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# Assessment of the Impact of Reduced Flows in the Waiau River since 1969 on the Ecosystem of Foveaux Strait

Report prepared for

**Electricity Corporation of New Zealand Ltd**

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*Taihoro Nukurangi*

# Assessment of the Impact of Reduced Flows in the Waiau River since 1969 on the Ecosystem of Foveaux Strait

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A report prepared for

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## EXECUTIVE SUMMARY

**Issues:** Reduction of lower Waiau River flows has brought concerns that the reduced freshwater discharge into Te Waewae Bay may have affected the Foveaux Strait marine ecosystem. This may have been a factor in the mass mortality of Foveaux Strait oysters which had occurred in the late 1980s and recent toxic algal blooms.

**Discussion:** The Foveaux Strait marine environment is highly productive and supports a number of highly valuable fisheries (e.g. whales (historically), dredge oysters, mutton birds, squid, as well as spiny lobsters and blue cod (Bradford-Grieve 1996). Much of this productivity is generated from dissolved inorganic nutrients derived from the properties of the Subtropical Convergence which change rapidly across the front, tidal stirring, river water, and from an undefined oceanic source (probably uplift of subtropical water over the Puysegur Bank). The region is also significantly impacted by general oceanic variability driven by weather and climate scale events through mechanisms which are not wholly understood.

While river water might be expected to be a significant influence in the nearshore region, through its contained dissolved inorganic nutrients and humic substances, it is difficult to separate its impact from that of the other processes contributing to nutrient renewal. Measurements in 1978, of dissolved inorganic nutrients in Foveaux Strait were relatively high while flows in the Waiau River were low (Bradford et al. 1991).

Data, summarised by Robertson (1993b), on nutrient content of the Waiau River and Lake Manapouri suggests that the nutrient contribution the river makes to the south coast has probably decreased only slightly post control. The concentration of nitrate-nitrogen in Lake Manapouri is relatively low (25 mg/l) compared with the concentrations in the Waiau River (up to 50-325 mg/l). This difference seems to be related to the different land uses, primarily forests and agriculture, in the lake and river catchments (Robertson 1993b). Nevertheless, the nutrients from the lake are not lost to the marine system; Lake Manapouri water enters the ocean from the Fiordland coast and is entrained into the flow down the southwest coast and east into Foveaux Strait.

Overall there has probably been little impact of changed flows in the Waiau River on the salinity of Foveaux Strait, as the water of Lake Manapouri has not been lost from the marine system of southern New Zealand. This water eventually reaches Foveaux Strait via the Fiordland coast.

Natural seawater conditions during summer in Foveaux Strait often appear to be conducive to the development of phytoplankton blooms of unusual luxuriance and species composition compared to other New Zealand coastal regions. Bradford-Grieve (1996) noted that the early 1996 bloom followed a period of high rainfall, and subsequently by a calm spell, and concludes that phytoplankton blooms in the region and the occasional occurrence of toxic species are unrelated to human activites.

Declines in the oyster populations have been recorded in 1940, 1963, and 1986, a periodicity of about every 22-23 years. These declines have occurred both before and after the Waiau River flow was controlled and have been related to periods when oysters were in poor condition and also suffering parasitic infections. The 1986 decline in oysters was accompanied by declines in muttonbird condition, and shorebirds starved off the Otago coast. These events suggest that a widespread environmental disturbance had occurred which was not restricted to Foveaux Strait.

**Conclusion:** While river water might be expected to be a significant influence on the nearshore marine ecosystem of Foveaux Strait, the reduction in flow of the Waiau River probably has not greatly altered the impact of river water, as dissolved inorganic nutrients and fresh water are not lost to the southern New Zealand marine system.

## 1.0 INTRODUCTION

In the more than 25 years since the flow of the Waiau River, Southland, has been controlled at some 24% of its average annual flow, no really compelling evidence exists that this reduced flow has had an impact on the functioning of the marine system of Te Waewae Bay and adjacent Foveaux Strait. Nevertheless, there are concerns that subtle effects may be operating. In particular these concerns relate to cyclical downturns in the commercial oyster fishery in Foveaux Strait or the appearance of toxic marine algae (Robertson 1993a), and in general to adverse effects that have been observed on enclosed bodies of water in other parts of the world (Stroud 1992).

This report is an overall assessment of the effects of the reduced flow from the Waiau River since 1969 (as a result of hydro-electric power generation from the Manapouri Power Scheme) on the marine ecosystem of Foveaux Strait, as far as the existing information, understanding, and knowledge permits.

## 2.0 GENERAL IMPACT OF FRESH WATER ON MARINE PRIMARY PRODUCTION SYSTEMS

The most obvious impact that river water has on the ocean is the reduction in salinity. In the estuarine situation this reduction can be extreme to the point where sea water is only a small fraction of the estuarine water. On the open coast, salinity is reduced usually at the surface with the extent of the influence of fresh water depending on the flow in the river and the local hydrographic regime; usually the percentage contribution of fresh water on the open coast from river water is small.

It is in enclosed embayments/estuaries with extensive shallow areas that the reduction in salinity can have rather special effects. Estuarine organisms are specially adapted to variable salinities and estuarine production systems. These animals and plants are particularly vulnerable to increases in pollution and changing of cues that determine migration routes and breeding grounds (Rozengurt 1992), caused by reductions in flushing by freshwater inflow.

Leaving aside estuaries, freshwater inflow can have several effects on the open ocean marine production system. Fresh water can provide stability to a seasonally unstable water column and therefore, in late winter, primary production may start a little earlier than it otherwise might. On

the other hand, if the quantity of fresh water is large, and, because it does not contain marine microscopic plants, it may take a considerable time for the mixing of fresh water and sea water to be seeded with marine phytoplankton, thereby delaying increased primary production as a result of the increased vertical stability.

Fresh water from different catchments, besides lowering salinity, carries with it dissolved inorganic nutrients, and other substances, which may impact the nearby ocean. Sometimes these dissolved inorganic nutrients in river water can produce a perceptible impact on the productivity of the sea if the water into which the fresh water is flowing is devoid of plant nutrients. An example of such a situation is found on the west coast of South Island where the silica content of river water is related to the growth of diatoms (Chang & Bradford 1985). In another instance river water served only to dilute the ocean with respect to its dissolved reactive phosphorus content (Bradford *et al.* 1980). Sometimes the contained dissolved materials are not beneficial. They may be pollutants, or they may be naturally occurring trace metals, which in large quantities are toxic. The impact of these on the ocean very much depends on the catchment the river water comes from, including the land use of the catchment and any discharges into the rivers.

River water may also carry with it fine sediment and dark-coloured dissolved humic substances which can alter the transparency of sea water. This lowered transparency has the effect of making the depth at which effective phytoplankton growth can take place shallower. Humic substances are well known to form organo-metalic complexes which increase the availability of certain metals, e.g. iron and manganese, whilst reducing the toxicity of others, e.g. of copper to phytoplankton (Prakash & Rashid 1968; Gedziorowska & Plinski 1989; Rashid 1985).

## 2.1 SUMMARY

- On the open coast, river water has positive and negative impacts on the marine production system. Fresh water may impart stability to an unstable environment, enabling primary production to begin in late winter rather than spring in some locations.

- Too much fresh water dilutes the marine phytoplankton so that they would take a long time to multiply to numbers which could take advantage of the stable water column with its optimal light environment.

- River water often carries dissolved inorganic nutrients and other trace substances which can have a positive impact on primary production.

- Fine particulate material and humic substances in river water can reduce the extent of light penetration into sea water, thus making the depth at which effective phytoplankton growth can occur shallower. The presence of humic substances, which are able to form organo-metalic complexes, may have a positive impact on phytoplankton growth.

- Pollutants or naturally occurring trace metals may have a negative impact on the marine ecosystem

## 3.0 THE OCEANOGRAPHIC SETTING OF SOUTHERN NEW ZEALAND

The general flow in the New Zealand region is from west to east. Water flowing eastwards through Foveaux Strait originates from the Tasman Sea where it flows along the southern flank of the Challenger Plateau and along the continental slope of the southwest coast of South Island. This flow turns eastwards as the Southland Current and continues on up the east coast of South Island (Heath 1985) (Fig. 1). Within Foveaux Strait the non-tidal currents are strongly wind-driven, whereas to the south of Stewart Island the non-tidal currents appear to be independent of Invercargill winds (Chiswell 1996). The mean flows in the origins of the Southland Current off Westland can be up to more than 20 cm per second (Stanton 1976; Chiswell 1996).

The New Zealand tidal regime has the phase of the main lunar and solar tides embracing the complete range of phases from 0-360 degrees (Heath 1985). Or in other words, at any particular time there is a high tide somewhere on the New Zealand coast. In some constricted areas such as Foveaux Strait, the time of high tide changes very rapidly over short distances. As a consequence, strong tidal flows are encountered in these regions (Heath 1985) and may be as great as 1.8 knots in Foveaux Strait narrows (Hydrographic Office, Royal New Zealand Navy 1993).

Southern New Zealand lies in a complex region of the Subtropical Convergence (STC) a major oceanic front which extends round the whole of the Southern Hemisphere (Fig. 1). This front extends from the southern Tasman Sea around Stewart Island and northward parallel to the Otago and South Canterbury coasts before extending eastwards over the top of the Chatham Rise. The STC is a region where surface salinity, temperature (Heath 1985), and nutrient levels (Bradford & Taylor 1980) change rapidly. The STC in the New Zealand region is denoted by a surface temperature of 15°C in summer and 10°C in winter and salinites of 34.7-34.8. Recent work has shown that there are complicated processes within the oceanic

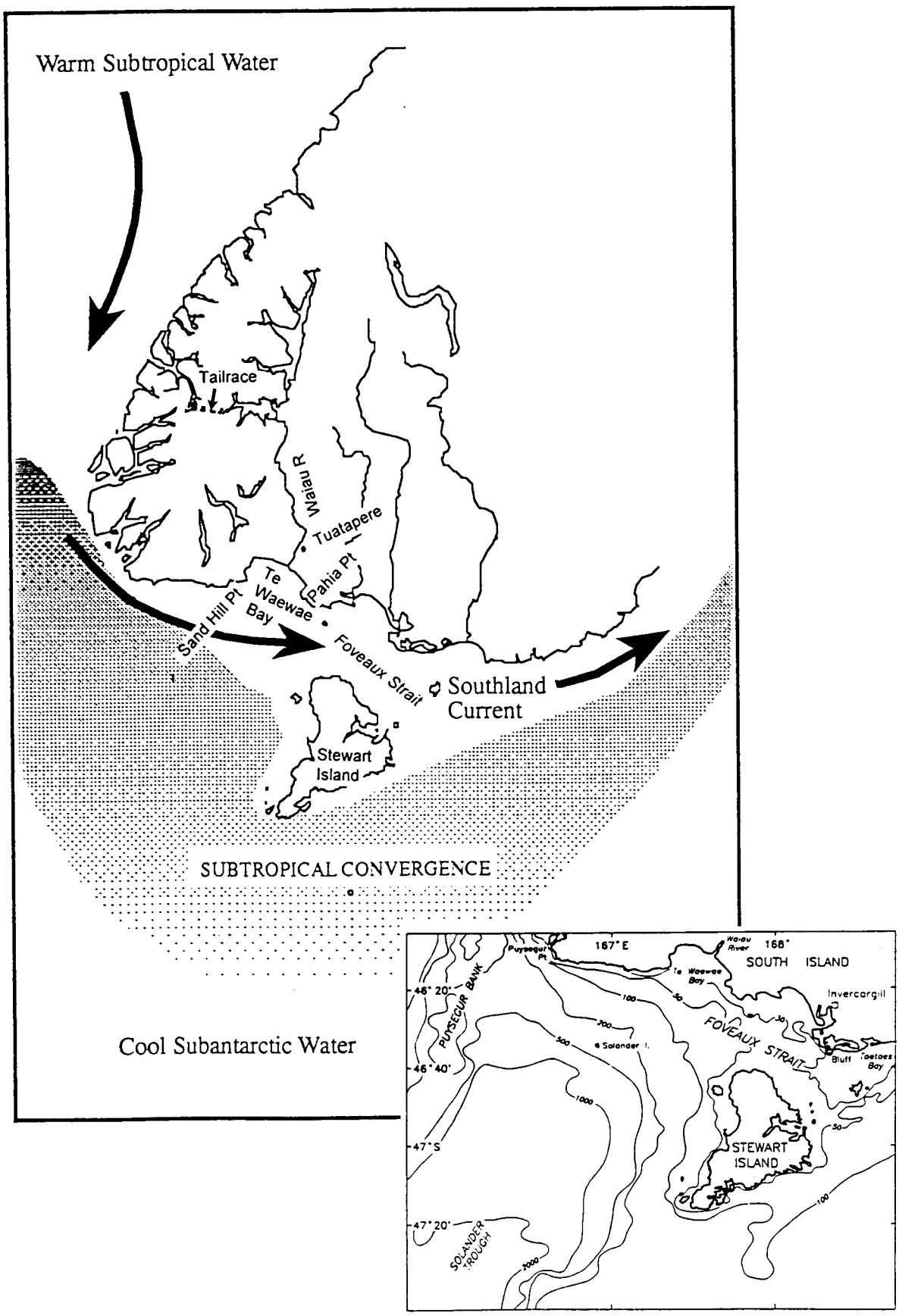



Fig. 1 Major ocean currents and approximate location of the Subtropical Convergence Zone, southern New Zealand. Inset shows the bathymetry (m) and geographic and bathymetric features mentioned in the text (from Robertson 1993a; Bradford *et al.* 1991).

waters of the STC which can enhance plant nutrients, but these processes are not well understood and are thought to be intermittent (Bradford *et al.* 1991; Bulter *et al.* 1992).

The hydrographic properties are further complicated by runoff from the southern coast (Bradford *et al.* 1991). Fiordland has one of the highest rainfalls in the country (Anon. 1983) which is reflected in the salinities of the southwestern fiords (Stanton & Pickard 1981). This water is carried to the south by the mean circulation and may be continuous into Foveaux Strait (Bradford *et al.* 1991; see Fig. 5, 1980). The water coming from Doubtful Sound also contains the flow from the Manapouri Power Station (Stanton & Pickard 1981).

### 3.1 SUMMARY

- The general flow is from west to east in the southern New Zealand region.
- The Foveaux Strait region is adjacent to the Subtropical Convergence, a region where water properties change rapidly.
- There are complicated oceanic processes occurring which can enhance plant nutrients, but these processes are not well understood.
- Tides in Foveaux Strait are strong, and the non-tidal currents there are strongly wind driven.
- The Foveaux Strait region is impacted by freshwater runoff from the southern coast and indirectly from Fiordland, which has the highest rainfall in New Zealand. The water coming from Doubtful Sound also contains the flow from the Manapouri Power Station.

## 4.0 INFLUENCE OF THE WAIAU RIVER

Recordings of the flows in Waiau River at Tuatapere, began 5 years before water was first diverted out of Lake Manapouri to Deep Cove. Mean flows (Fig. 2) for the years 1964–1969 were 560 cubic metres per second (cumecs), whereas from 1973 to 1991 inclusive the mean flow was 137 cumecs (Riddell *et al.* 1993). The mean flow is heavily weighted by floods and the river flow is less than 137 cumecs for 72% of the time.

The dissolved constituents of the Waiau River at Tuatapere are taken here to represent the input to the ocean (Robertson 1993b). The levels of

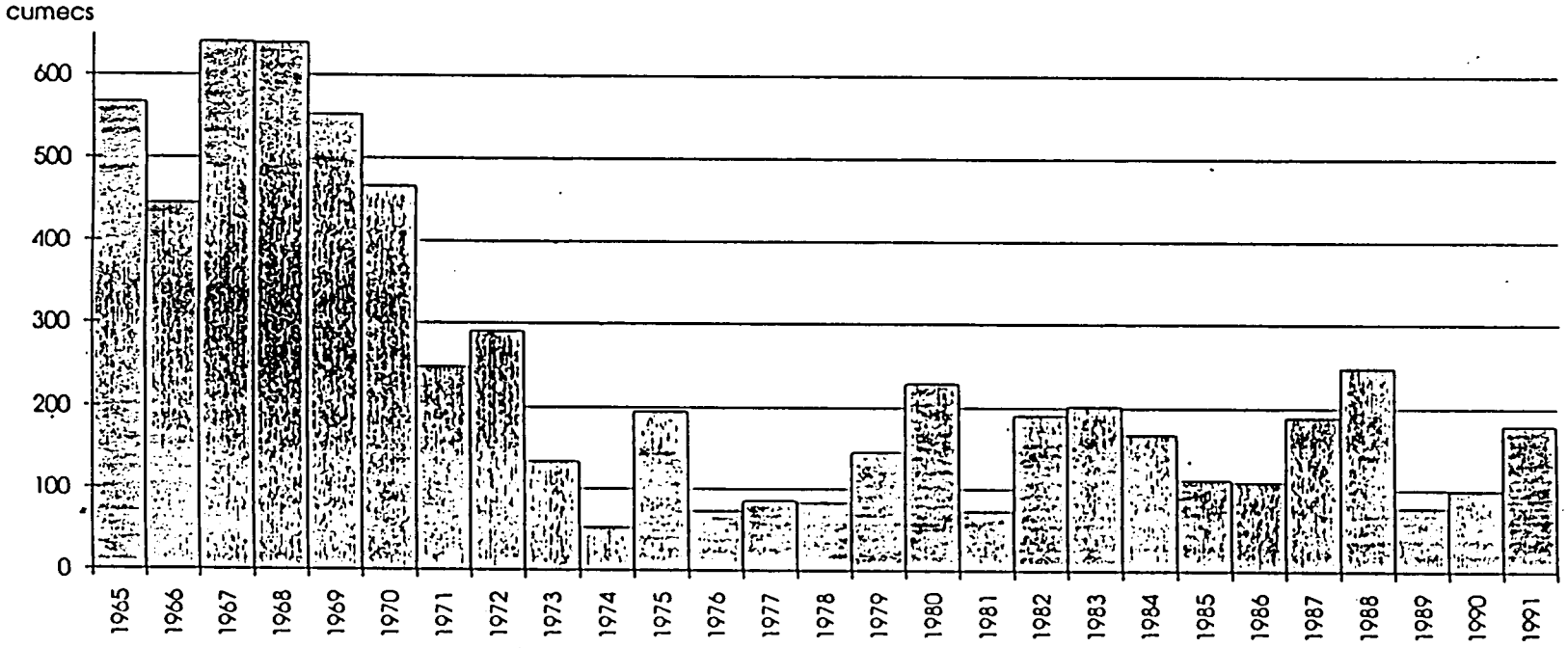



Fig. 2. Waiau River mean annual flows at Tuatapere (from Riddell *et al.* 1993)

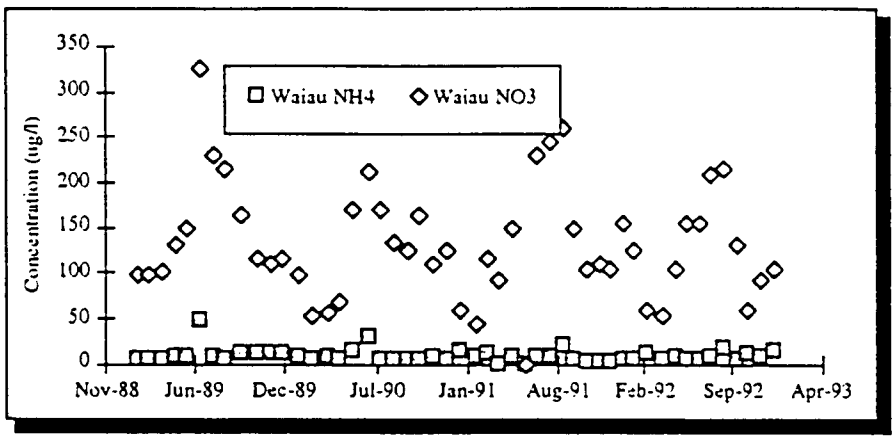



Fig. 3 Monthly nitrate-nitrogen and ammonia-nitrogen concentrations (µg/l) in the Waiau River at Tuatapere (National Monitoring Network data) (from Robertson 1993b).

nitrate-nitrogen are variable and, together with ammonia-nitrogen, are quite high compared with the ocean nearby in summer (Bradford *et al.* 1991) (see Fig. 6). Robertson (1993b) reports National Monitoring Network data from November 1988 to December 1992 which shows that nitrate-nitrogen can vary seasonally from 50–325 mg/l, whereas ammonia-nitrogen was less variable and ranged from about 5–50 mg/l (Fig. 3). Dissolved reactive phosphorus varied from 1–22 mg/l.

The reduction of flow from Lake Manapouri down the Waiau River in 1969 probably served to elevate nutrient concentrations slightly at Tuatapere. The reason for this is that the nutrient content of Lake Manapouri in the summer of 1993 (25 mg/l nitrate-nitrogen) was less than the backgound levels in the river (approximately 50 mg/l nitrate-nitrogen). The rate of addition of nutrients to the southern coast has probably been lowered only slightly, post control, although the exact amount is difficult to estimate. Nevertheless, these nutrients are not lost to the marine system; Lake Manapouri water enters the ocean from Fiordland and is entrained into the flow down the southwest coast which turns east into Foveaux Strait.

One way of estimating the potential impact of nitrate-nitrogen derived from the Waiau River is by examining the percentage contribution that river water makes to nearshore waters in Te Waewae Bay. The minimum salinities that have been observed, as close to shore as research vessels have navigated, are between 32 and 33 (Bradford *et al.* 1991). If we assume the background salinity reflecting adjacent ocean water is 34.7 (the salinity of the STC) then a salinity of 32 represents an 8% addition of fresh water to the surface sea water. This percentage contribution of fresh water translates into an addition of 4–26 mg/l of nitrate-nitrogen to nearshore oceanic water. This nutrient addition, at the higher concentrations, would have the capacity to appreciably impact nearshore nutrient levels at peak periods - usually in winter. There is less information on dissolved reactive silica. DSIR Water Supply Investigations in 1987 (Robertson 1993b) show reactive silica at Tuatapere to be 7400 mg/l; we do not know how much of this remains dissolved nor what the background levels are in Foveaux Strait.

Another calculation that we can make is to compare the calculated theoretical dilution that is available if we know the tidal compartment (the new water that is introduced in one-tidal cycle). An indicative flushing time for Te Waewae Bay is calculated from the number of tidal cycles required to replace all the water of the bay. Each tidal cycle is assumed to bring into the bay a volume of new water equal to the surface area of the bay multiplied by the tidal range. We have taken the bay to be defined by the coastline on RNZN navigational chart NZ 76, "Western Approaches to Foveaux Strait", and a line drawn from Pahia Point to Sand Hill Point.

The area enclosed is 361 $km^2$. The neap tidal range is 1.3 m, and the spring range is 1.9 m (from the figures on the chart for neap tide at neighbouring Colac Bay). Thus the new water volume in a neap-tidal cycle is 1.3 m x (361 x $10^6$ $m^{2)}$ = 4.7 x $10^8$ $m^3$ and the volume in a spring-tidal cycle is 1.9 m x (361 x $10^6$ $m^2$) = 6.9 x $10^8$ $m^3$.

The volume of water contained in the Bay as defined above is 57 x $10^8$ $m^3$. Assuming tidal turbulence mixes the bay thoroughly between tides, the concentration of "old" water in the bay is reduced approximately by a factor 1 - 4.7/57 = 0.92 over one neap tidal cycle and by a factor of 1 - 6.9/57 = 0.88 over one spring tidal cycle. Thus approximately 17 cycles (8.5 days) are required to reduce old water to 25% of the contents of the bay during neap tides, and 11 cycles (6.5 days) during spring tides. Flushing times for other concentrations are tabulated in Table 1.

Table 1.
Estimated flushing times in Te Waewae Bay
for different numbers of tidal cycles.

| Concentration of "old" water | No. of neap cycles | Days |
|---|---|---|
| 1 | 0 | 0 |
| 0.75 | 3 | 1.5 |
| 0.5 | 8 | 4 |
| 0.25 | 17 | 8.5 |
| 0.1 | 28 | 14 |

Or, put in another way, the Waiau inflow at 100 cumecs delivers 0.04 x $10^8$ $m^3$ during a tidal cycle i.e., less than 1% of the tidal compartment. At 200 cumecs it delivers less the 2% of the tidal compartment.

Flushing times calculated by any means are only a crude indicator, based on gross assumptions and approximations. It is possible that sufficiently strong winds could flush the entire bay in a very short time. In the absence of wind, the tide will continue to flush the bay and the advantage of a tidal flushing time (based on the minimum tides) is that it measures the maximum time expected for the bay waters to be refreshed. Wind will ensure that the bay flushes more rapidly. Extensive field work or modeling would be needed to refine the flushing time calculated above.

Other consitutents potentially of concern include heavy metals, synthetic organic compounds, toxic gases and anions, and acids and alkalis. The latter pollutants are usually the result of heavy urban and industrial land use which do not occur in the Waiau catchment. Because

of intensive agricultural land use, pesticides and heavy metals bound to fertilisers might be expected to be present in runoff from the land into the Waiau River (Robertson 1993b). Nevertheless, Robertson (1993b) considers the potential for toxicants to enter the Waiau are limited. The only compound of concern is the heavy metal cadmium found in fertiliser. Robertson (1993a) notes the high concentrations of cadmium in Foveaux Strait oysters but could find no convincing evidence that the cadmium originated from the land. Even if it does, the rate of addition to the ocean has probably not changed pre to post control.

## 4.1 SUMMARY

- Dissolved inorganic nutrients in the Waiau River are high relative to the ocean.

- The rate of addition of dissolved inorganic nutrients to the south coast has probably decreased only slightly post control, because Lake Manapouri water is relatively low in nutrients. Nevertheless, the nutrients from the lake are not lost to the marine system; Lake Manapouri water enters the ocean from the Fiordland coast and is entrained into the flow down the southwest coast which turns east into Foveaux Strait.

- Overall there has probably been little impact of changed flows in the Waiau River on the salinity of Foveaux Strait, as the water of Lake Manapouri has not been lost from the system of southern New Zealand, as this water eventually reaches Foveaux Strait via the Fiordland coast.

- The contribution of dissolved inorganic nutrients from river water to the ocean is confined to near the shore and is probably related to the salinity, but in a way that can not be predicted given the seasonality in nutrient content of river water and the fact there are oceanic sources as well.

- River water contributes about 8% of the surface sea water with a salinity of 32; or contributes less that 1% of the tidal compartment (the new water brought into the bay on a tidal cycle) at 100 cumecs.

# 5.0 PHYTOPLANKTON BIOMASS IN RELATION TO SURFACE HYDROGRAPHY IN SOUTHERN NEW ZEALAND

Work was carried out in the late 1970s on environmental variability in relation to phytoplankton biomass (chlorophyll *a*) (Bradford *et al.* 1991). During this study data were collected in the southern New Zealand region, in consecutive Februarys of 1977–1980. Maps of the distribution of temperature, salinity, nitrate-nitrogen and chlorophyll *a* were created (Figs 4–7). Interpretation of these results allowed us to analyse the various sources of variability, and, although the results are not conclusive, they are suggestive.

## 5.1 EXPLANATION OF THE FACTORS MEASURED

It is very labour intensive to obtain information on some aspects of the marine system. Over the years, oceanographers, in their efforts to understand the interaction of the physical and chemical environment on the biological system, have developed a number of techniques which allow the marine system to be defined with the least effort.

Modern techniques using Conductivity / Temperature / Depth devices (CTD) enable the vertical and horizontal physical structure of the ocean to be defined from the temperature (°C) and salinity (in "practical salinity units" which are derived from the conductivity of sea water). With calibration of the electronic sensors and a knowledge of the background properties of the water masses (which have very conservative properties) the origin of water can be determined with confidence, as long as there is enough data on the vertical as well as horizontal distribution of physical properties.

Planktonic (floating) microscopic plants (phytoplankton) are usually quantified by measuring the amount of chlorophyll *a* (green photosynthetic pigment) that is in the water (in milligrams per cubic metre of sea water). Because there are other organisms of about the same size as phytoplankton (bacteria and very small animals), chlorophyll *a* is used as a measure of phytoplankton because they are the only organisms that contain chlorophyll *a*. Phytoplankton are at the base of the food web in the open ocean. All marine animals ultimately depend on phytoplankton, either directly or indirectly, for food. Marine animals such as oysters and toheroas feed directly on phytoplankton, whereas squid and seabirds feed on planktonic animals which are further along the food web.

Phytoplankton depend on light and inorganic nutrients to manufacture food in the same way that land plants do. Because the upper

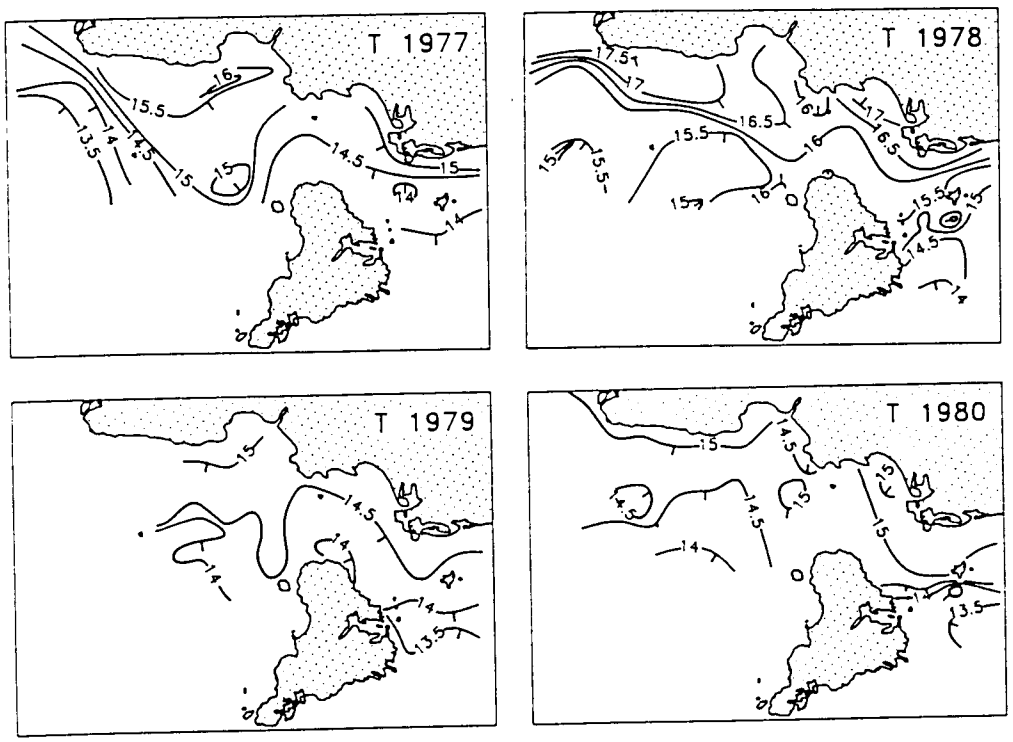



Fig. 4. Surface distribution of temperature (°C) in the southern New Zealand region in February 1977-1980 (from Bradford *et al.* 1991).

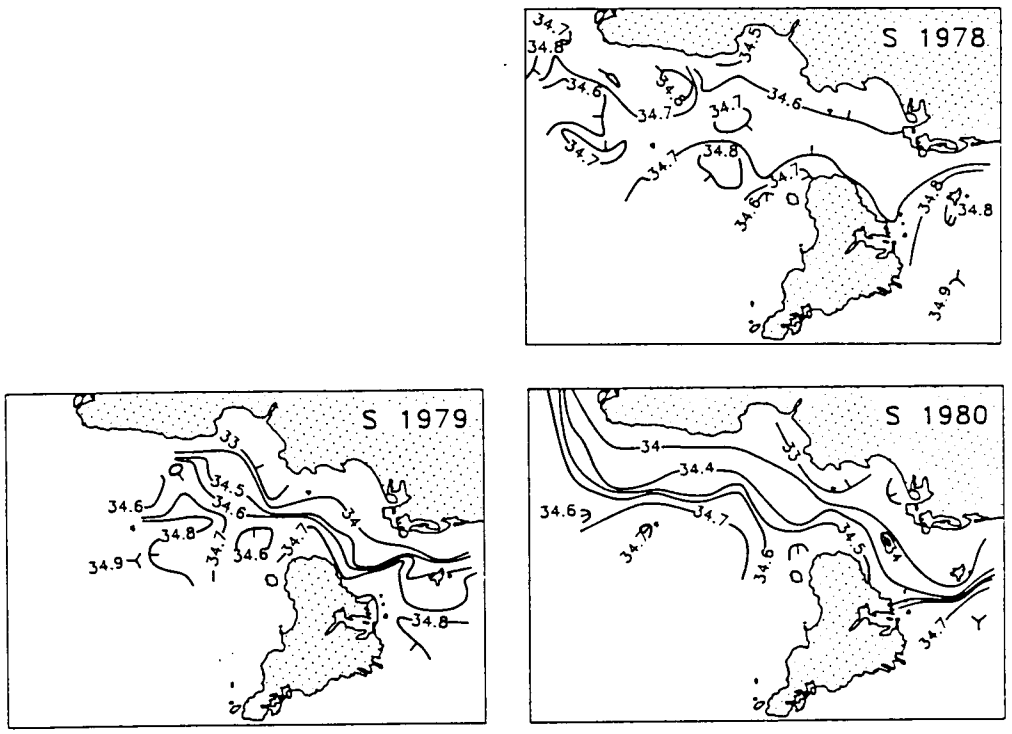



Fig. 5. Surface distribution of salinity in the southern New Zealand region in February 1978–1980 (from Bradford *et al.* 1991).

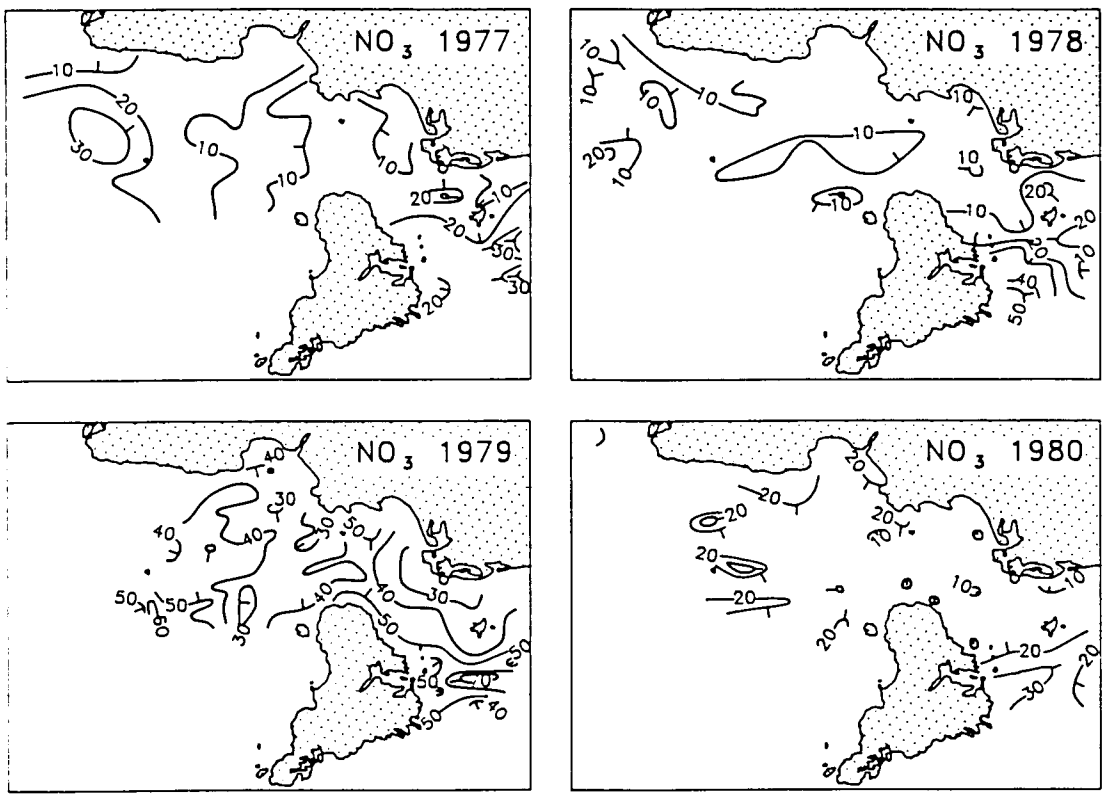



Fig. 6. Surface distribution of nitrate-nitrogen (µg/l) in the southern New Zealand region in February 1977–1980 (from Bradford *et al.* 1991).

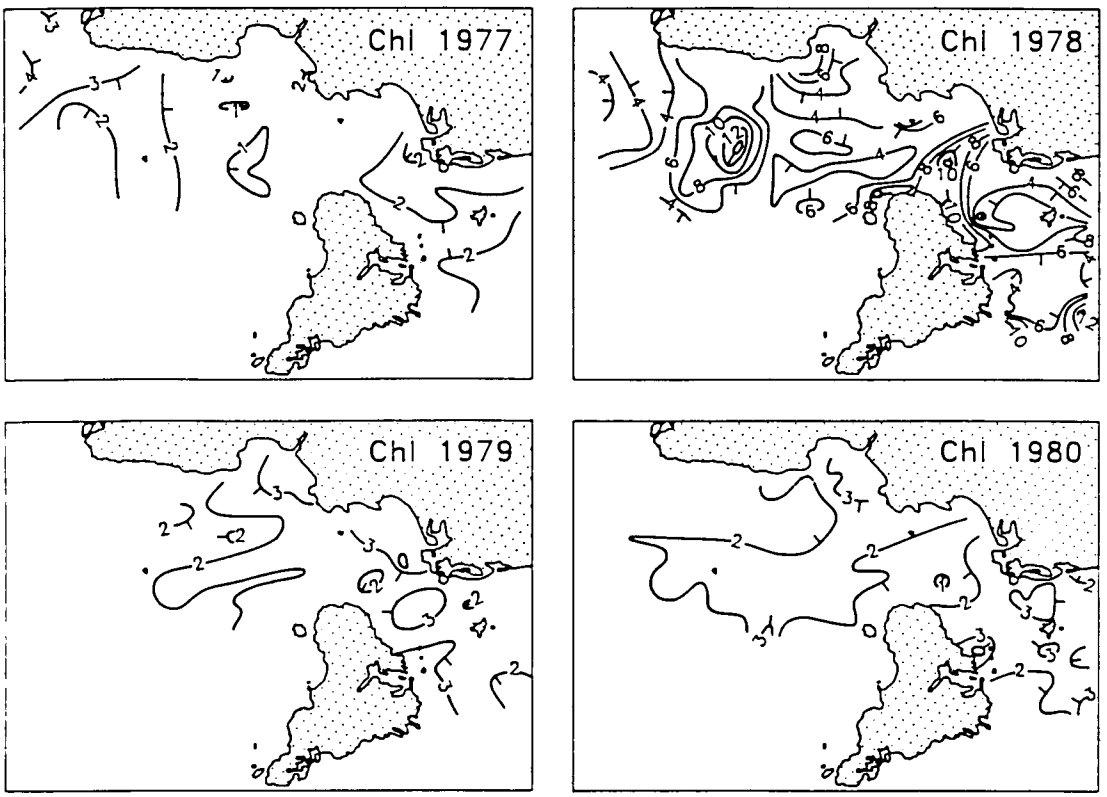



Fig. 7. Surface distribution of chlorophyll *a* (µg/l) in the southern New Zealand region in February 1977-1980 (from Bradford *et al.* 1991).

layers of the ocean can often be mixed below the level to which light reaches, phytoplankton can become light-limited in their growth, especially in winter. Also in summer, when surface layers become stable through heating by the sun, phytoplankton can become nutrient-limited in their growth as the plants use up the available nutrients. Nitrogen is thought to be one of the main limiting nutrients. It is available to phytoplankton in the form of nitrates, ammonia, and urea and may be measured in micrograms per litre of sea water (or mg/l). In addition, other commonly occurring phytoplankton nutrients are phosphorus (referred to as dissolved reactive phosphorus), and dissolved reactive silica, which is necessary for the growth of diatoms since it is the basic building block of their skeletons. As well as these macronutrients, there are other substances which are required in very small amounts, such as trace metals and vitamins; there are very few data on their occurrence in New Zealand waters.

## 5.2 SALINITY, TEMPERATURE AND NITRATE-NITROGEN

The general properties of southern New Zealand, adjacent to the STC, are complicated by proximity to the coast. Away from New Zealand salinities and temperatures decrease and nutrients increase from north to south. (Heath 1985; Bradford & Taylor 1980). In the vicinity of Foveaux Strait, the temperature trend remains the same as offshore (Fig. 4) but the salinity trend is reversed, presumably because of river runoff (Fig. 5); there is no particular trend in nitrate-nitrogen data although there is a slight tendency for it to be elevated in the low salinity water near shore (Fig. 6).

There are at least four possible causes of the variability observed in the summers of 1977–1980 in the southern New Zealand region (Bradford *et al.* 1991). Each of these causes is treated separately below with a discussion of whether they are likely to have influenced the nitrate-nitrogen content of the sea water.

### 5.2.1 River Water

Salinities were consistently low along the southern coastline of South Island, especially in 1979 and 1980 (Fig. 5) and were related to the local runoff (Fig. 8); flows in the Waiau River were very low in January and February 1978. It is also clear that freshwater run-off also entered the area from the Fiordland coast in 1980 (Fig. 5). The absence of substantial run-off in 1978 coincided with higher temperatures in the region and separate this year from 1979 and 1980, these later years were characterised by a narrow range of temperatures but a wide range of salinities (Figs 4,

5). In 1979 and 1980, nearshore water had similar salinities and chlorophyll *a* concentrations (Fig. 7) but had very different nitrate-nitrogen content (Fig. 6). This suggested, all other things being equal, that there must have been a source, other than riverine, for the much higher nitrate-nitrogen content of the general region in 1979.

### 5.2.2 Nearshore Inflow from the West

In 1978, high salinity water appeared in conjunction with relatively high temperatures over the continental shelf between Puysegur Point and Te Waewae Bay (Figs 4, 5). The satellite sensed sea surface temperature pattern of 5 March 1987 supports the general conclusion that warm water from the Tasman Sea contributes to flows around southern New Zealand and the east coast (Fig. 9) (see also Butler *et al.* 1992). At the time this scene was recorded, concurrent current meter data, collected at 50 m depth off Big Bay on the Fiordland coast (Cahill *et al.* 1991), revealed this was a period of increasing temperatures and southerly flows. The properties of the nearshore water entering the area from the west fluctuated. In 1979 and 1980 this water was cool (<15°C) and of low salinity (<34) (Figs 4, 5). In 1978 it had a higher temperature (>17°C) and salinity (>34.7). Nitrate-nitrogen concentrations in this nearshore water in 1978 lay between 10 and 15 mg/l (Fig. 6). In 1979 the region surveyed did not extend far enough west to be certain that west coast water had been sampled. The surface nitrate-nitrogen concentrations in the vicinity of Puysegeur Point in 1977 and 1978 were similar to the surface measurement made at Station 618 during *Eltanin* cruise 26 in 1966 (Fig. 10), but were greater then the 1.4-7.0 mg/l recorded at the surface off Westland in February (Bradford & Chang 1987). Therefore nearshore inflow from the west does not appear to be the source of nutrients.

### 5.2.3 Tidal Mixing

It is difficult to be certain about the influence of tidal mixing on Foveaux during the period studied, in the absence of information on the vertical structure.

In the present study the northward bulge of the isotherms north of the extremity of Stewart Island (Fig. 4), was sometimes accompanied by higher nitrate-nitrogen (1977, 1979) (Fig. 6). This partial orientation of the isotherms with the bathymetry across the strait (Fig. 1) is similar to the distribution of well-mixed water in depths <50 m in May 1960; this was interpreted by Houtman (1966) as resulting from the mixing effects of tidal currents and high winds. This effect was most pronounced in February 1977 when the cool water was bounded by a relatively strong gradient, at least to the west (Fig. 4). This cool water was associated with

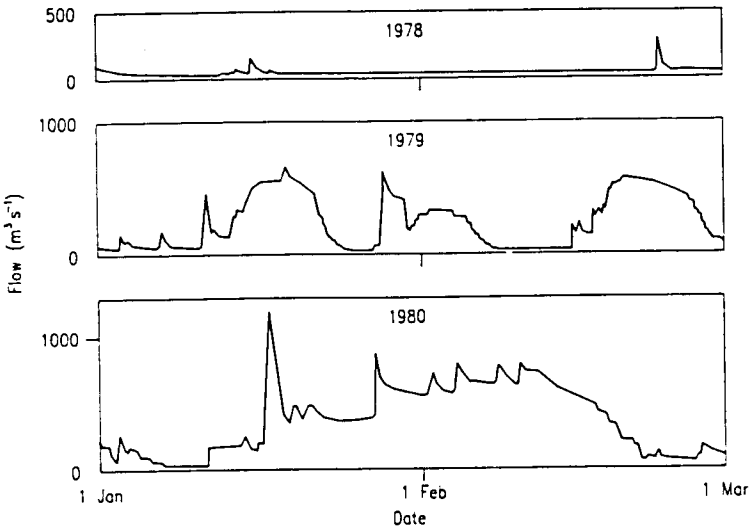



Fig. 8. Flow (cumecs or $m^3 s^{-1}$) of the Waiau River at Tuatapere for January and February 1978, 1979, 1980 (from Bradford *et al.* 1991).




Fig. 9. Sea surface temperature in the southern New Zealand region from satellite imagery, 5 March, 1987 (from Bradford *et al.* 1991).

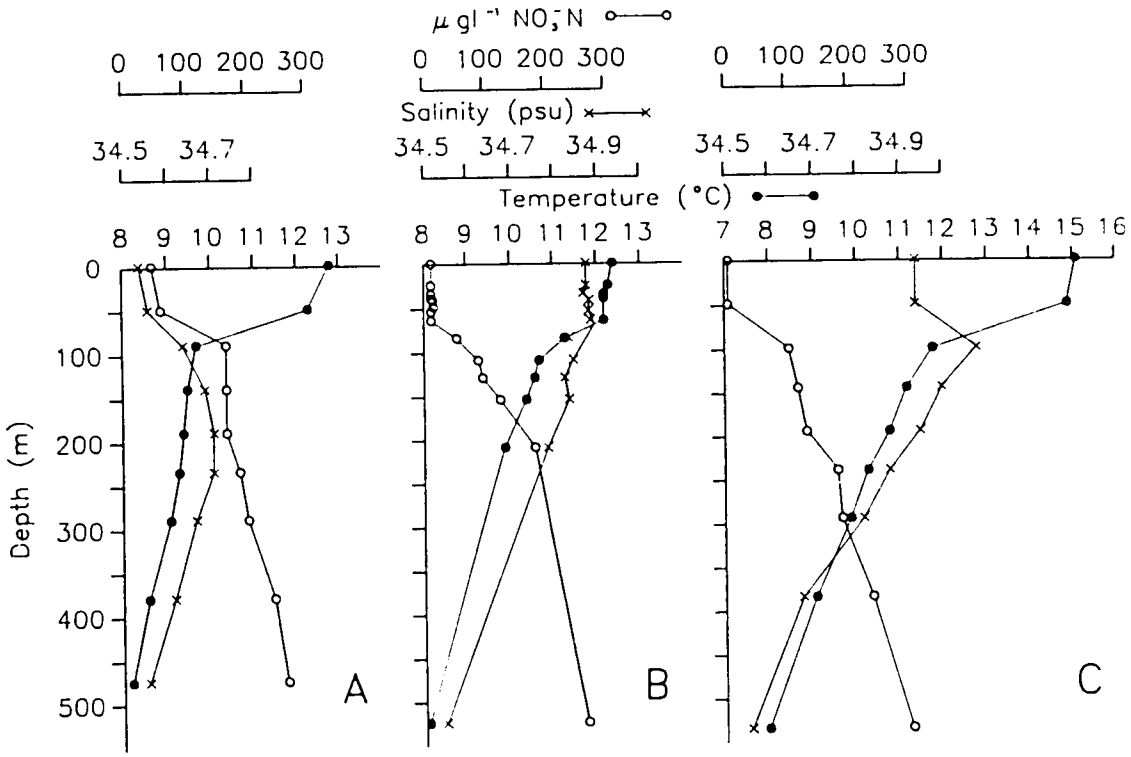



Fig. 10. Profiles of salinity, temperature, and nitrate-nitrogen at three *Eltanin* stations in the southern New Zealand region (from Bradford *et al.* 1991).
**A**, Stn 399, Cruise 16, 5 February 1965, 47°05'S, 162°10'E;
**B**, Stn 618, Cruise, 26, 16 December 1965, 45°20.4'S. 165°58.2'E;
**C**, Stn 398, Cruise 16, 3 February 1965, 44°21'S, 162°02'E.

high concentrations of nitrate-nitrogen (up to 15 mg/l), bounded by north to south-oriented nitrate-nitrogen isopleths (Fig. 6). This distribution of cool nutrient-rich water is similar to that observed by Bradford et al. (1986) in Cook Strait. Though it is possible that tidal mixing contributes to the nitrate-nitrogen enrichment of surface waters in Foveaux Strait narrows, there is evidence that it is not the only process doing so. In 1977 and 1979 there were other, apparently unrelated, centres of high nitrate-nitrogen water near Solander Island.

### 5.2.4 Intrusion of Saline, Nutrient-rich Water

In 1978, 1979, and 1980 relatively saline water (>34.75) appeared as tongues of low-temperature water in Foveaux Strait extending from the south, between Solander Island and Stewart Island, and east of Stewart Island (Figs 4,5). These tongues had differing maximum concentrations of nitrate-nitrogen: 45 mg/l (1977); 55 mg/l (1978); 60 mg/l (1979); 25 mg/l (1980) (Fig. 6) which were associated positively with the value of the maximum salinities of this water: least (34.75) in 1980, and greatest (34.96) in 1979. It is not possible to come to definite conclusions about the mechanism by which high-nutrient water enters Foveaux Strait, as no vertical data were collected during this study and there are few historical data on vertical nutrient distribution in this area. Bradford *et al.* (1991) considered two possible origins for the high-nutrient water, but dismissed water from the south, as the salinity would have to have been lower (34.45) than that observed (>34.75).

The other possible origin of high-nutrient water is from below the nutrient-depleted near-surface zone, by some form of uplift of deeper water layers. If we assume the vertical structure of Stations 398 or 618 from *Eltanin* cruises 16 and 26 (Fig. 10) are indicative of the properties of water entering the Foveaux Strait region, then uplift of water from 50-100 m at these stations could have produced the surface temperatures, salinities, and nitrate-nitrogen concentrations observed in the late 1970s, given there would also be some mixing with more dilute, warmer coastal water at the surface. Does this type of uplift occur? The remotely sensed sea surface temperature from 5 March 1987 (Fig. 9) shows a band of cold water near the Pusegur Bank, separating warm water west of Fiordland from the warm water south of South Island. This water could have been derived from deeper in the water column but existing data (see also Butler *et al.* 1992) does not allow this possibility to be evaluated. It is noted, however, from the same scene, that a tongue of cold water west of Stewart Island appears to be entrained into an anti-clockwise circulation at the head of the Solander Trough.

It has been noted that off Westland there is considerable non-seasonal variability in salinity, temperature, and continental slope currents (Heath & Ridgeway 1985). In particular, between March and May 1982, more saline water which had been transported from either offshore or alongshore from the north, replaced low-salinity water off Westland. Since the flow of water of subtropical origin around New Zealand is linked to that on the west coast of South Island (Stanton 1976), it is expected that a similar variability will be observed in the Foveaux Strait region.

## 5.3 CHLOROPHYLL *A* AND ENVIRONMENTAL VARIATION

The average chlorophyll *a* concentrations recorded at the surface in the late 1970s (Bradford *et al.* 1991) were similar to those found off Westland in February (Bradford & Chang 1987). However, there were also regions in 1978 (the warmest, most saline year: Fig. 7) where chlorophyll *a* values were considerably elevated compared with Westland.

Chlorophyll *a* concentrations during the study of the late 1970s showed no direct overall relationship with the nitrate-nitrogen content of the water (Figs 6, 7). The explanation for this lack of relationship was that these were "snapshots" of data taken in what is a dynamic sequence of events. Some events in such a sequence may be represented by "snapshots" from February in another study period. For example, it is possible that the circumstance recorded in 1978 was preceded by an influx of nutrient-rich water such as occurred in 1979 (Fig. 6, 7). "Snapshots" such as those from the late 1970s also may not be a good indicator of conditions prevailing throughout the summer. For example, an experiment, studying growth of oysters on the sea floor, in the last two summers sampled, found that oysters had grown twice as fast in the summer of 1978/79 as they had in 1979/1980. The mean chlorophyll *a* values for the station sampled in the "snapshots" were effectively the same (2.5 mg/l in February 1979 and 2.2 mg/l in February 1980). The elevated nutrient levels in 1979 may have resulted in much higher phytoplankton levels later that summer and resulted in the higher oyster growth rate that year.

It is possible that the full range of possible plankton variability has not been recorded as there have been major population declines (see section 5). There are two explanations of assumed poor feeding conditions which concern a greater-than-usual intrusion of water from the Tasman Sea. One explanation concerns warm, subtropical water, low in dissolved inorganic phytoplankton nutrients. If this water was not mixed vertically then the biomass of phytoplankton would be low, like that found offshore off Westland (Bradford & Chang 1987). Alternatively, if this greater inflow of subtropical water was in the form of uplifted, high-salinity, high-nutrient, relatively low-phytoplankton water (as in February 1979: Figs 5,6) and the intrusions were frequent, then phytoplankton biomass would be expected to remain low.

## 5.4 SUMMARY

- A study of variability of surface temperature, salinity, nitrate-nitrogen, and chlorophyll *a* (quantity of phytoplankton) in February 1977–1980 in the southern New Zealand region allows analysis of sources of variability.

- River waters lower salinity along the coast. This river water comes from Fiordland as well as the rivers flowing onto the southern coast.

- The year of lowest flow from the Waiau River (1978) was the year of highest nitrate-nitrogen, suggesting a non riverine source of nitrate-nitrogen at that time.

- Tidal mixing may renew nutrients in surface waters in Foveaux Strait narrows.

- It is postulated that uplift of water of subtropical origin (over Puysegur Bank) is a mechanism by which nitrates may be elevated with relatively high salinities.

- The connection between elevated phytoplankton nutrients and high phytoplankotn biomass has not yet been directly demonstrated.

- Data collected to date suggests that the outflow from the Waiau River has an insignificant effect on the nutrient/phytoplankton dynamics of Foveaux Strait, relative to other local hydrographic phenomena.

We do not know the environmental circumstances that lead to 22–23 year declines in oyster populations, only that the effect appears to be wider spread than the Southland coast.

# 6.0 FISHERIES

Foveaux Strait and its approaches support several large populations of economically important species. The predominant commercial species are oysters, squid, and sooty shearwater and these have sustained high levels of exploitation relative to other parts of New Zealand. The dependence of these species on a planktonic food source indicates that the Foveaux Strait region has high primary and secondary productivity.

The Solander area (the western entrance to Foveaux Strait) was the world's prime sperm whale fishing ground (Bullen 1899). The recent discovery and exploitation of high densities of squid in the Solander area

(Tyson *et al.* 1986, 1987) points to the possibility that sperm whales had been congregating to exploit this squid production. The Stewart Island area is also the main breeding ground for a large population of sooty shear water (*Puffinus griseus*), the juveniles of which (mutton birds) have been subject to exploitation since Maori occupation (Richdale 1946). There are also commercial fisheries for rock lobster and blue cod.

Foveaux Strait oysters (*Ostrea chilensis*, see Cranfield & Michael 1989) are present throughout New Zealand, but it is only on the floor of Foveaux Strait that their numbers are sufficient to support a commercial fishery of major significance. Unlike any other population of oysters around the world, this population has been productive enough to withstand substantial exploitation for over 100 years (Cranfield 1979). Nevertheless there have been major population declines in the winters of 1940, 1963, and 1986. These declines did not result from over fishing and they coincided with periods when oysters were in extremely poor condition. Parasitic infections were implicated in the subsequent heavy mortalities in 1963 and 1986. In each case the extremely poor condition of the oysters was considered to have lowered their ability to resist disease. The parasite *Bonamia* caused the mortality in 1986 and probably also in 1963 (Dinamani *et al.* 1987) although the 1963 mortality was attributed (Stead 1971) to *Bucephalus*, the only parasite apparent in the technically-limited investigation of that period. During 1986 not only were oysters in extremely poor condition, but mutton bird condition was apparently also very poor. Shore birds along the Otago coast were also affected in the same period. Spotted shags (*Phalacrocorax punctatus*) failed to breed successfully in late 1985 and yellow-eyed penguins starved from December 1985 through the 1986/87 season (see Bradford et al. 1991). These widespread events suggest that a broadly occurring environmental disturbance was in progress which was not restricted to Foveaux Strait.

Toheroa are one of Southland's most important traditional and recreational fisheries (McKinnon & Olsen 1994). Since 1978 the only beaches in New Zealand capable of supporting open seasons have been Oreti Beach and to a lesser extent Te Waewae Bay (Bluecliffs Beach). Open season were held at Bluecliffs Beach in 1972, 1974, 1978–1980, but in no years since. The Southland Toheroa reach legal size after 7 years (compared with 4–5 years for North Island Toheroa) so they are vulnerable to over-harvesting and take a longer time to recover if stocks are depleted. Toheroa are also susceptible to environmental changes which can result in large fluctuations in the population size and distribution, and recruitment failure. McKinnon & Olsen (1994) contend that sediment type and instability of Bluecliffs Beach appears to restrict settlement of toheroa, and that the recovery of the population will therefore depend on the beach environment. However they are not specific about what type of instability or sediment type is optimum or disadvantageous.

## 6.1 SUMMARY

- Foveaux Strait supports several large populations of economically important species.

- Major population declines in Foveaux Strait oysters occurred in the winters of 1940, 1963 and 1986, and were related to periods when oysters were in poor condition and probably had parasitic infections.

- The 1986 decline in oysters was accompanied by declines in mutton bird condition, and shorebirds on the Otago coast starved. These widespread events suggest a broadly occurring environmental disturbance that was not restricted to Foveaux Strait.

- Toheroa are vulnerable to over fishing and change in the sediment regime of beaches.

- Information to date suggests that outflow from the Waiau River does not impact populations of animals that support local fisheries.

# 7.0 NON-COMMERCIAL FLORA AND FAUNA

A substantial amount is known about the flora and fauna of the region (see e.g., Thompson 1987). However, apart from commercial fisheries, no quantitative studies have been made which allow a comparison to be made of Foveaux Strait biota before and after control of the Waiau River.

# 8.0 TOXIC AND NOXIOUS PHYTOPLANKTON

## 8.1 THE BIOTOXIN MONITORING PROGRAMME

The routine monitoring of shellfish for biotoxins throughout New Zealand began in January 1993, and 11 sampling sites were chosen in area (J) along the Foveaux Strait, and Stewart Island coasts (Table 2).

Only a few of these sites (primary sites) are sampled on a regular weekly basis (e.g., J07, J08, J09, J13). Other sites such as the mid Foveaux Strait sites (J06A, & J06B), which are located over the oyster beds, are only sampled just prior to and during the harvesting season, or to increase the spatial coverage in the event of the detection of biotoxin contamination at the primary sampling sites. Samples of shellfish are tested by mouse

Table 2.
Southland shellfish biotoxin monitoring sites Zone J.

| Sampling site | Location | Species sampled |
|---|---|---|
| J06 (A & B) | Foveaux Strait | Oyster (*Tiostrea*) |
| J07 | Monkey Island (Te Waewae Bay) | Oyster (*Tiostrea*) |
| J08 | Jacobs Estuary (Riverton) | Cockle (*Austrovenus*) |
| J09 | Te Waewae Bay | Mussel (*Perna*) |
| J11 | Colac Bay | Mussel (*Perna*) 7 |
| J12 | Horseshoe Bay, Stewart Island | Cockle (*Austrovenus*) |
| J13 (A–C) | Big Glory Bay, Stewart Island | Mussel (*Perna*) |
| J14 | Wakapatu | Mussel (*Perna*) |

bioassay for the presence of Paralytic Shellfish Poisoning (PSP) toxins, lipid soluble toxins (Diarrhetic Shellfish Poisoning (DSP) toxins and Neurotoxic Shellfish Poisoning (NSP) toxins) and for domoic acid (Amnesic Shellfish Poisoning (ASP) toxin) by High Performance Liquid Chromatography (HPLC) analysis.

From biotoxin monitoring statistics (New Zealand Marine Biotoxin Management Board reports) the incidence of shellfish-biotoxin contamination in Foveaux Strait is amongst the highest in any region (18% of 343 bioassays during 1994) throughout the country, however the data are weighted by the number of lipid toxin positive bioassays resulting from the gymnodimine contamination events subsequently shown not be toxic to humans. During 1994, eight samples of oysters (2% of total bioassays) tested positive for PSP toxins though none of these exceeded the 80 mg / 100g of shellfish meat regulatory limit.

## 8.2 PHYTOPLANKTON MONITORING

Very few phytoplankton samples from other locations have been collected at any time so knowledge of the phytoplankton composition in the southern New Zealand area is rather limited. The most intensive phytoplankton sampling that has occurred at any time was between February and April, and August and October 1994 at site J06A & J06B during an investigation of the gymnodimine contamination phenomenon (Mackenzie *et al* 1996). Further phytoplankton sampling was carried out (usually only once) at a number of locations along the coast during January 1996 as a result of the re-appearance of gymnodimine contamination of oysters and mussels, and mass mortalities of surf clams and other shellfish.

### 8.2.1 *Gymnodinium* spp. blooms in Foveaux Strait Jan-Feb 1994

During January 1994 an acetone soluble toxicity was detected (by mouse bioassay) in dredge oysters (*Tiostrea chilensis*) collected from Foveaux Strait (sites J06A and J06B). As a result a large area of the coast of South Island was closed to shellfish harvesting (Mackenzie 1994; Mackenzie *et al.* 1996). The symptoms and dose response of bioassay mice were unusual and subsequent chemical analysis of affected shellfish revealed a new bioactive compound ("gymnodimine") was responsible (Seki et al. 1995, 1996). Examination of phytoplankton samples showed that high numbers of *Gymnodinium* spp. cells were associated with this toxicity. The dominant cell type in the population, which was comprised of at least 3 morphological types, was one closely resembling *Gymnodinium mikimotoi* but differing from this species in the form of its nucleus. A few cells of *Gymnodinium breve* were observed though it is unlikely these were responsible for any shellfish toxicity. Traces of PSP toxin were observed in some contaminated oysters at a time when low numbers of *Alexandrium minutum* were observed in the plankton. A south-north progression of shellfish toxicity, accounts of the mortality of a variety of marine fauna, and the appearance of *Gymnodinium* sp. in the plankton was observed over a four month period. The origin of the toxicity was confirmed by the bioassay of cultured *Gymnodinium* sp. cell concentrates and the toxicity acquired by oysters after feeding with *Gymnodinium* sp. cultures.

Different shellfish species metabolise or eliminate gymnodimine at very different rates, and oysters (*Tiostrea*) in particular retain the toxin for a considerable period after the contamination episode has ceased. Rat feeding experiments with gymnodimine contaminated oysters showed **that gymnodimine was not toxic on oral administration and did not constitute a hazard to human consumers** (New Zealand Marine Biotoxin Management Board 1994) (see section 8.2.2).

### 8.2.2 *Gymnodinium* spp. blooms in Foveaux Strait Jan-Feb 1996

In late December 1995 an acetone extractable toxin, subsequently diagnosed as gymnodimine contamination, was detected in shellfish from Foveaux Strait monitoring sites. It soon became obvious that this was a repeat of the 1994 event and involved a suite of planktonic dinoflagellate species identical (though perhaps more numerous) to that which existed in Foveaux Strait waters in 1994 (Mackenzie 1996).

Chronology of the summer 1995/96 Foveaux Strait *Gymnodinium* bloom incident. MU = Mouse Units

- 27 December 1995: Toxicity (38 MU/100g) first detected in lipid acetone screen in mussels at Te Waewae Bay on the Southland coast.
- 7 January 1996: Biotoxin sampling for planned Foveaux oyster enhancement programme harvest reveals toxicity >93 MU/100g (acetone extracts) <10 MU/100g (ether extracts).
- 10 January 1996: News of mass mortalities of paua (abalone) and some fish species, communicated by Biotoxin Surveillance Unit after reports by paua divers. Some accounts suggested some abalone recovered from these effects. These reports extended from Invercargill to Balclutha and were associated with reports of a red/brown dis-colouration of the water.
- 10-11 January 1996: High numbers (up to 5.0 $x10^5$ cells / l) of at least 3 *Gymnodinium* species were observed in samples from Foveaux Strait, Waikawa Bay, and the Lower Catlins Estuary. These dinoflagellates were obviously the cause of the reports of discoloured water. *Gymnodinium breve* was present but in very low numbers (<1.0 $x10^2$ cells/l) . The dominant species was identical to the gymnodimine producing *Gymnodinium* cf. *mikimotoi* isolated during the 1993/94 bloom in Foveaux Strait The dinoflagellate bloom followed a period of heavy rain succeeded by two weeks of fine, sunny, calm weather. Several isolates of all species (including *G. breve*) were successfully established in laboratory culture from these samples.
- 13 January 1996: Mass stranding (about 1 million) of surf clams (various species) occurs at Colac Bay, Waikawa and Oreti beaches. Press coverage is limited to a few short items in the local newspaper.
- 14 January 1996: Harvesting of Foveaux Strait oysters begins after clearance by Biotoxin Unit based on the nature of the symptoms of bioassays mice (typical of gymnodimine) and the identification of the dinoflagellate. Over the succeeding weeks 1200 sacks (30,000 oysters) are harvested and consumed by the public with no known ill effects. Nationwide publicity about the long awaited availability of Bluff oysters.
- 15 January 1996: Fish kill (trout and other fish) reported from Waituna lagoon, plankton samples contain *Gymnodinium* spp. <3.0 $x10^5$ cells/l.
- 17 January 1996: Very low numbers (7.0 $x10^2$ cells / l) of *Gymnodinium* spp. observed in Foveaux Strait, replaced by diatom dominated community.
- 13 February 1996: Toxicity of 416 MU/100g in acetone screen test of Foveaux oysters.
- 20 February 1996: *Gymnodinium* spp. undetectable in Foveaux Strait waters.
- 1 March 1996: Oyster harvest, plankton sampling and mouse bioassay testing of Foveaux oysters ceases (very high toxicity of 945 MU/100g remains in oysters).

Conclusions drawn from the 1996 event.

- It is probable that *Gymnodinium* spp. blooms and gymnodimine contamination is a common summer time phenomenon in Foveaux Strait / South Otago waters. The blooms themselves appear to be relatively brief events though "gymnodimine"'contamination persists in oysters for a considerable period.

- These blooms may originate off southwest Fiordland and are propagated through the Strait and up the South Island east coast though as yet there is only limited information regarding the hydrographic/environmental background to these events to support this hypothesis. Perhaps significantly, the 1996 bloom followed a period of high rainfall followed by a fine calm spell.

- The oyster harvest seems to confirm that gymnodimine is not a hazard to human health since there were no ill effects in consumers. Nevertheless it is important that a reliable method of "gymnodimine" analysis is perfected so that it can be easily discriminated from other lipid toxicities detected by mouse bioassay.

- The presence of *G. breve* in Foveaux strait suggests there is a potential for NSP contamination in this area though it is unlikely to have played a role in the 1996 event.

- There is compelling circumstantial evidence that the *Gymnodinium* spp. bloom led to mass moralities of fish and shellfish though the mechanism involved in these is uncertain. It would have had a significant effect on the natural populations of shellfish in some areas.

- Available information suggests that waters from the Waiau River are unlikely to have a major influence on the occurrence of toxic phyto-plankton in Foveaux Strait.

### 8.2.3 Big Glory Bay phytoplankton monitoring

Phytoplankton sampling for the identification of harmful micro-algae species has been carried out since early 1989 on a regular basis (approximately fortnightly) in Big Glory Bay, Stewart Island, as a precaution against a repeat of the mass mortalities of salmon (the result of a *Heterosigma carterae* bloom) that occurred in the bay in January 1989 (e.g., Chang *et al.* 1990; Mackenzie 1991). Sampling has been more frequent during perceived danger periods (usually mid summer), and during this time several incidents involving micro-algal blooms and salmon mortalities have occurred. These blooms have involved several species within different phytoplankton groups (raphidophytes, prymnesiophytes,

and dinoflagellates) and have invariably occurred during prolonged periods of calm fine weather, presumably as a result of an increase in the water retention time in the bay (Chang *et al.* 1993); the bloom appears when the surface water reaches and exceeds 15°C. These events are essentially localised although they could conceivably be related to larger scale climatic/ oceanographic events within the Southland region.

Shellfish biotoxins have been monitored at mussel farms in Big Glory Bay since the inception of the monitoring programme. At no time have positive bioassays been returned from these samples though potentially toxic *Gymnodinium* spp., *Dinophysis acuta, Alexandrium ostenfeldii* and *Pseudonitzschia* spp. have been observed and the area was closed for some time during the 1994 gymnodimine incident. During the *Heterosigma* bloom in 1989, *Dinophysis acuta* (up to $2x10^4$ cells per litre) was numerous within the bay (Chang et al. 1993) and mouse bioassays carried out at this time indicated the presence of lipid soluble biotoxins, probably due to DSP-toxin contamination in cultivated mussels (Mackenzie 1991).

## 8.3 SUMMARY

- Natural seawater conditions during the summer in Foveaux Strait often appear to be conducive to the development of phytoplankton blooms of unusual luxuriance and species composition (compared to other NZ coastal regions), and may be the seed source for the propagation of more extensive blooms along the South Island east coast. Phytoplankton blooms in the region and the occasional occurrence of toxic species are apparently unrelated to human activities.

- The reason for the high summer phytoplankton productivity within this area is unknown though it may be related to the high nitrate-nitrogen levels that have been observed in surface waters, on some occasions originating from oceanic or terrestrial sources (river inflows).

- During the summers of 1993/94 and 1995/96 dinoflagellate blooms dominated by a species of *Gymnodinium* caused Foveaux oysters (and other shellfish) to be contaminated with a novel biotoxin (gymnodimine). Investigations have revealed that this toxin is unlikely to be a hazard to human health though it may have effects on other marine organisms since the *Gymnodinium* spp. bloom in January 1996 was associated with widespread mortalities of a variety of marine fauna.

- Toxic phytoplankton species observed in Foveaux Strait to date include; *Gymnodinium* cf. *mikimotoi, Gymnodinium breve, Alexandrium minutum, Alexandrium ostenfeldii*, and *Dinophysis acuta*. Other potentially toxic species (eg. *Pseudonitzschia australis*) may also occur from time to time.

## 9.0 CONCLUSIONS

The situation in Te Waewae Bay on the southern coast of South Island in no way resembles the situation in enclosed estuaries in other parts of the world where reduced flows from rivers are responsible for possibly irreversible changes to the biota and productive capacity of the receiving waters. Te Waewae Bay is on the open coast and average flows of the River represent less that 2% of the new water that enters the bay on every tidal cycle. In addition, at the sea surface close inshore, salinities of 32 represent 8% fresh water which is less dense than sea water and therefore tends to lie at the surface. In addition, the potential for toxicants to enter the Waiau River are considered to be limited in the Waiau Catchment Water Quality Review (Robertson 1993b, Southland Regional Council).

There is no doubt that the contribution (especially of nutrients) that river water makes to the nearshore zone in Te Waewae Bay would have a significant influence on that zone. There are no data to allow quantification of the freshwater effect on the local marine ecology. Nevertheless the overall impact, even before controls were put on the flows, was probably highly variable depending on season and year.

Although we deduce that river water is probably a significant, if variable, influence on the functioning of the local marine system, there has probably been very little change pre and post control. There has probably been only a slight reduction in the **rate** of addition of nutrients to the south coast from the Waiau River, as the diverted water from Lake Manapouri appears to have a relatively low nutrient content.

The fresh water diverted from the Waiau River, through the Manapouri Power Station, still influences the southern coast but by a different route. The low salinity water along the southern coast is derived not only from the rivers flowing directly from the southern coast, but also from freshwater input from Fiordland, which is carried south by the mean circulation round southwest South Island.

In addition to a freshwater source of nutrients there are other sources of nutrients (subantarctic water, tidal stirring, and possible uplift of subtropical water over Puysegur Bank). We know that on some occasions the input from rivers appears to be unrelated to nutrient levels in greater Foveaux Strait.

Natural seawater conditions during summer in Foveaux Strait often appear to be conducive to the development of phytoplankton blooms of unusual luxuriance and species composition compared to other New Zealand coastal regions. It is noted that the early 1996 bloom followed a period of high rainfall, and a subsequent calm spell. It is concluded that

phytoplankton blooms in the region and the occasional occurrence of toxic species are unrelated to human activites.

Oyster population declines are related to events that occurred pre control, as well as post control, and the 1986 event was not confined to the southern coastal region. There is no evidence that declines in the oyster populations are in any way linked to the inflow of river water.

Overall there is no recorded evidence that reduction in the flow from the Waiau River has had a measurable effect on the ecosystem of Foveaux Strait. Also, given the current understanding of the regional oceanographic situation, its variability, and the factors driving this variability, it is unlikely the reduced flow in the Waiau River has had any significant effect on Foveaux Strait.

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