Cape Egmont) and the outer portion becomes less steep than the inner (McDougal & Brodie 1967). In the area between Cape Egmont and Tasman Bay (referred to below as north-west Cook Strait) the shelf is broad, relatively shallow, and flat or undulating; it steepens slowly westward to the Challenger Plateau and more rapidly south-eastward into the North-west Trough (Fig. 1).

Most of the shelf is smooth or undulating. There are considerable areas which cannot be worked by trawlers because of minor irregularities or obstructions on the sea floor, but there are few large shoals, reef systems, or submarine canyons. The most conspicuous shoals are Pandora Bank (near Cape Reinga) and shallow sand bars off harbours between Hokianga and Manukau.

METHODS

Temperature and salinity (T/S) data were collected from r.v. *James Cook,* a 550 t stern trawler, during a series of demersal trawl surveys on the continental shelf. Hydrological stations were usually worked after each trawl shot, with occasional intermediate stations between trawls. Stations were worked along east-west sections at approximately 1° latitude intervals between Cape Reinga and Cape Farewell, and along north-south sections in Cook Strait and Tasman Bay (Fig. 2). There were non-aligned stations in Golden Bay and near Separation Point, Tasman Bay. Extra lines of stations, also at 1° latitude intervals, were worked between the main lines of stations in January 1971 in association with a plankton sampling programme. On these occasions, extra midwater T/S data were obtained. Hydrological data were collected during six cruises between January 1971 and January 1972, in July 1972 (to replace a cancelled cruise in July 1971), and in March 1973.

Surface temperatures were measured with a mercury thermometer in a bucket-sample between January and May 1971, and thereafter with a hull-mounted continuous temperature recorder (accuracy ± 0.2°c). The surface temperatures were used to calibrate mechanical bathythermographs (accurate to ± 0.5°c), lowered at each station.

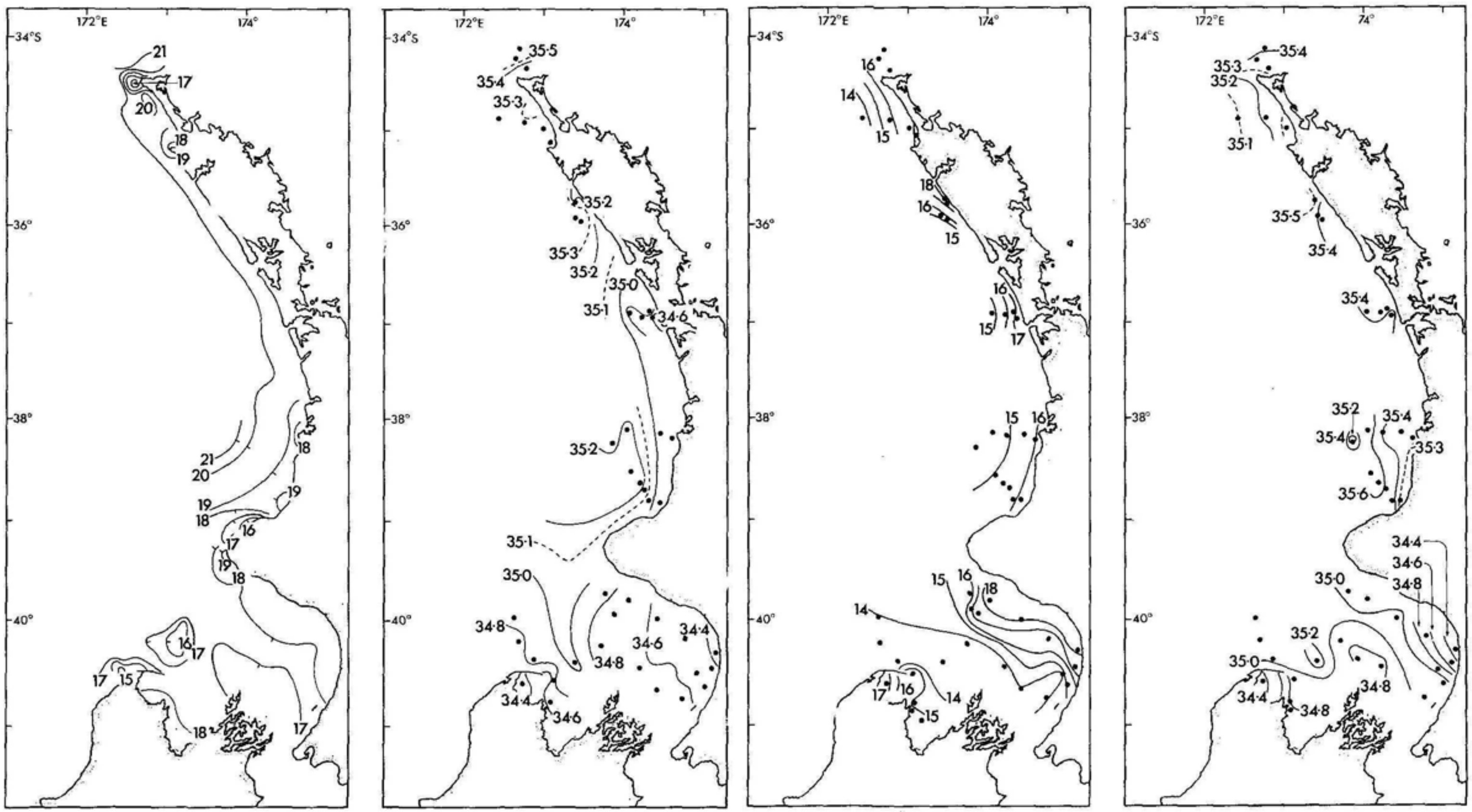


FIG. 3—*Left to right:* sea-surface isotherms (°c); sea-surface isohalines (‰); sea-bottom isotherms (°c); sea-bottom isohalines (‰); Cruise J1/72, 7–17 January 1972. Sea-surface isotherms drawn from continuous temperature records between station positions shown on surface isohaline map.

Mixed layer depth is defined as the depth to the upper boundary of the seasonal thermocline (Hela & Laevastu 1961). To allow discussion of seasonal changes in thermocline intensity, temperature and depth changes between the points of inflexion marking upper and lower boundaries of the thermocline were calculated to give the rate of temperature change through the thermocline (°C. m^{-1}).

Surface and bottom salinities were collected with Knudsen reversing bottles. The lower bottle was attached 3 m above the bathythermograph which was lowered to within 2 m of the sea bottom at shallow stations. "Bottom" salinities were thus collected 3–5 m above the substrate in shallow water. However, in deeper areas (100–200 m), because of tidal currents and wind, it was difficult to obtain bottom samples within 20 m of the substrate. Water samples were analysed within 5 weeks of collection in the Wellington laboratory on a Beckman inductive salinometer. Analyses are considered to be correct to ± 0.01‰ salinity, but evaporation from bottles used in May, September, and November 1971 reduced the accuracy of these samples to ± 0.1‰ salinity.

Temperature profiles are based entirely on bathythermograph records. Isotherms are usually placed at 1°C intervals except in winter when 0.5°C intervals are also used. Isohalines are usually plotted at 0.1‰ salinity intervals in oceanic water (over 34.8‰ salinity) and usually at 0.2‰ or 0.5‰ intervals of salinity in shore. Salinity-depth profiles were obtained on only one cruise, in January 1971, using Knudsen bottles at 0, 10, 50, 100, and 200 m depths. Sea floor profiles are generalised and based on depths at each station, and do not show small scale bathymetric features.

In this paper, the terms "off shore" and "deep" refer to areas or stations influenced by oceanic water; "in shore" and "shallow" refer to areas or stations normally affected by coastal dilution. There was no permanent line between "off-shore" and "in-shore" waters but the boundary was usually at a depth of about 75–100 m.

RESULTS AND DISCUSSION

GEOGRAPHICAL VARIATIONS

On the west coast north of Cape Egmont there was no evidence, in either surface or bottom temperature or salinity distributions (Figs 3 & 4), of north-south oriented tongues similar to those found by Garner (1961, figs. 2 & 3). Rather, the surface pattern in that area was of isolines parallel to the coast, indicating mixing between warm, high salinity oceanic water and cooler, low salinity coastal water.

One persistent feature in shelf hydrology south of Manukau Harbour (especially in the winter) was of low salinity surface water overlying higher salinity bottom water, a pattern also recorded by Ridgway (1977) in Tasman Bay. Lowered surface salinities, seen as tongues of water extending seaward from the mouths of rivers or harbours, obviously resulted from freshwater discharges (Figs 3 & 4). This feature is quite clear in the plots of sea surface and sea bottom salinity against time and latitude for in-shore stations (Figs 5 (left) & 6), at very shallow (< 20 m) and shallow (20–50 m) depths. But at deeper stations (> 85 m) surface salinities were usually higher than or about the same as bottom salinities (Fig. 5, right). The limited midwater salinity data collected in January 1971 indicated that this low salinity water (i.e., < 35.2‰) influenced coastal water to a depth of about 50 m (Fig. 7), and up to 95 km from the shore. Salinity profiles off Kaipara Harbour, Waikato River, and Mokau River show the low salinity water to overlie a core of water with a maximum salinity of 35.4‰ at 50–150 m depth.

This core of oceanic water, which had presumably sunk below less dense water flowing from the shore, possibly represents an undercurrent flowing southwards. Such phenomena are not unexpected in eastern boundary current regions (see Stanton 1971, p. 150). The 35.4‰ salinity water was present at the surface at northernmost stations (Reinga, Hokianga) but was not apparent at southern stations (Farewell) and may represent the West Auckland Current, an ephemeral surface feature (Heath 1974). In surface in-shore waters, very low salinity water (< 35‰) developed in May at about the latitude of Cape Egmont and was evident further northward during winter and spring (Fig. 5, top left). There was a similar effect apparent in bottom in-shore waters (Fig. 5, bottom left) but restricted to winter months when freshwater inflow and vertical stability are minimal. The low salinity feature is less evident at the surface further off shore, (Fig. 5, top right), and is absent in off-shore bottom waters (Fig. 5, bottom right). As the low salinity layer was first evident near Cape Egmont and spread northward over the shelf, it probably results from northward displacement of low salinity Cook Strait water by D'Urville Current water further south, as suggested by Garner (1961). However, the salinity maps (Figs 3 & 4) show that a considerable amount of freshwater also flows from west coast harbours, bays, and rivers, and this low salinity water would mix with, and modify, displaced Cook Strait water, and spread westward and northward across the North Taranaki shelf.

The D'Urville Current is sometimes apparent in maps of both surface and bottom salinity as a tongue of high salinity water (35.0–35.3‰) originating in the west or north-west. Also, it is sometimes distinguished in surface temperature maps but not in bottom temperature maps. The D'Urville Current appears to vary in its points of entry into Northwest Cook Strait, sometimes penetrating along the South Taranaki coast (November 1971, July 1972, March 1973), sometimes in the central region (January 1971), and sometimes across the top of Tasman Bay (January 1972). Tongues of high salinity water protruding landward near Cape Egmont (in January and May 1971) indicated that the D'Urville Current may sometimes branch off the Tasman Current at about this latitude.

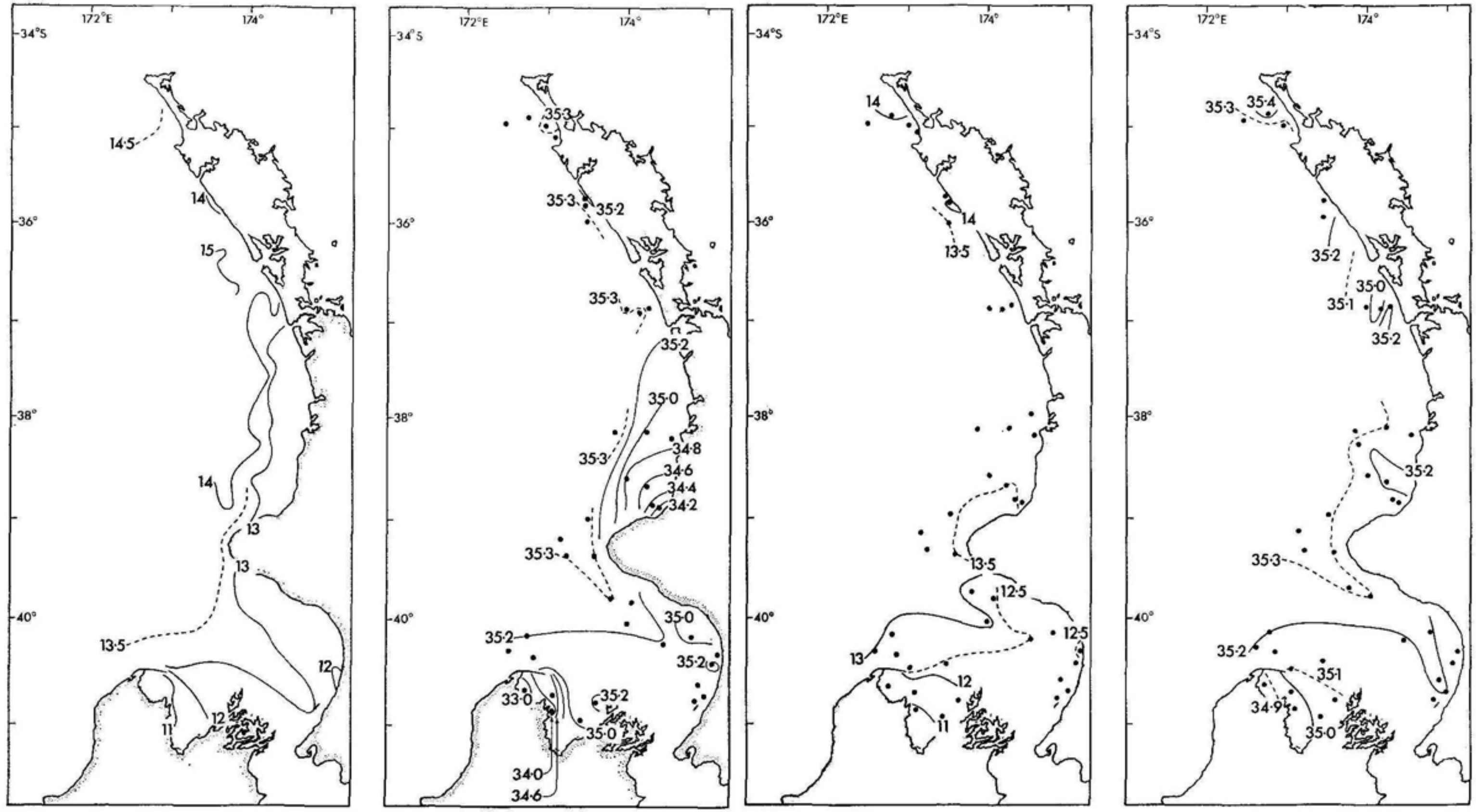


FIG. 4—*Left to right:* sea-surface isotherms (°c); sea-surface isohalines (‰); sea-bottom isotherms (°c); sea-bottom isohalines (‰); Cruise J10/72, 25 July–5 August 1972. Sea-surface isotherms drawn from continuous temperature records between station positions shown on surface isohaline map.

Bottom salinities showed two consistent patterns, neither of which were seasonal in nature. The first feature was of higher salinities in the north and lower salinities in the south. Bottom salinity maps also show a tongue of relatively high salinity water (35–35.2‰) extending along the South Taranaki Bight, probably representing the D'Urville Current. As at the surface, the position of the core of the tongue varied from cruise to cruise. Significantly, the surface and bottom tongues of high salinity intrusions usually coincided in position and month, indicating that transport in the D'Urville Current occurs throughout the water column.

An area of high salinity surface water (35.2–35.5‰) near Kapiti Island in May 1971 was not derived from the north, and possibly represents an intrusion of East Cape Current water through southern Cook Strait. Plots of sea surface salinity against latitude and time (Fig. 5, top left) also indicate the intrusion of a tongue of water from the south (rather than the north) along the Kapiti coast in May 1971.

Individual stations showed marked between-cruise fluctuations in salinity that were not seasonal but related to the degree of penetration of oceanic water or freshwater influence. This effect was most noticeable in shore (e.g., Golden Bay, Kapiti Island, New Plymouth, Albatross Point) where salinity fluctuations of up to 2.5‰ were recorded from one cruise to the next. Further off shore, fluctuations were a feature of North-west Cook Strait and South Taranaki Bight stations, reflecting the varying influence of high salinity D'Urville Current water from the west and of low salinity water usually present in Cook Strait.

SEASONAL CHANGES

Annual ranges of sea surface and bottom temperatures and salinities are summarised in Table 1: the temperature range was greater in shore than off shore, and greater at the surface than at the bottom. Typical ranges at individual stations were 6–10°C at the surface and at the bottom in shallow waters, but only 1.5–2.5°C at the bottom where the depth was greater than 75 m (Figs 8 & 9).

TABLE 1—Annual ranges of sea surface and sea bottom temperatures and salinities for shelf waters, north-west coast of New Zealand.

		Maximum	Minimum	Range
Temperature (°C)				
Surface	off shore	22.5	13.5	9.0
	in shore	22.0	10.2	11.8
Bottom	off shore	16.0	12.0	4.0
	in shore	21.5	10.8	10.7
Salinity (‰)				
Surface	off shore	35.6	35.0	0.6
	in shore	35.4	32.5	2.9
Bottom	off shore	35.5	35.0	0.5
	in shore	35.5	34.3	1.2

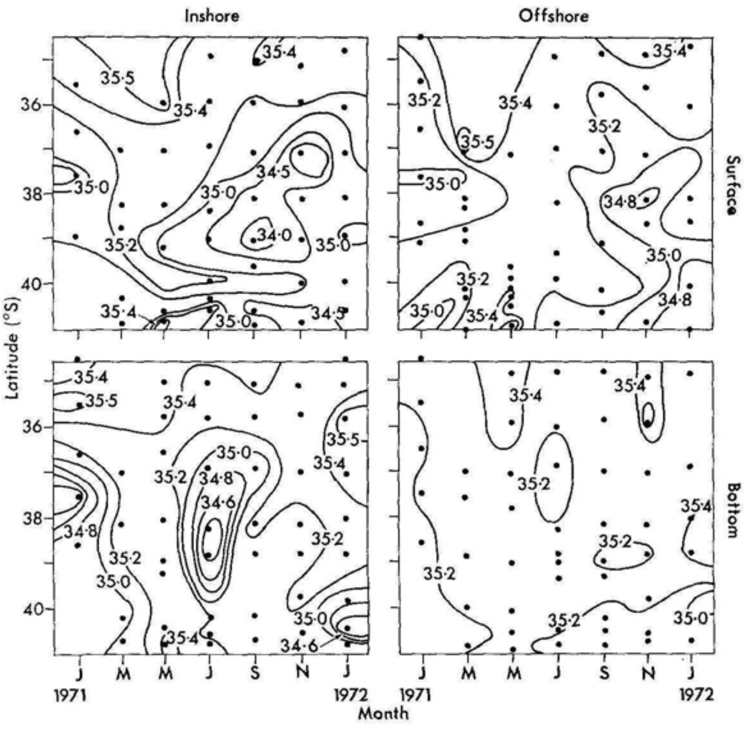


FIG. 5—Seasonal and latitudinal variation of sea-surface and sea-bottom salinity (‰) at in-shore and off-shore stations. *Note*: July data were collected in 1972.

Surface and bottom temperatures both showed definite seasonal trends. At the surface, temperatures peaked in January-March and reached a minimum in July. Bottom temperatures showed a similar trend, except that in some areas they continued to rise through autumn (May) before dropping rapidly to a winter minimum. In midwinter, sea bottom temperatures were often higher than at the surface. In July 1972, 40 stations were occupied; of these, 14 stations were over 0.5°c warmer at the bottom, 21 stations showed generally isothermic conditions, and only 5 (offshore stations) were warmer at the surface.

Seasonal changes in the subsurface temperature distribution in relation to latitude and depth are shown in the temperature section for midsummer (January 1972) and midwinter (July 1972) in Fig. 10.

At the sea bottom in summer (Fig. 3) temperatures were high in shore (to 22°c) and low off shore (13–14°c at 150–200 m) giving a pattern of isotherms parallel to the coast, that is, related to the bathymetry. In-shore water cooled during autumn so that by winter (Fig. 4), in-shore and off-shore sea-bottom temperatures were similar (12–14°c throughout the study area), and isotherms tended to parallel the lines of latitude.

Surface and bottom salinities at individual stations did not follow consistent seasonal trends (Fig. 6). In some shallow areas (e.g., Golden Bay) there was a winter–spring minimum at the surface, reflecting

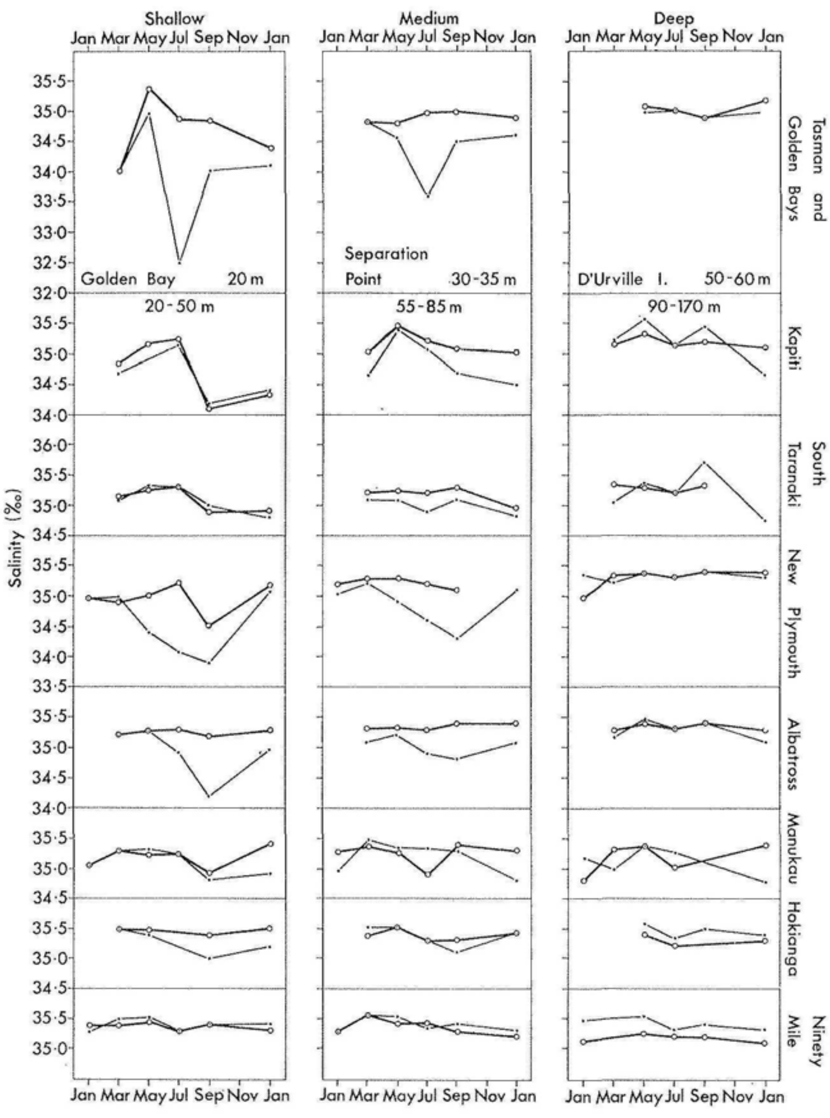


FIG. 6—Seasonal changes in sea-surface and sea-bottom salinity (‰) at selected stations along the north-west coast of New Zealand, January 1971–January 1972 and July 1972. Surface data indicated with thin lines, bottom data with heavy lines.

increased freshwater influence, but this was not apparent off shore, and only rarely at the bottom in shore. In shore, salinities were more variable than off shore, and surface salinities more variable than those at the bottom in shallow areas. However, there was only a small annual range in off-shore surface or bottom salinities (Table 1, Figs 5 & 6).

UPWELLING

Steeply rising isohalines (Fig. 7) and isotherms (e.g., Fig. 10) toward the coast in the salinity and temperature profiles indicate that upwelling occurred in summer on the west coast, where it is probably wind-induced (Stanton 1973a). As pointed out by Stanton (for the north-western part of the North Island) the upwelling seems to be mainly in the top 100 m, but occasionally it originates from greater depths. For example, our January 1971 profiles off Cape Reinga show isohalines tilted from below 200 m (Fig. 7) although isotherms were tilted from 80–150 m. Stanton (1973a) visited this area in March 1971, and his profiles show that the upwelling also occurred then, although it was limited to shallow depths.

Upwelling was apparent in temperature or salinity profiles in January, March, or May 1971 off Spirits Bay, Cape Reinga, Manukau, Albatross Point, New Plymouth and in central Cook Strait. Further evidence of upwelling was seen in the presence of low surface temperature and salinity areas in the distribution maps for January 1972 (Fig. 3, left). These occurred at Cape Farewell, north of Farewell Spit, Cape Egmont, Reef Point, and Cape Reinga. The upwelling at Cape Egmont was still present in early February 1972, but had disappeared by the end of February (Roberts 1974).

The hydrology off Cape Farewell appears to be more complicated than further north. In January 1971, low salinity surface water at stations 20–50 km from the coast (Fig. 7) was part of a water mass of minimum salinity 34.8‰ not connected to the subsurface water mass further off shore. This low salinity water was probably derived from river outflow mixed with oceanic water and carried to greater depths by vertical turbulence. However, the temperature profile for this area in January 1971 indicates upwelling from 60–80 m. These conflicting data indicate that this area is of some hydrological interest, and warrants further study.

THERMOCLINE DEVELOPMENT

By late spring (November), a seasonal thermocline was present (Fig. 11) at most stations (87% of in-shore stations less than 50 m depth and all off-shore stations). The thermocline depth was 5–25 m (mean 11 m) in shore and 3–66 m (mean 18 m) off shore. The change in temperature through the thermocline was less than 3°c with a rate of change of temperature generally between 0.08–0.40°c. m^{-1} (but with occasional highs of up to 1.0°c.m^{-1} in shallow water).

By January, the thermocline had increased slightly in depth and intensity with individual stations showing a 6°c change through the thermocline. In January 1971 a secondary thermocline was present within the upper mixed layer at many stations, giving a stepped appearance to bathythermograph traces. Changes in this secondary thermocline were up to 2.8°c with a rate of change of 0.65°c. m^{-1}. Secondary thermoclines were less numerous in January 1972.

By March, isothermal conditions prevailed at about one-third of the in-shore stations (Fig. 11). The

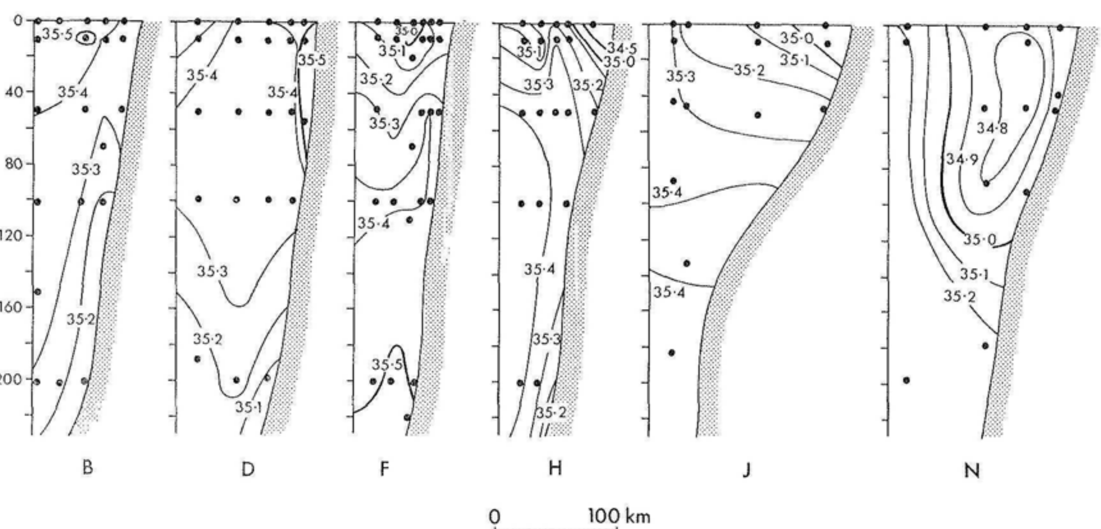


FIG. 7—Salinity (‰) : depth (m) profiles along east–west transects, north-west coast of New Zealand, January 1971.

thermocline had moved deeper. Temperature change through the thermocline had lessened in-shore but remained about the same off-shore, compared with January. Also the rate of change of temperature through the thermocline had decreased in-shore but was about the same off-shore.

By May, nearly isothermal conditions prevailed at 90% of in-shore and 30% of off-shore stations with lower temperature changes through the thermocline, presumably resulting from autumnal turbulence.

The summer thermocline was completely broken up by July when isothermal conditions, sometimes with slight positive gradients (i.e. warmer at the surface) prevailed over the continental shelf. At in-shore stations south of 38°S, a shallow temperature inversion of 0.5–1.0°c was apparent, resulting in warmer bottom waters, but by September winter and spring storms had destroyed this shallow cold layer leaving isothermal water or a slight negative gradient from surface to bottom.

Garner (1961, 1969) and Stanton (1973a) have briefly mentioned the thermocline as being present at between 20–50 m in summer and 70–100 m in autumn. The data collected in 1971–73 show that during prolonged calm periods the mixed layer depth can be shallower than normally expected (i.e., 10–50 m in January and 30–75 m in May). The depth of water of mainly isothermal characteristics above the thermocline varies considerably from area to area within any month. These variations (in mixed layer depth, change of temperature, and rate of change of temperature through the thermocline) were so great as to make predictive equations meaningless. The "mean" conditions shown in Fig. 12 indicate that the mixed layer depth increases with increasing bottom depth and deepens with the onset of autumnal mixing. Apart from this depth effect, there were no discernible differences within cruises, in mixed layer depth or thermocline characteristics between Cape Reinga and Tasman Bay.

HYDROLOGY AND FISH MOVEMENTS

The effects of the very settled weather and sea conditions in 1971 were reflected in the distribution, species composition, and size composition of tuna stocks off the west coast. From January to April 1971, New Plymouth fishermen trolling for albacore, *Thunus alalunga* (Bonnaterre), located schools of fish near shore within 80 km of their home port. However, in January 1972, with local surface cooling near Cape Egmont (interpreted above as the result of upwelling), albacore remained in the New Plymouth area for only about 3 weeks; thereafter they were found in abundance only between Albatross Point and Kaipara Harbour, where vertical stratification was more stable (Roberts 1974b), and where nutrient enrichment from river and harbour run-off presumably resulted in consistently high production of albacore food items.

There were two other major differences in the trolling catch in 1971 compared with the previous

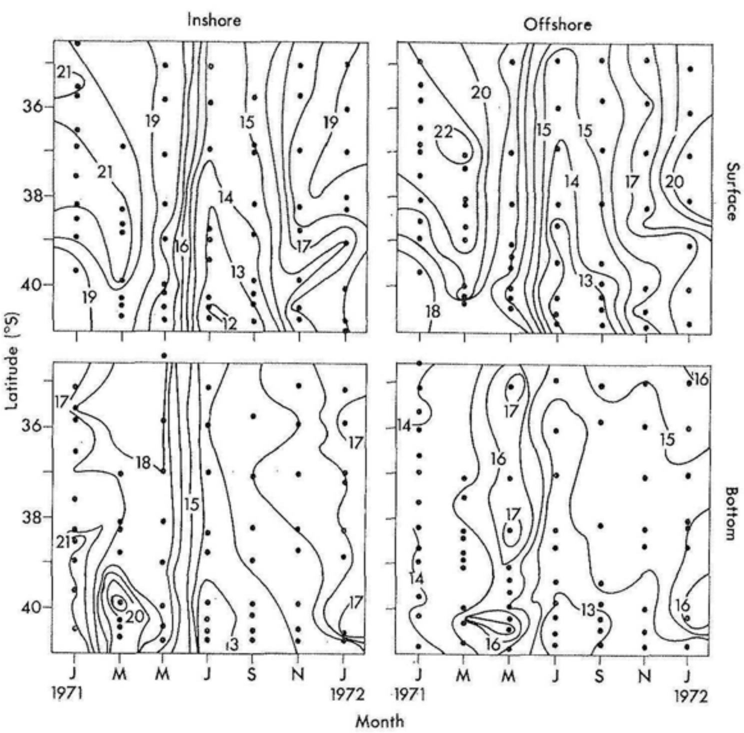


FIG. 8—Seasonal and latitudinal variation of sea-surface and sea-bottom temperature (°c) at in-shore and off-shore stations. *Note*: July data were collected in 1972.

summer. Firstly, large numbers of southern bluefin tuna *Thunnus maccoyi* (Castelnau) were caught along with albacore. The southern bluefin were immature 2–3 y old fish (7–10 kg fresh weight), usually recorded only near the Australian coast (Shingu & Hisada 1971), and not reported since 1971 in New Zealand waters. Secondly, fishermens' logbooks from New Plymouth show that the average weight of albacore caught in 1971 was lower than in 1970, indicating a predominance of fish in the 1+ and 2+ age groups. In 1971 small albacore were also abundant off Fiordland and Foveaux Strait, whereas they

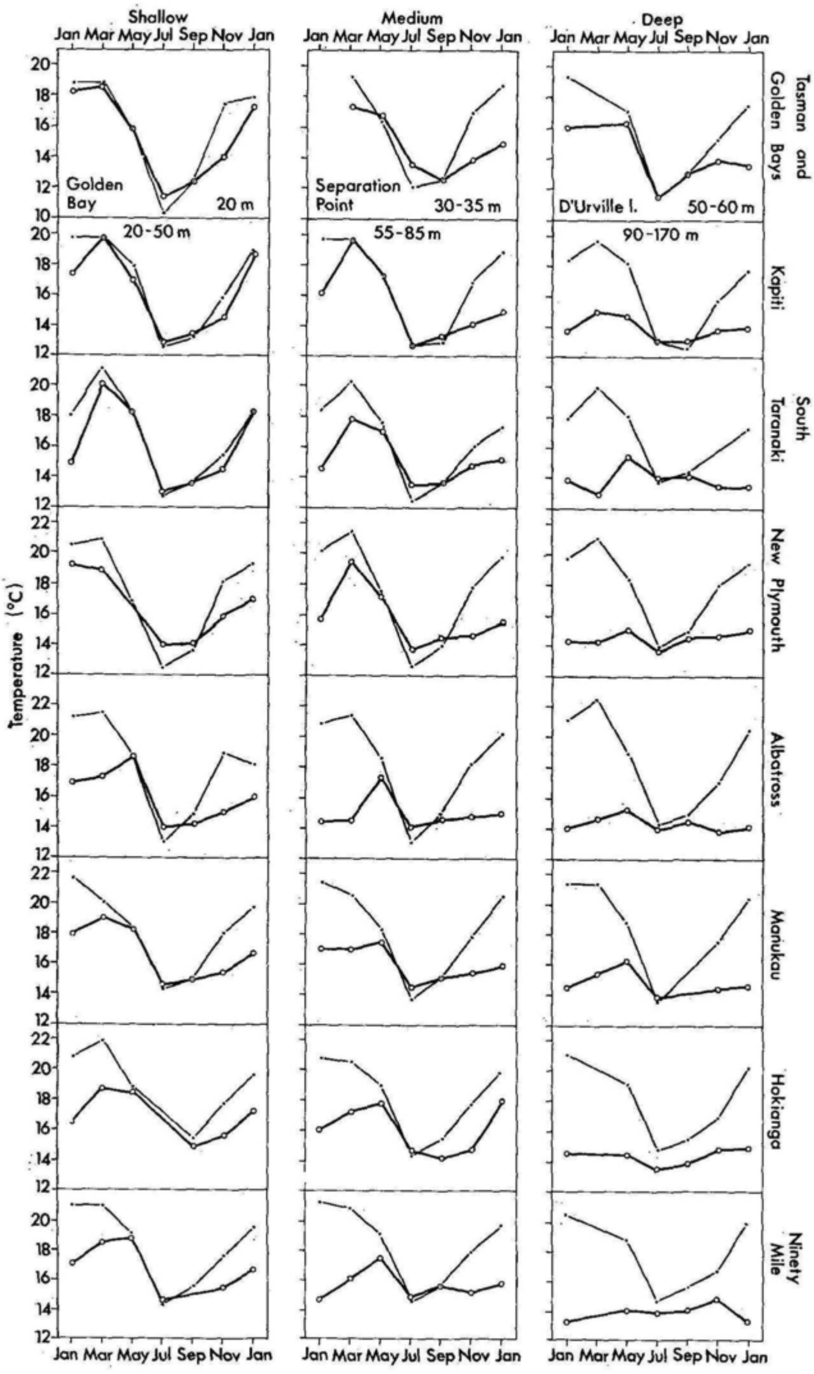
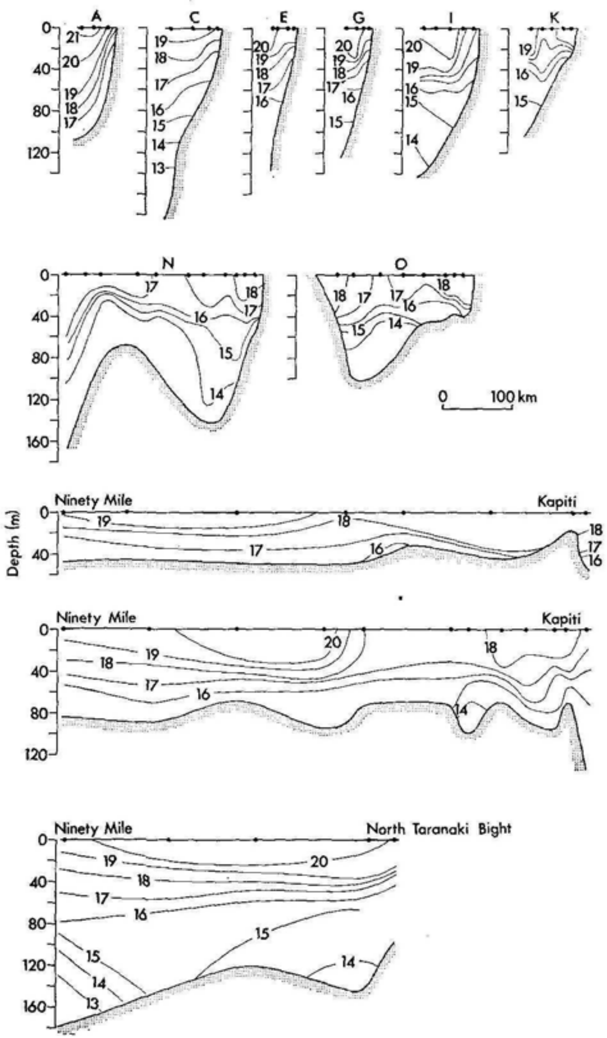


FIG. 9—Seasonal changes in sea-surface and sea-bottom temperature (°c) at selected stations along the north-west coast of New Zealand, January 1971–January 1972 and July 1972. Surface data indicated with thin lines, bottom data with heavy lines.



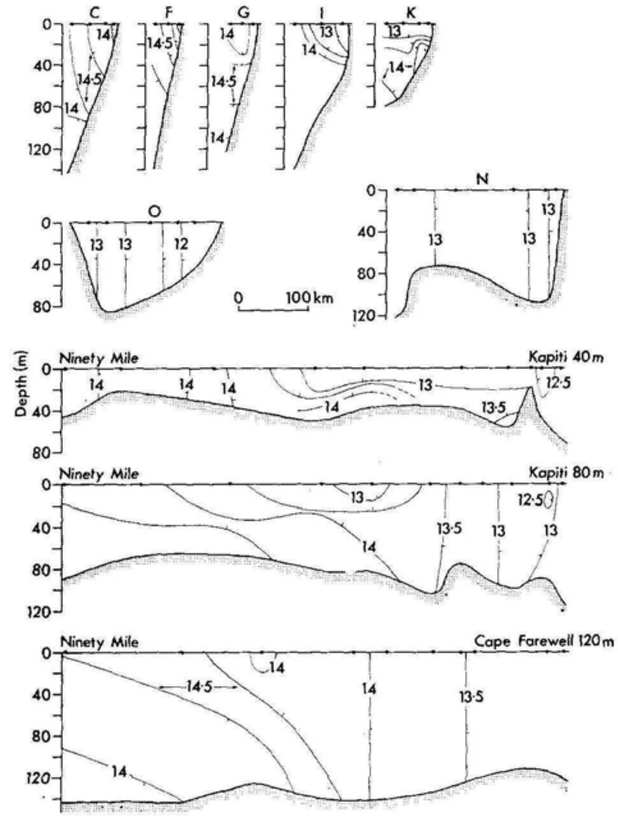


FIG. 10—Temperature (°C) : depth (m) profiles along east-west transects (*upper*) and north-south transects (*lower*); *Left*: Cruise J1/72, 7–17 January 1972; *Right* (*above*): Cruise J10/72, 25 July–5 August 1972.

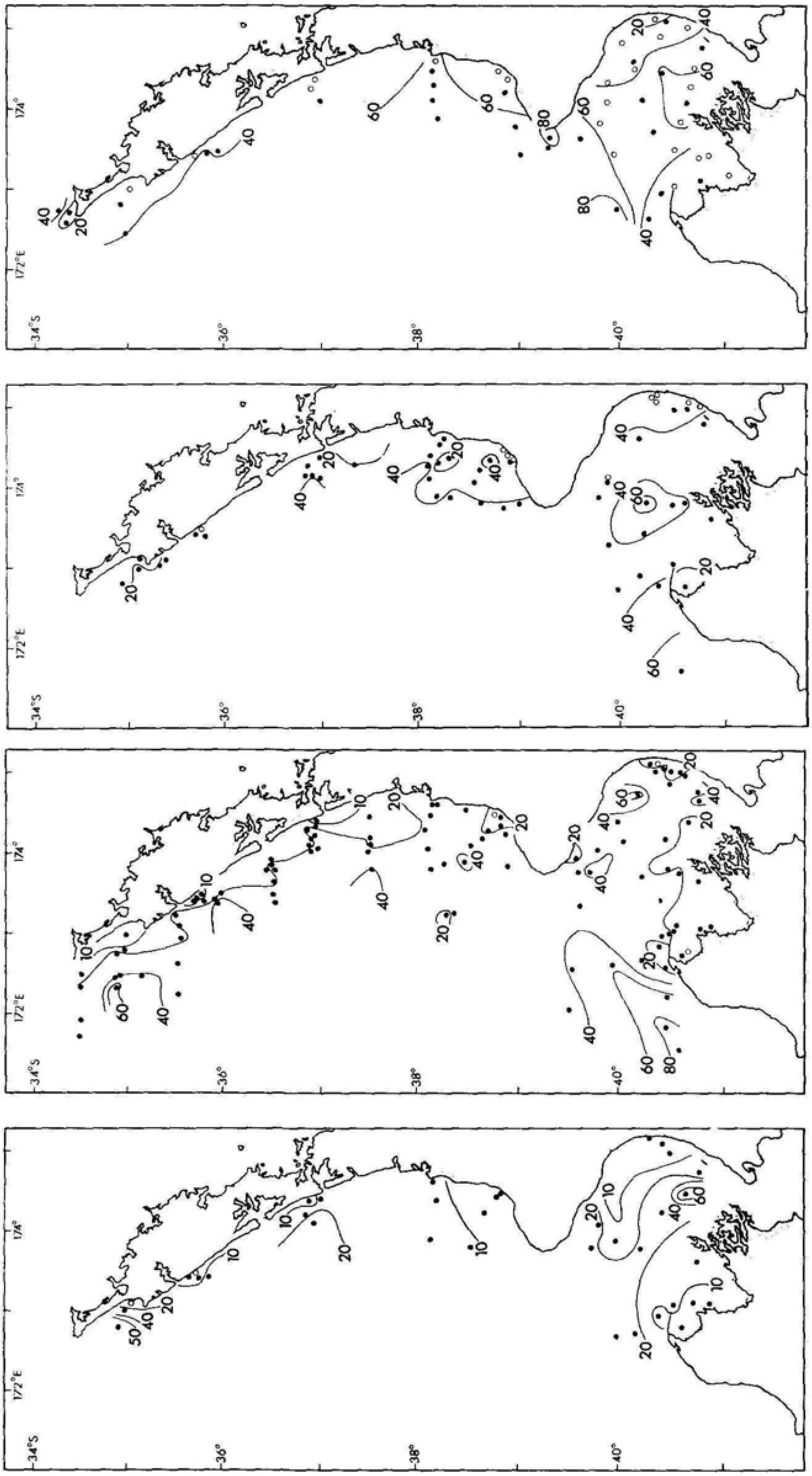


FIG. 11—Depth of the mixed layer (m) above the thermocline along the north-west coast of New Zealand in (*left to right*): November 1971; January 1971, 1972; March 1971, 1973; and May 1971. Stations with no thermocline indicated with a hollow circle.

normally do not migrate south of Cape Foulwind, approximately 500 km further north (Roberts 1974a).

Detailed data on the commercial catches of most demersal species are not available to us. However, monthly landings of the most important species snapper *Chrysophyrys auratus* (Forster), grouped into six statistical fishing areas between Cape Reinga and Tasman Bay, are available for 1960–1974 (Ritchie *et al.* 1975, Ministry of Agriculture and Fisheries, unpublished data). Neither the quantity of snapper caught per area, nor the timing of peak catches (spring in the north, spring and/or autumn in the south), showed 1971 to be different from other years.

The catch data for demersal fish collected during the trawling cruises (Paul *et al.* in press), have been analysed, but it is beyond the scope of this paper to provide a correlative synthesis of hydrology and fish species distribution and abundance. However, some generalisations can be made.

Few of the 85 fish species recorded showed any distribution pattern which could be correlated with hydrological conditions. This is perhaps not surprising in view of the hydrological uniformity of the North Island's west coast, where most of the water is derived from the Tasman Current. Some species were taken in moderately deep water along the shelf edge, where temperature might have been a limiting factor, but their occurrence was too irregular for a clear analysis. Other irregularly occurring species were obviously off-bottom or pelagic species fortuitously caught while the net was being hauled up. A large number of species were taken in most shelf depths over the entire region. Some of these have distributions apparently governed by the bottom substrate, e.g., the leatherjacket *Navodon scaber* (Forster), and porcupine fish *Allomycterus jaculiferus* (Cuvier) were taken in greatest numbers where bryozoan and shell remains were present. Others were quite uniformly distributed over a particular depth range; important commercial species in this group include tarakihi *Cheilodactylus macropterus* Forster, barracouta *Thyrsites atun* (Euphrasen), and red gurnard *Chelidonichthys kumu* (Lesson & Garnot).

A few species had either distinctly northern or southern distributions. Two northern outer shelf species were the longfinned boarfish *Zanclistius elevatus* (Ramsay and Ogilby) and the spotted gurnard *Pterygotrigla picta* (Gunther). The two most strongly southern species were red cod *Physiculus bachus* Forster and elephant fish *Callorhinchus milii* Bory de St Vincent, which occurred only in Tasman Bay and around Kapiti Island. The warehou *Seriolella brama* (Gunther) also had a southern distribution, with small numbers occurring north to Manukau on occasions.

The distributions of several fish species were plotted against bottom temperature and salinity for two summer (March 1971, January 1972) and two winter (September 1971, July 1972) cruises. Six species, commercially important in the area (snapper, trevally, tarakihi, barracouta, red gurnard, and jack mackerel (*Trachurus declivis* (Jenyns) and *T. novaezelandiae* (Richardson) and seven less important species with restricted distributions (scaled gurnard *Lepidotrigla brachyoptera*, Hutton, spotted gurnard, longfinned boarfish, red cod, elephant fish, northern dogfish *Squalus blainvillei* (Risso), and southern dogfish *S. acanthias* L.), were considered. As anticipated from their geographical distribution and abundance, most showed either no relationship to temperature and salinity within the range of values examined, or were too sparsely distributed to reveal clear patterns. The "northern" and "southern" species were,

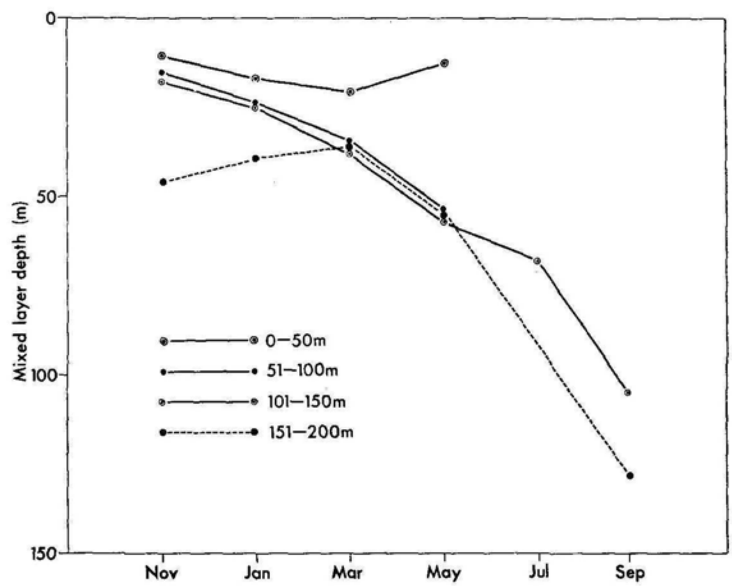


FIG. 12—Seasonal variation in the mean depth of the thermocline (m) by bottom depth (m), for all stations combined, north-west coast of New Zealand, January 1971–March 1973.

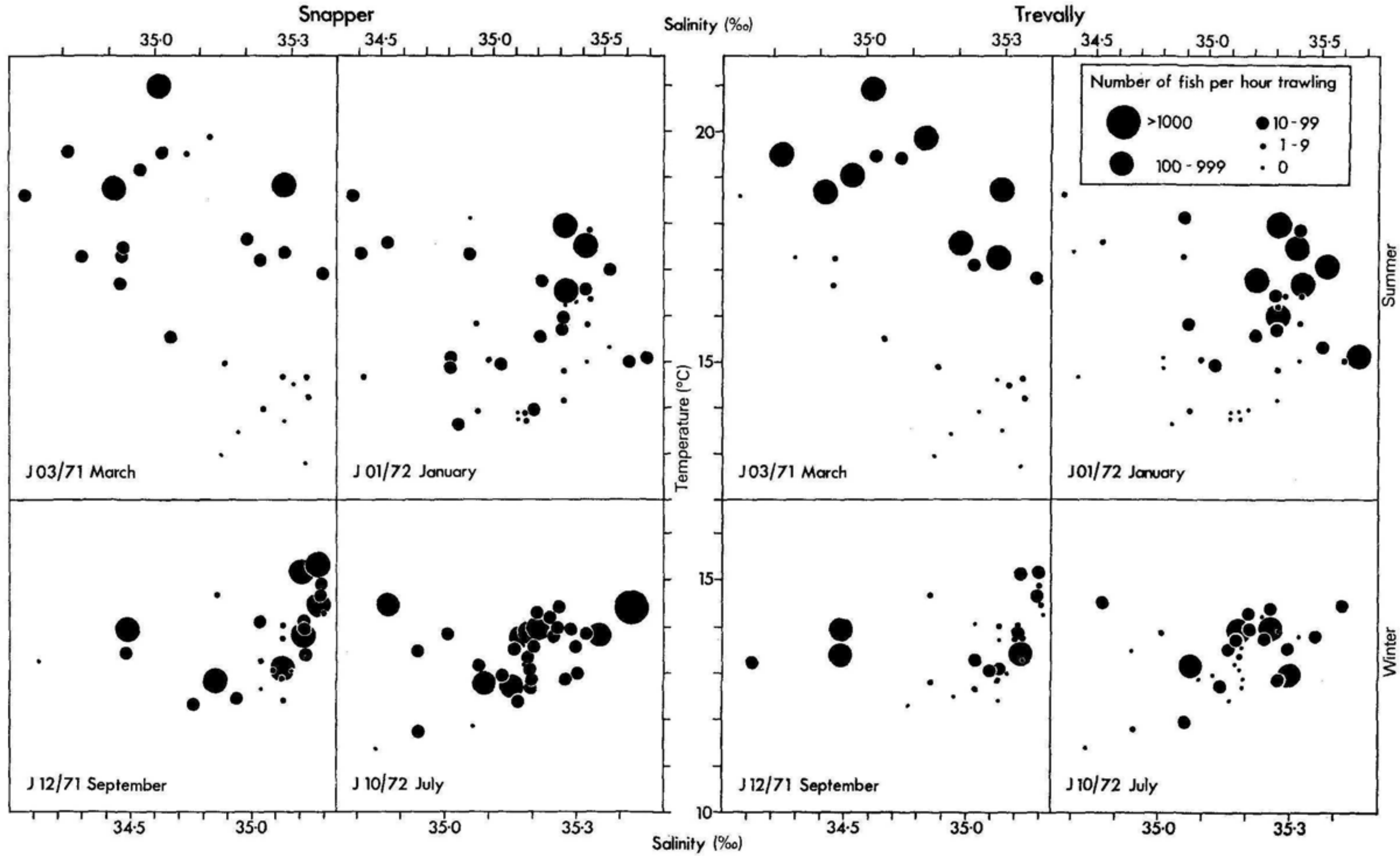


FIG. 13—Distribution and abundance of snapper *Chrysophyrys auratus* and trevally *Caranx georgianus* in summer and winter in relation to temperature and salinity.

in fact, more clearly separated geographically than hydrologically.

Two species, snapper *Chrysophrys auratus* and trevally *Caranx georgianus* Cuvier, did show some preference for warmer water of higher salinity (Fig. 13). This is less pronounced in winter, perhaps because the temperature range is smaller. To some extent this simply reflects the essentially northern distribution of these two species, but combined with the seasonal hydrological changes presented in this paper it allows some speculation on their possible movements on this coast.

On the shelf north of Cape Egmont and particularly north of Manukau, where bottom temperatures generally remained warmer in shore than off shore throughout the year, snapper and trevally could be expected to concentrate in shore along the coastline in summer and autumn, dispersing in winter as temperatures became more uniform, and perhaps favouring the mid-shelf region off Ninety Mile Beach where it remained relatively warmer than both inshore and more southern areas. There would probably be a summer movement of snapper and trevally into the shallow embayment north of New Plymouth, where temperatures remained quite warm from spring until autumn; there is a snapper nursery ground there (L. J. Paul, unpublished data).

The southern region, from Cape Egmont and Cape Farewell to Cook Strait, behaves as a shallow shelf. It warms first around the margins in spring, particularly in the South Taranaki Bight where it remains warmest (and at least as warm as most inshore localities north of Cape Egmont (Fig. 9)) during summer and autumn; about May, temperatures drop sharply. Demersal fish species such as snapper would move to shallow margins in spring, initially Patea and Kapiti and then Tasman Bay. Autumnal cooling would either disperse these fish uniformly over the shelf, as there was no warmer refuge in the deeper central area, or would initiate a movement out to the deeper shelf north-west of Cape Farewell, where bottom temperatures were higher than at inshore localities between June and October.

These fish movements, inferred from our 1971–73 hydrological data, are consistent with the conclusions of Shuntov (1969), based on experimental trawling in 1964–68, that some of the abundant shelf species spawned in shore in spring, moved south to feed in late summer and autumn, then returned north and into deeper water in late autumn and winter.

Nosov & Shurunov (1975) made a more extensive study of the distribution, migrations, and spawning of jack mackerel in central New Zealand waters, in relation to hydrological conditions. They considered that the general circulation of water in the area was stable, and that the seasonal and year-to-year fluctuations in the hydrological regime were primarily the result of latitudinal displacement of meteorological pressure systems. These fluctuations strongly influenced the migration and spawning of jack mackerel. Nosov & Shurunov (1975), using data from a standard hydrological profile between Cape Farewell and Cape Egmont, found 1971 to be the warmest year in the period 1965–71, and that in this year there was a delayed winter migration of jack mackerel northwards from the South Island, and a wider distribution of young fish in north-west Cook Strait during winter. Although this pre-1977 work on jack mackerel is partly invalidated by the recent discovery that two species are present in many areas (Stephenson & Robertson 1977), findings such as these have obvious significance in defining the fishing strategy of large off-shore fishing vessels.

There is little published information on the activities of large overseas trawlers, principally Japanese and Russian, on the north-west shelf, although recorded sightings (New Zealand Government, unpublished data) and newspaper accounts (interviews and reports of trips) indicate a concentration of vessels on the central and outer shelf between Cape Egmont and Albatross Point. Records of the Japanese trawler fleet's fishing activities are available by 0.5° squares for 1972–76 (Fisheries Research Division unpublished analyses), and reveal a major fishing ground in this area. Although these vessels fish principally for jack mackerel and barracouta, other more typically demersal species are taken in some quantity. Further work in this region, which lies at the south-eastern end of the deep New Caledonia Basin, is desirable because it appears to exhibit hydrological conditions and features favouring a number of demersal, midwater and perhaps pelagic fish species.

CONCLUSIONS

In this paper we have presented hydrological data collected during a series of bottom trawl cruises along the west coast of the North Island. Essentially they confirm earlier findings, and demonstrate that this shelf region, influenced by the north-flowing Tasman Current, is rather uniform in both space and time. The results of seasonal warming and cooling, upwelling, freshwater discharge from the land, and intrusion of water through Cook Strait are superimposed on the characteristics of the Tasman Current and on variations in its branch, the D'Urville Current, which flows south-eastward through Cook Strait. Although the D'Urville Current may be a persistent feature of north-western Cook Strait, its point of entry into the strait appears to vary from north of Cape Egmont to near Cape Farewell.

The wide dispersal of most demersal fish species results from the hydrological uniformity of this region. The few species that had localised distributions were more clearly separated geographically, or by depth and bottom type, than they were by hydrological conditions. Only snapper and trevally showed a preference for warmer water in summer. There was no clear relationship between pelagic species and regional hydrological features, although upwelling near New Plymouth may have influenced albacore distribution, and warmer water species will tend to be concentrated in the north of the region. Although the temperature and salinity patterns were quite stable during the period of observation it is possible that year-to-year variations in temperature, current strengths, and upwelling, would have a controlling influence on the distribution of many fishes, particularly pelagic tunas and midwater barracouta and mackerels.

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