Weather and Climate (1992) 12: 32-39

A BIOLOGIST'S VIEW OF MARINE CLIMATE

W. J. Ballantine

University of Auckland
Leigh Marine Laboratory
Box 349, Warkworth, New Zealand

ABSTRACT

Although the climatology of land and the atmosphere has a long history, marine climatology scarcely exists as a subject. 'Marine' meteorology is concerned mainly with the atmosphere above the sea, some sea surface phenomena and very short time scales. Physical oceanography, which would logically include the climate of the sea itself, has traditionally been concerned with mean conditions and their causes, not with the variation in these conditions.

Only quite recently has there been any attempt to record the variations in locality, strength and frequency of those features, such as currents, mixing layers, fronts, gyres, photic zones, eddies, etc., which make up the climate of the sea. Even less has been done to relate all this to biological phenomena.

Nevertheless, examples are already available for the New Zealand region which demonstrate both the feasibility of obtaining information on marine climates and the value of having it. Although relatively small in number, these examples cover a wide range of geographical localities, methods of data collection and analysis, and phenomena studied (both physical and biological). They also show a range of theoretical and practical application.

INTRODUCTION

Present investigations of climate do not include any formal or efficient system for studying the climate of the sea itself. No particular group is to blame for this and the situation is similar world-wide. It results from many decisions made in good faith over a long period. Nevertheless the omission has no scientific justification. Recent technological advances provide ways to start filling this gap. To take this opportunity, meteorologists, climatologists, oceanographers and marine biologists will need to broaden their traditional attitudes and cooperate actively in new ways. This paper attempts to show, with examples, that this is feasible and would have practical and theoretical benefits, especially in New Zealand.

Climatology and meteorology are generally regarded as studies of atmospheric conditions and dynamics. Their central concern is the air around us and our terrestrial habitat. The interactions of the atmosphere with the sea may be investigated in order to understand the weather and climate of our environment, but variations in the dynamics of the sea are only studied by meteorologists and climatologists for their effects on the atmosphere. Consequently they rarely consider anything but surface phenomena in the sea and even these are only studied to provide appropriate boundaries for their real interest.

If challenged on this point, 'atmospheric' climatologists are likely to say that a study of marine dynamics is the field of physical oceanography. Logically this is fair comment, but in the sea physical oceanographers have serious practical problems when addressing the kinds of variation which are commonly studied in the atmosphere. Until very recently all physical studies of the sea were ship-based. Ships are very expensive, move slowly and can only sample one locality at time. Enormous areas had to be covered by grid surveys, each taking weeks to complete. Nothing that varied during this time was accessible to study and the need to link data from different cruises caused further limitations. Oceanographers naturally concentrated on investigations of mean conditions (e.g. average current flows) and the causes of these large scale phenomena.

When new methods became available - e.g. satellite sensors, long-term proxy data (biological or chemical), and moored or free-floating buoys - practicalities had already hardened into traditions, specialisations had become formalised and it was nobody's responsibility to invent the 'new' science that had become practical. Whilst satellite data are used by meteorologists for short-term forecasting, proxy data by palaeobiologists and transmitting buoys by oceanographers, the fields tended to remain unconnected.

Despite these general tendencies, there are actual examples from the New Zealand region of successful cooperation between fields, producing new and useful insights. New Zealand lies at the centre of the 'water hemisphere' (Fig. 1), surrounded and dominated by oceanic waters, characterised by latitudinal zones (Fig. 2). The general climate of New Zealand is strongly influenced by conditions in the surrounding oceans and variations in our weather patterns may be controlled by variations in the climate of the sea. The main effect of the New Zealand land mass is to deflect the sub-tropical convergence southwards, so the whole of New Zealand lies in the same marine climate zone. This would simplify prediction and the understanding of the processes involved.

Fig. 1. Hemisphere centred on New Zealand.

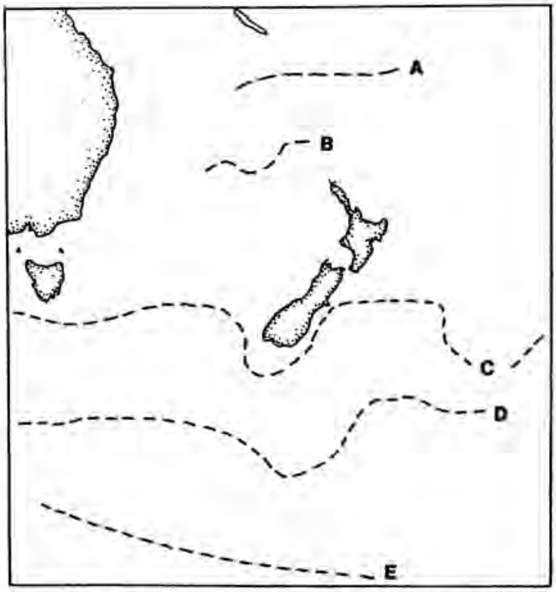

Fig. 2. Major oceanographic features that effectively delimit marine climatezones in the New Zealand region. A, tropical convergence; B, Tasman front; C, subtropical convergence; D, subantarctic front; E, polar front (redrawn from Heath, 1985).

SINGLE PARAMETER TIME SERIES

Daily air temperatures have been routinely recorded at some sites in New Zealand since the 1850's, and collected systematically throughout the country for more than 100 years. Sporadic readings of sea temperatures occur only from the 1920's (Hounsell, 1935).

Daily sea surface temperatures (SST) have been recorded since 1967 on the open north-east coast of the North Island at Leigh (Ballantine, 1982, Evans, 1992). In addition to the expected seasonal variation (average annual range 6.6°C), there are strong differences between years (Fig. 3.). Conventional analysis of SST, for long term trends and periodicities, do not reveal much of interest, either in New Zealand (Grieg et al., 1988) or for longer time series in Britain (Maddock and Swann, 1977).

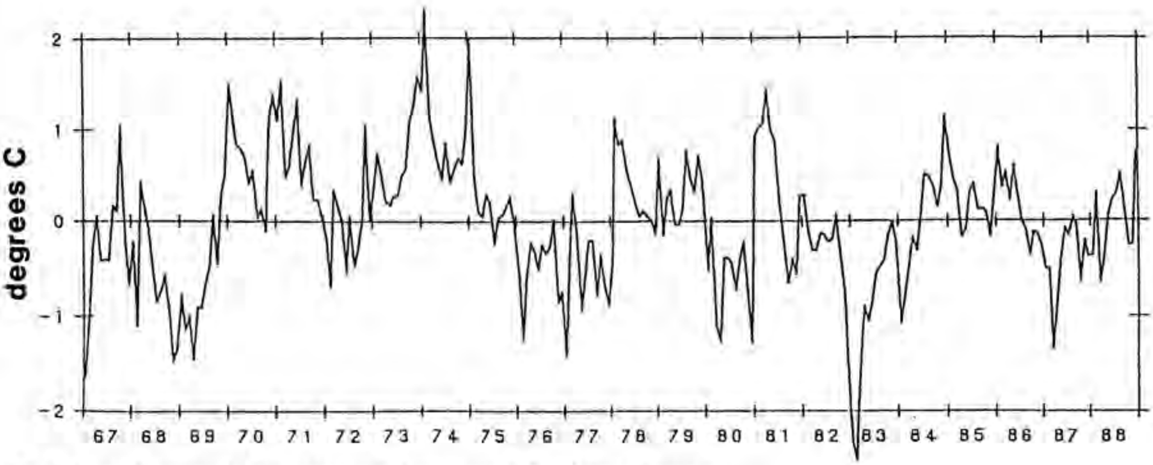

Fig. 3. Monthly sea surface temperature departures at Leigh over 22 years.

Biologists, however, view the matter differently. They notice that the variation in SST between years are often a significant proportion of the annual range, and furthermore that the anomalies are very persistent in sign (1 to 3 years). These points are biologically important and are additive in their effects on organisms.

If 'summer' is defined at Leigh as the time with SST at or above 20°C, then, on average, summer lasts three months from early January. However, looking at real years with this definition, summer may begin at any time from mid-December (1973) to late February (1977) or not occur at all (1969 and 1983). The biological effects of these variations are multiple and widespread and during extreme anomalies they dominate (Taylor et al., 1985).

Physical scientists may be more interested to note that the SST anomalies are geographically widespread, that they correlate well with other factors and that they may change very rapidly (Harris, 1985). The variations recorded at Leigh are very similar to those derived from satellite measurements offshore (Grieg et al., 1988) and correlate well with other New Zealand coastal stations even in the far south. Whatever is driving this variation, it seems to operate throughout the New Zealand seas north of the sub-tropical convergence.

The Leigh SST departures correlate well with a range of other climate indicators, including not only air and earth temperatures, but also wave surge and wind directions. There is a surprising lack of correlation with salinity variations, but a strong correlation with the Southern Oscillation Index (Grieg et al., 1988; Harris, Ballantine and Evans, unpublished data). Large changes in the Leigh SST anomaly (that then persist) may be very rapid (1.5-2.0°C in a month) and tend to occur in late spring or early summer. On at least two occasions (January 1978 and December 1980) these rapid changes were also very widespread (Fig. 4).

The persistence of SST anomalies, their ease of measurement and their correlation with other climate factors make them excellent proxy data and predictors, despite the occasional sharp switching. If the sea temperature anomaly at Leigh is negative, there is a strong probability that it will remain negative for several months. While it remains negative there is a strong probability that air and earth temperatures will be lower than usual and easterly swells and winds less common.

This type of prediction, which refers to a general climate pattern, is particularly useful to biologists (and farmers), but is viewed with suspicion by physical scientists because it lacks specificity. Standard weather forecasts are more likely to be correct when conditions are close to average, but SST-based predictions improve with the size of the anomaly. This feature suits biologists who are especially interested in conditions that might be limiting, but worries statistical meteorologists who are uncertain how to scale for it.

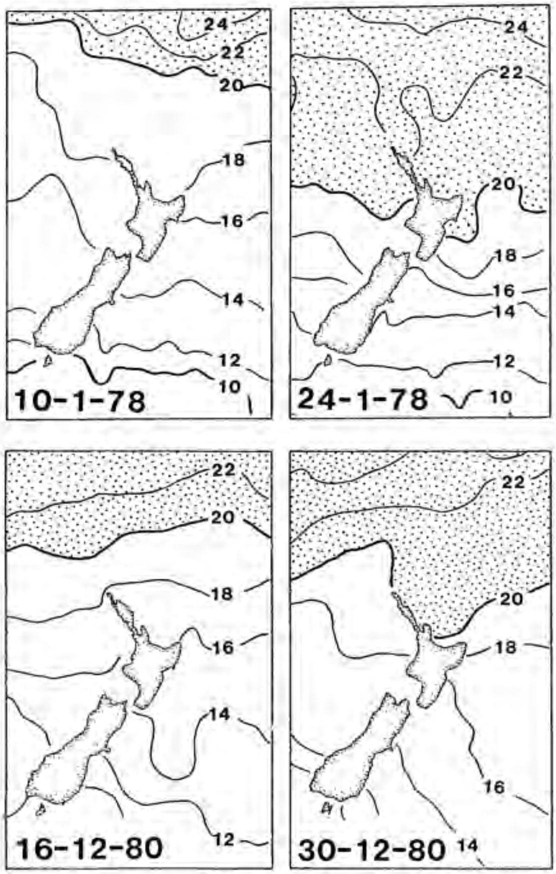

Fig. 4. Movements of the 20°C sea surface isotherm north of New Zealand over two weeks in summer (satellite data from GOSSTCOMP).

Although long-term series of physical data are recognised as standards in atmospheric climatology, and have a wide variety of uses (Lamb, 1972; Hay, 1991), there are few examples for the sea, despite intense interest in climate change (Paul, 1990). More are needed to act as baselines, calibrations for remote data systems, proxy measurements and predictors.

Short-Term Regional Variation

The latitudes immediately north of New Zealand (including the Three Kings Is) have long been known to show marked oceanographical variations (reviewed by Heath, 1985; Harris, 1985). These include upwelled patches of very cold water, anticyclonic eddies and meandering zonal jets associated with the highly variable Tasman Front. Some of these variations have been recorded by ships carrying out grid surveys and some are clearly shown on charts of satellite-derived sea surface temperatures produced by the N.Z. Meteorological Service, despite problems with cloud cover, and the fact these charts are produced weekly and may include different days (Fig. 5).

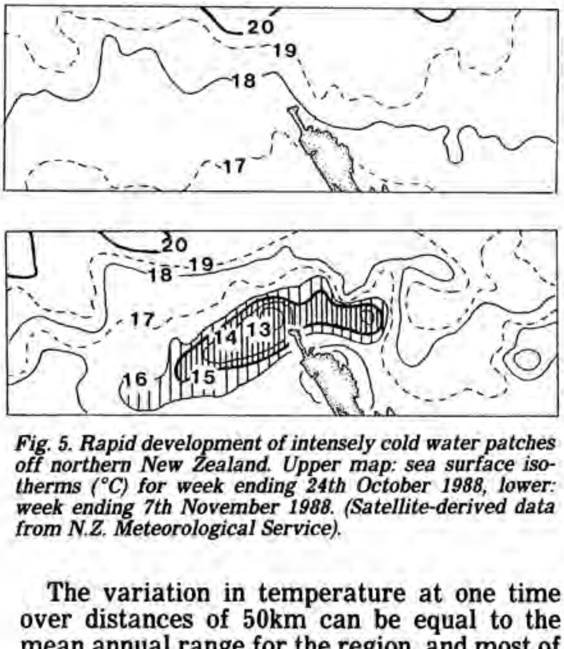

Fig. 5. Rapid development of intensely cold water patches off northern New Zealand. Upper map: sea surface isotherms (°C) for week ending 24th October 1988, lower: week ending 7th November 1988. (Satellite-derived data from N.Z. Meteorological Service).

The variation in temperature at one time over distances of 50km can be equal to the mean annual range for the region, and most of this range may be covered in a week at one point. The biological consequences of this variation include the highly anomalous shallow water flora and fauna of the Three Kings, which show a mixture of cold temperate and subtropical forms (Ballantine, 1990).

Although this may be an extreme example, many marine areas around New Zealand show similar variations, with the mean conditions being less important than the range and type of the variations. If we are ever to understand these areas, there is a need for continuous archiving of satellite data, the description of meso-scale patterns, and regular analysis of the location, frequency and amplitude of these patterns. At present, no one has a direct responsibility to ensure this, and it is merely the accidental result of other business if the data is stored for future use.

Marine Biology and Marine Climate

Whenever marine biological information is collected over a period of years and/or over a range of localities, the inter-annual and small scale geographic variations are very large. Variations in reef fish faunas along the north-east coast of New Zealand are very marked both in latitude and distance offshore (Ward and Roberts, 1986). Simple information on current patterns helps prediction (Fig. 6), but a knowledge of interannual variation is even more helpful (Francis and Evans, 1991).

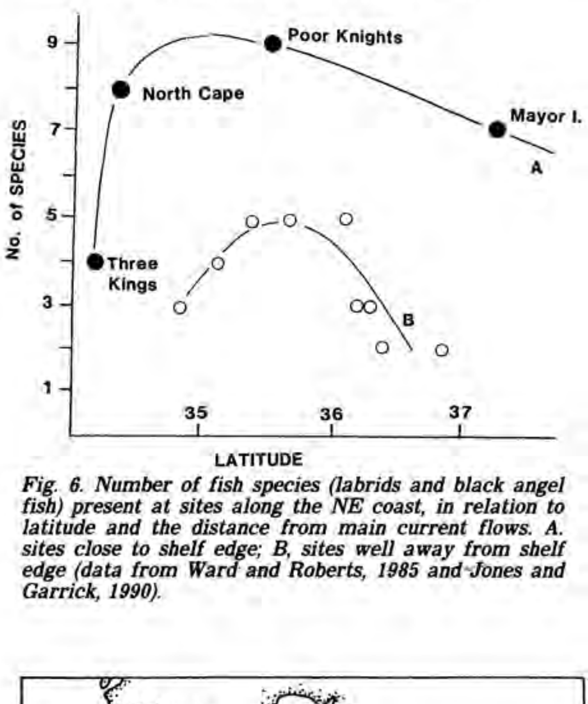

Fig. 6. Number of fish species (labrids and black angel fish) present at sites along the NE coast, in relation to latitude and the distance from main current flows. A. sites close to shelf edge; B, sites well away from shelf edge (data from Ward and Roberts, 1985 and Jones and Garrick, 1990).

Whether the information is on larval recruitment (Booth et al., 1991), the size of animals (Ralph, 1956), fish catches (Paul, 1976; Gilbert, 1982), human pathogens in shellfish (Power, pers. comm.), or primary productivity (Vincent et al., 1991), it seems that the local and inter-year variations in marine climate are often of great or over-riding importance.

In Foveaux Strait, investigated by Bradford et al. (1991), differences between years were very strong. In the same locality and in the same season, sea temperatures varied by 2°C, primary production increased fivefold (Fig. 7) and oyster growth doubled.

An Integrated Example

In their study of the Cook Strait region, Bowman et al. (1982) have described cold eddies that are produced along the west coast of the South Island and peel off Farewell Spit. They were able to trace these eddies in time and space by their physical and biological properties, using a combination of methods. Although pieced together from various times and types of data, the sequence of events seems clear (Fig. 8).

Cold water rich in nitrate and phosphate ('nutrients' for plant growth) is upwelled from deep water along the NW coast of S.Island forming a northward moving plume, containing cold-core clockwise-rotating eddies, of the order of 20km in diameter (A: in Fig. 8). North of Farewell Spit these eddies turn eastwards into Cook Strait as part of the D'Urville Current, rapidly becoming indistinguishable in physical terms. The biological evolution of

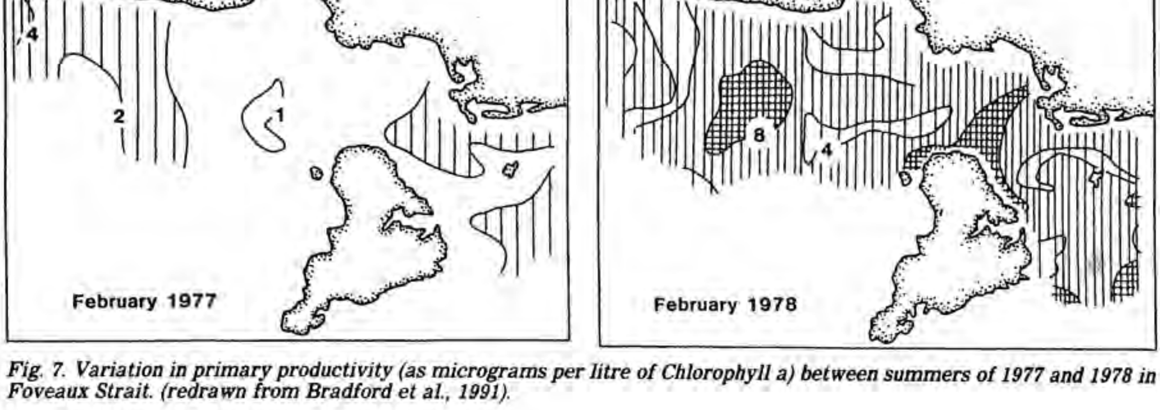

Fig. 7. Variation in primary productivity (as micrograms per litre of Chlorophyll a) between summers of 1977 and 1978 in Foveaux Strait. (redrawn from Bradford et al., 1991).

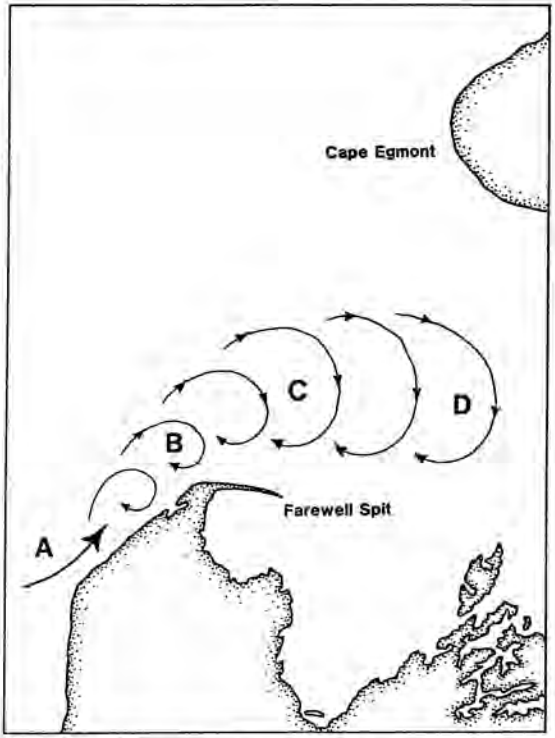

Fig. 8. The formation and subsequent history of cold eddies in western Cook Strait. A to D explained in text. (redrawn from Bowman et al., 1982).

these eddies begins with a phytoplankton bloom, as diatoms multiply rapidly (B). This rich primary production attracts zooplankton which feed on it and grow (C). The zooplankton aggregations attract squid, and high densities of these are exploited by Japanese squid fishing vessels (D).

A number of points should be stressed:

(i) The history of a single eddy, while lengthy, is fairly straightforward and is well-supported by physical and biological theory.

(ii) The eddies are highly mobile. Data analysed in relation to an eddy makes sense, but data from fixed locations would be extremely variable and difficult to understand.

(iii) When eddies are physically senescent, they are well-developed biologically.

(iv) It would be relatively easy (using SST data from satellites, fishing boat locations, and other proxy data) to determine the general pattern of eddy formation, their size and frequency and their trends with respect to tides, weather, seasons and years.

PROXY MEASUREMENTS

The scarcity of marine climate data for the New Zealand region in the past cannot be remedied by any direct action now. However, unless some information is obtained to show previous variations in time, even major data collection from now on will not yield useful predictions until these have been collected for periods 2-10 times longer than the fluctuations. Proxy measurements are the only possible solution to this problem.

Fortunately work in terrestrial systems in New Zealand, and in marine systems in other parts of the world, has already shown that proxy measurements of past climates are possible and useful. The time scales for these range from a few years, through decades and centuries to the entire Pleistocene.

Terrestrial proxy measurements of past climate include analysis of tree rings, archaeological records, glacial coring and moraine studies, and the stratigraphy of fossil pollen in swamps. In the sea useful results have been obtained from the analysis of annual rings and isotope ratios in coral skeletons and mollusc shells (living and fossil), from studies of surface dwelling micro-planktonic skeletons preserved in deep sea sediment, from records of layered sediments in shallow water and from biological and topographic evidence of sea-level changes (see reviews in Fraser, 1973; Hay, 1991; Montaggioni and MacIntyre; 1991; Paul, 1990).

The available techniques for relative and absolute dating include radio-carbon dating, layer and ring counts, statistical and pattern correlations, oxygen isotope ratios and a whole range of biogeographic comparisons. The reliability and usefulness of the results depend less on the particular method than on the careful cross-calibration of different methods.

Most of these methods would be applicable in New Zealand, but only a scatter (due to accidents of academic curiosity) are likely to be used unless there is a deliberate and high-level policy to encourage their development and application.

CONCLUSIONS

The climate of the sea itself can and should be recognised now as an important and proper subject in its own right. This recognition would be specially appropriate and useful in New Zealand. The previous neglect of this subject is due to historical accidents, mainly technical points that no longer apply. Before any serious progress can be made, atmospheric climatologists, physical oceanographers and marine biologists will have to adjust their traditional concerns and cooperate in new ways. The changes include:

(a) All marine data, including all biological data, should be recorded in absolute time, including the actual year, and should be related to the best available information on the marine climate at that time (not just average conditions for the season).

(b) To assist this, existing climate indices (such as SOI, zonal indices and sea surface temperature anomalies) should be calculated routinely and be freely available.

(c) All marine data should be located in relation to major and mesoscale climate patterns at the time, not merely as a latitude/longitude.

(d) To assist this, all satellite data relating to New Zealand seas should be archived in New Zealand so that the historic record is preserved for future analysis. With a short time-delay to cover any commercial use, it should be freely available for analysis. Such analysis, by a wide range of interests, should be actively encouraged.

(e) The analysis of marine satellite data should include the description of large and mesoscale patterns. The location, frequency and intensity of these patterns should be routinely analysed and freely available.

(f) A deliberate search should be made for proxy measurements of medium and long-term marine climate in the New Zealand region.

ACKNOWLEDGEMENTS

As compiler of this review, I am grateful to all those who recorded and analysed climate data at Leigh over the past 25 years, especially Jo Evans; to those who assisted with the establishment and development of the climate work at Leigh, especially the N.Z. Meteorological Service and the Physics Department of the University of Auckland; and to all those who discussed and explained their specialities with me especially Janet Bradford, Brian Foster, Malcolm Francis, Dave Gilbert, Sandy Harris, Larry Paul and Fergus Power.

REFERENCES

Ballantine, W. J., (editor) 1982: Sea surface temperatures: Waterfall Reef Site B. *Leigh Climate Report*, I, 1-43. University of Auckland.

Ballantine, W. J., 1990: The significance of island reserves for ecological restoration of marine communities. In Ecological restoration of New Zealand islands. *Conservation Sciences Publication* No. 2. Department of Conservation, Wellington p.22-36.

Booth, J. D., Carruthers, A. D., Bolt, C. D. and Stewart, R. A., 1991: Measuring depth of settlement in the red rock lobster, *Jasus edwardsii*. *New Zealand Journal of Marine and Freshwater Research* 25, 123-132.

Bowman, M. J., Foster B. A. and Lapennas, P. P., 1982: Ocean water properties. In *Maui Development Environmental Study: Report on Phase Two 1977-1981*. University of Auckland, p. 77-97.

Bradford, J. M., Cranfield, H. J. and Michael, K. P., 1991: Phytoplankton biomass in relation to the surface hydrography of southern New Zealand and possible effects on the food chain. *New Zealand Journal of Marine and Freshwater Research* 25, 133-144.

Evans, J. H., (editor) 1992: Leigh Climate Report 1991. *Leigh Laboratory Bulletin* No. 27. University of Auckland.

Francis, M. and Evans, J. H., 1991: Immigration of subtropical marine animals in relation to the Southern Oscillation. In Hay, J. E. (editor) *South Pacific Environments: Interactions with weather and climate*. University of Auckland Environmental Science Department, Auckland. p. 44-45.

Fraser, R., (editor) 1973: *Oceanography of the South Pacific 1972*. New Zealand National Commission for UNESCO,Wellington.524pp.

Gilbert, D., 1982: A study of the Firth of Thames flounder fishery. Unpublished report presented at N.Z. Marine Sciences Society. Fisheries Research Division, Ministry of Agriculture and Fisheries, Wellington.

Greig, M. J., Ridgway, N. M. and Shakespeare, B. S., 1988: Sea surface temperature variations at coastal sites around New Zealand. *New Zealand Journal of Marine and Freshwater Research* 22, 391-400.

Harris, T. F. W., 1985: *North Cape to East Cape: aspects of physical oceanography*. Physics Department, University of Auckland. 178pp.

Hay, J. E., (editor) 1991: *South Pacific environments: Interactions with weather and climate*. University of Auckland Environmental Science Department, Auckland. 237pp.

Heath, R. A., 1985: A review of the physical oceanography of the seas around New Zealand - 1982. *N.Z. Journal of Marine and Freshwater Research* 19, 79-124.

Hounsell, W. K., 1935: Hydrographic observations in Auckland Harbour. *Transactions of the Royal Society of New Zealand* 64, 257-264.

Jones, A. and Garrick, A. S., (compilors) 1990: Tuhua (Mayor Island) marine habitats: an intertidal and subtidal survey. *Department of Conservation Technical Report Series* No. 4, 84pp.

Lamb, H. H., 1972: *Climate: present, past and future.* 2 vols. Methuen, London.

Maddock, L. and Swann, C. L., 1977: A statistical analysis of some trends in Sea temperature and climate in the Plymouth area in the last 70 years. *Journal of the Marine Biological Association (U.K.)* 57, 317-338.

Montaggioni, L. F. and Macintyre, I. G., (editors) 1991: Reef as recorders of environmental changes. *Coral Reefs* (special issue) 10 (2), 53-125.

Paul, L. J., 1976: A study on age, growth and population structure of the Snapper, *Chrysophrys auratus* (Foster), in the Hauraki Gulf, New Zealand. *Fisheries Research Bulletin* No. 13, Ministry of Agriculture and Fisheries, Wellington.

Paul, L. J., 1990: Marine Fish, Fisheries and Aquaculture. In *Climate Change: Impacts on New Zealand.* Ministry for the Environment, Wellington. 85-94.

Ralph, P. M., 1956: Variation in *Obelia geniculata* (Linnaeus, 1758) and *Sicularia bilabiata* (Coughtrey, 1875) (Hydroida, F. Campanulariidae). *Transactions of the Royal Society of New Zealand* 84, 279-296.

Taylor, F. J., Taylor, N. J. and Walsby, J. R., 1985: A bloom of the planktonic diatom *Ceratulina pelagica* off N.E. New Zealand in 1983. *Internationale Revue Gestamten Hydrobioogie* 70 (6), 773-795.

Vincent, W. F., Howard-Williams, C., Tildesley, P. and Butler, E., 1991: Distribution and biological properties of oceanic water masses around the South Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 25, 21-42.

Ward, C. and Roberts, L., 1986: The East Auckland current: one explanation for the distribution patterns of the coastal and offshore fish faunas of north-eastern New Zealand. *Information Series* 16, 211-219. Department of Lands and Survey, Wellington.