BIOLOGICAL OCEANOGRAPHY

Fertilising the continental shelf: biological oceanographic studies on the northeastern New Zealand continental margin

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The transfer of nutrients between the open ocean and the continental shelf is a vital process in the maintenance of the rich shelf ecosystem. Recent NIWA research has identified three mechanisms responsible for this transfer in northeastern New Zealand.

THE SEAS overlying the continental shelf and slope occupy only about 10% of the total global ocean surface area, yet it is estimated that they contribute between 18 and 33% of marine phytoplankton production and a huge 90% of the world's fisheries production. The pelagic sedimentation (see panel, page 16) from this production reaches the bottom rapidly in the relatively shallow shelf waters. As a result, the sediments of continental margins also trap about half of the global total of the atmospheric carbon drawn into the oceans by photosynthesis. Thus, from the standpoints of managing coastal resources and understanding global biogeochemical cycles and global climate, comprehension of phytoplankton production cycles on continental margins is crucial.

Phytoplankton and nitrate levels

The major factors which influence phytoplankton production on the continental margins are solar radiation, nutrient supply (nitrate), grazing pressure from zooplankton, and physical water column structure. Nitrate fertilises the production cycle and often ultimately limits the maximum level of phytoplankton biomass.

Nitrate arrives on the shelf via several pathways including:

- local regenerative processes in the sediments (e.g., microbial decay of organic matter);
- input from rivers;
- oceanic circulation, as water masses bearing low or high concentrations of nitrate are transferred across the shelf from the open ocean.

On many coastlines the third pathway – the dynamic interactions of shelf waters with oceanic waters – is the most important source of nitrate and is pivotal to the functioning of the continental shelf phytoplankton production cycle. These interactions include incursions from offshore which can bathe the shelf with surface water which is nitrate-poor. Alternatively, upwelling of deep water onto the shelf can supply large amounts of "new" nutrient from the great pool of regenerated nitrate which exists below the depths of phytoplankton growth.

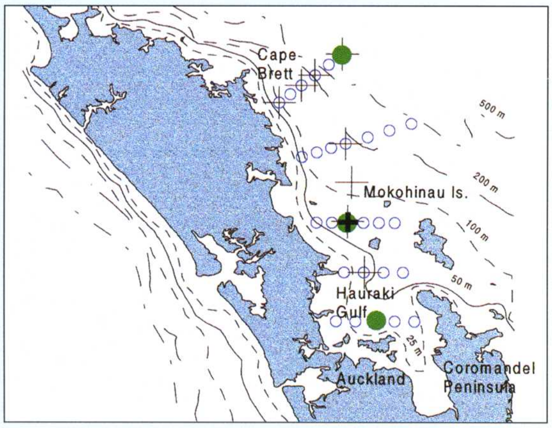


Figure 1
Sampling stations for Biological Effects of Cross-Shelf Water Transfer field programme, September to February 1996–97. Open circles denote routine transect stations, and filled circles denote stations with intensive sampling, including primary production and grazing rate experiments. Crosses denote mooring positions, and the bold cross denotes the position of the in-situ nitrate analyser. The shelf break is typically at a depth of about 150 m.

Studies in northeast New Zealand

The interactions between shelf and oceanic waters are particularly intimate in many parts of New Zealand because the continental shelf platform is very narrow. Over the last four years "Nearshore–Offshore Exchange", a research programme funded by the Foundation for Research, Science and Technology (FRST), has examined the physics of cross-shelf water mass exchange along the northeastern continental shelf between Cape Brett and Auckland.

In spring and summer 1996–97, this physics programme was combined with a new programme, "Biological Effects of Cross-Shelf Water Transfer", to undertake the largest-ever deployment of oceanic mooring and ship sampling effort on the New Zealand continental shelf.

The work involved four voyages on NIWA's research vessels, *Kaharoa* and *Tangaroa*. Studies of the physics of water and nutrient flux across the northeastern shelf (Figure 1) were combined with biological studies of primary production and the community ecology of phytoplankton (including toxic algae), bacteria, microbes, micro- and mesozooplankton, and pelagic sedimentation.

From September to February eight moorings were deployed to measure currents, temperature, nitrate, submarine light and sedimentation. Satellite data (measuring sea surface temperature and chlorophyll *a*) and weather data were also acquired.

Our aim was to determine the factors that cause phytoplankton productivity to vary from spring through summer on the continental shelf, both as a function of seasonal succession and as a result of higher-frequency events, such as oceanic incursions.

This article describes some early results of the 1996–97 programme. We also explain the findings on nutrient dynamics in terms of our understanding of the physics of the system gained over the last few years and highlight some of the new questions that we hope to answer as our analysis proceeds.

Spring bloom

Figure 2 illustrates a time series of satellite sea-surface temperature, and nitrate and chlorophyll *a* concentrations, all obtained during the 1996–97 voyages. The nitrate and chlorophyll *a* data are shown from two sampling transects across the shelf from the coast to the shelf edge (from depths of 60 m down to over 500 m); and one in the shallow Hauraki Gulf (around 40 m deep).

In September, cool water covered the continental shelf of northern New Zealand, reflecting deep mixing of the water column from the previous winter. However, in spite of the cool temperature, our September ship survey found high chlorophyll *a* values across the shelf and in the Hauraki Gulf, showing that a "spring bloom" of phyto-plankton was in progress. This bloom was a result of increasing sunlight, developing stratification and abundant nitrate made available by the previous winter's mixing. Figure 2 also shows that at the inner shelf and Hauraki Gulf sampling stations, the bloom had completely used up the available nitrate in the upper 30 m or so of the water column. Below this "surface mixed layer" nitrate concentrations on the shelf and upper slope increased with depth.

By the time of our second voyage in October chlorophyll *a* levels were considerably lower, indicating that the spring bloom had collapsed. The collapse probably resulted from a combination of grazing by zooplankton, nutrient limitation, and phytoplankton sedimentation. The relative importance of each of these factors in the decline of the bloom will be determined from our further analyses.

Current-driven upwelling

In September and October the shelf surface waters off the northeast coast were cooler than those offshore, and the shelf bottom waters (below the euphotic zone) had higher nitrate than offshore waters at similar depths. These are fairly consistent features of the northeast shelf and are understandable given our present knowledge of the currents in the region.

The upper slope area between North Cape and East Cape is dominated by the East Auckland Current (EAUC), which originates in the Tasman Front between Australia and New Zealand. Our previous physical studies of the interaction between the shelf waters and the EAUC have demonstrated that cool, nutrient-rich waters originating near the bed of the upper slope are transferred up and onto the shelf by the current. This creates a long-term averaged upwelling environment in the region. We refer to this first mode of nutrient transfer as "current-driven upwelling".

Wind-driven upwelling

By late November, the satellite time series showed that offshore waters had warmed considerably. This is expected, as this time of year usually sees the most rapid warming of sea-surface temperatures in the annual cycle. However, the shelf waters between North Cape and the Coromandel Peninsula were as cool as they had been in October, and there was a very sharp temperature front between the shelf and EAUC waters offshore. The reason for this 2°C negative temperature anomaly on the shelf can probably be found in the winds that blew in the region during late spring.

Figure 3 shows a five-month time series of "wind stress" calculated from wind data recorded at the Mokohinau Islands (Figure 1) on the mid-shelf. It shows that during November there was a lot of wind stress blowing along the shelf from the northwest. Physical considerations dictate that under these conditions the Coriolis force should turn the shelf surface waters offshore. As the surface waters are diverted offshore, they are replaced from beneath by deeper, cooler, upwelled water from the upper slope. Thus, a second mode of upwelling, which we refer to as "wind-driven upwelling", was evident in our study.

Ship samples taken in late November/early December showed that this upwelled water was laden with nitrate (Figure 2). Higher concentrations of nitrate were found in the surface waters on the inner shelf, and there was also greatly increased nitrate in the Gulf. The wind data suggested that upwelling would have started in early November, and that nitrate-rich water should have been present for a similar time.

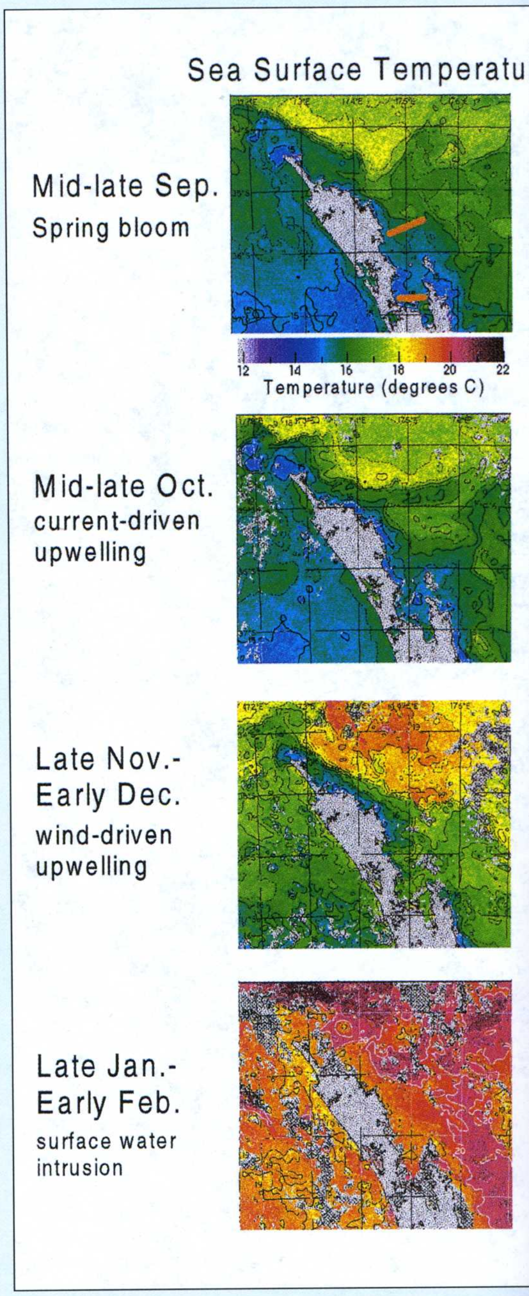
At this stage it is useful to look at output from an instrument we moored on the shelf near the entrance to the Hauraki Gulf (Figure 1). This was an "*in situ* nitrate analyser" (Figure 4) which acquired a nitrate value from near-bottom waters every three hours for five months of our study. The record shows that nitrate values increased coincidentally with the incidence of northwesterlies during November and remained high until early December.

High nitrate, low chlorophyll *a*

Unlike nitrate, chorophyll *a* values in our late November/early December samples were low (Figure 2). Why? After all, nitrate is the phytoplankton fertiliser, and concentrations had been high for a number of weeks before our sampling.

One possible explanation is that the water column was not very stable during upwelling, resulting in less-than-ideal growth conditions for phytoplankon: the plant cells were being mixed to depths where there was barely enough light for growth. Another possibility is that phytoplankton *were* growing quickly under the rapid supply of nitrate, but were just as rapidly being grazed by zooplankton.

In the Hauraki Gulf, November and December are peak months for the production and rearing of larval snapper, which depend on zooplankton for food. Therefore it is important that we understand as much as possible about how the ecosystem works at this time.



Surface water intrusion

By the time of our next ship survey in late January/early February 1997, conditions had again changed dramatically. The satellite data (Figure 2) showed that the strong temperature front at the shelf-edge had broken down. Now the entire shelf was bathed in warm water.

Our moored thermistors showed that much of this warming occurred in a 2°C jump over about eight days around New Year. Our earlier work has shown that such sudden warming is unlikely to result from direct solar heating, but is the result of shoreward movement of subtropical oceanic surface water across the shelf break toward the coast.

We know that surface water will tend to move towards the shore under the influence of along-shore winds from the southeast.

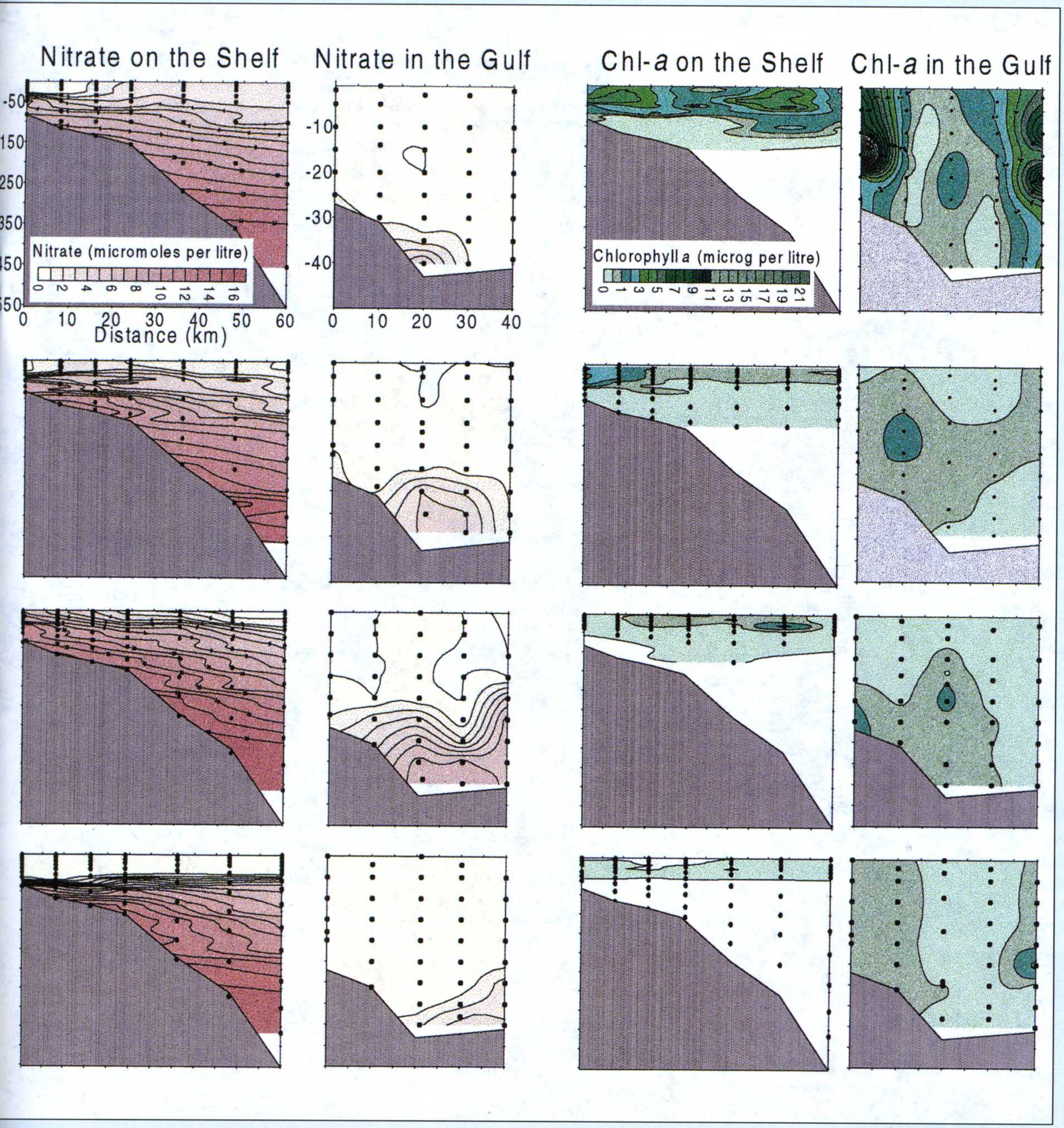


Figure 2
Time series of satellite sea-surface temperature, and ship-derived nitrate and chlorophyll a. Temperature data were obtained from Advanced Very High Resolution Radiometer sensors on NOAA satellites, and nitrate and chlorophyll a data were from ship sampling on the shelf and gulf transects shown by the orange lines in the first satellite image. Temperatures and nitrate and chlorophyll a concentrations are shown by coloured scale bars.

The movement is also favoured in summer as the waters become stratified and the warmer surface layer can "slide" over the cooler deep waters at the thermocline. The wind record (Figure 3) shows that at New Year cyclone Fergus impacted the northeastern North Island, imparting strong southeasterly wind stress to the shelf seas and further offshore. It was these winds that drove the warm subtropical surface water onto the shelf.

Figure 2 shows that the upper 75 m of the shelf water column sampled during our late January/early February voyage was uniformly low in nitrate and chlorophyll *a*, as was the water column throughout the Hauraki Gulf. Using our 1996–97 data we aim to examine the effects on the biological community of this "capping" of the shelf and coastal waters by a low-nutrient layer.

Implications for fisheries: toxic algae

The shoreward progression in summer of offshore surface water is an annual event in the northeastern region that brings the "blue water" onto the shelf, and with it billfish and tuna, important to recreational and commercial fisheries. The event may also have connections with periodic blooms of toxic algae. Current hypotheses propose that unusually high concentrations of nutrients in oceanic surface waters, possibly related to El Niño, foster increased quantities of toxic cells offshore, which are then introduced to the coast in the surface water intrusion. During the El Niño period of 1992, nutrient concentrations were unusually high in the offshore surface waters and this was followed in early 1993 by the first incidence of toxic shellfish poisoning recorded in New Zealand, off the northeast coast.

Three mechanisms and more questions

So far, it looks as if at least three distinct processes affect the transfer of nutrients across the continental shelf in northeast New Zealand: current-driven upwelling, wind-driven upwelling and surface water intrusion.

The first mechanism is probably relatively weak but is likely to be quite consistent year round.

The second is probably the more effective of the upwelling modes in supplying the annual quota of nitrate to the shelf. It is episodic, responding to weather events primarily from autumn to spring.

The third mechanism is a summer phenomenon and usually lowers nutrient concentrations in the upper water column.

These processes add variability to the nutrient supply, to the hydrographic structure and hence to the biological production of the shelf waters, over and above that caused by seasonal succession.

Where is our research leading from here?

First, we plan to look into some specific questions arising from our findings from the 1996–97 research programme. These topics include: the mechanisms leading to the collapse of the spring phytoplankton bloom; the reasons for occurrences of low phytoplankton biomass in spite of high nutrient levels; the effects of the presence of a sharply separated layer of low-nutrient surface water in summer.

A more global issue that we wish to examine is how carbon and nutrients are passed into and out of the continental shelf system, to examine the role of the continental shelf in biogeochemical cycling.

And for the future, the challenge is to transfer our findings to larger scales. We would like to be able to predict, for example, how seasonal and higher-frequency variations in nutrient supply cause productivity to change over the annual cycle and between years, under such influences as El Niño. ■

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Figure 4
Stuart Pickmere (NIWA, Hamilton) services the in situ *nitrate analyser during one of the 1996–97 voyages. A battery pack in the lower compartment powers a multiport syringe (centre), which mixes reagents from the upper compartment with a seawater sample. This is assayed photometrically, following cadmium reduction and colour development, and the data are stored.*

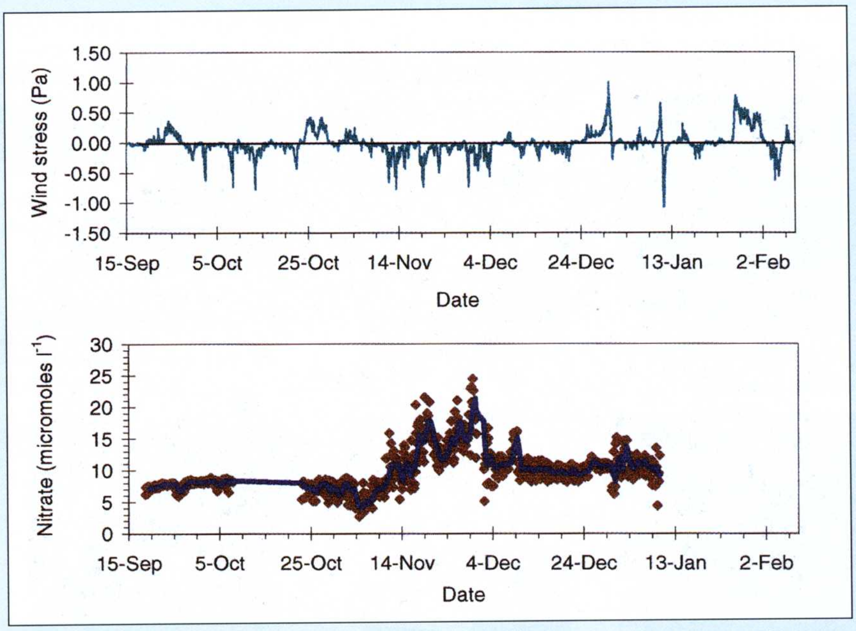

Figure 3
The upper panel shows a time series of wind stress data recorded at the Mokohinau Islands (Figure 1) on the mid-shelf, over the 5-month period. The data are displayed in terms of the frictional stress (Pascals) the winds were exerting on the sea surface. The stresses are calculated for the components of the winds blowing along-shelf, either from the southeast (positive in the figure) or from the northwest (negative). The lower panel shows in situ *nitrate analyser results over most of the wind data period. The analyser was 15 m from the bottom, in 67 m of water at the red cross in Figure 1. Values are shown for every datum (brown) and as a daily smoothed line (blue). Note how increased nitrate correlates with winds from the northwest (upper panel). The instrument malfunctioned from 8 to 22 October.*

Further reading

Sharples, J. 1997. Cross-shelf intrusion of subtropical water into the coastal zone of northeast New Zealand. *Continental Shelf Research 17* (7): 835-857.

Oceanographic terms

biomass: a term describing the weight of living matter at a given time.

chlorophyll *a*: the major energy-accepting pigment of phytoplankton. It is frequently used as a measure of phytoplankton biomass.

continental shelf and slope: the "continental shelf" is an area of shallow ocean of variable width, around the perimeter of a land mass, typically with a gradient of about 1 in 500. Its outer limit is defined as the area where the gradient increases to about 1 in 20 to form the "slope" which falls off to the depths of the ocean proper.

Coriolis force: the rotation of the earth gives rise to the Coriolis force which results in the wind-driven currents in the upper wind-mixed layer in the open sea moving in a direction to the right of the wind direction in the Northern Hemisphere and to the left in the Southern.

euphotic zone: the upper layers of water into which enough light can penetrate for photosynthesis to take place.

pelagic sedimentation: this refers to the "rain" of tiny particles which are released from the living material in the pelagic (near-surface) zone in the ocean (e.g., dead phytoplankton and zooplankton carcasses and faeces and their particulate breakdown products).

phytoplankton: the term for the tiny plants which live suspended in water column in both marine and fresh waters. These plants are mostly single-celled algae.

productivity: net increase in amount of living matter.

stratification: the separation of sea water into layers on the basis of density. This normally occurs during calm periods in summer as solar radiation heats up the upper waters.

surface layer: the layer between the surface and the top of the thermocline. The temperature of this layer is usually similar to the surface water temperature because of mixing due to winds.

thermocline: the depth at which the temperature gradient (rate of decrease of temperature with increasing depth) is at a maximum. In effect, this is the zone in stratified waters in which the temperature suddenly falls.

zooplankton: small animals which live in the water column and survive mainly by "grazing" the phytoplankton or predating other zooplankton.