OCEANOGRAPHIC MODELLING

What fuels algal production in the Hauraki Gulf?

Niall Broekhuizen

Techniques for predicting marine algal populations using computer models could play an important role in locating future marine farming ventures.

THE STRETCH OF WATER sandwiched between the main spur of the North Island and the Coromandel Peninsula and Barrier Islands is known as the Hauraki Gulf. Currently, there are resource consent applications to establish more than 1000 ha of new shellfish farms within the Gulf, and the Auckland Regional Council is developing a new catchment management plan which may have implications for this area. Clearly any tools that can help us to determine whether the Gulf can "assimilate" human influences will aid in the area's management.

The Gulf receives water from several very different sources, including runoff from New Zealand's largest city, and from one of the North Island's most intensively farmed areas. Nonetheless, the largest influence is believed to be the exchange with the open sea. The continental shelf passes very close to the Gulf and intrusions of "oceanic" (as opposed to "coastal") water are frequent. These may be particularly important since the nutrients carried by the oceanic waters appear to "fertilise" the Gulf, and there is some evidence that the toxic phytoplankton which can lead to the closure of shellfish farms are associated with oceanic intrusions.

Physical models

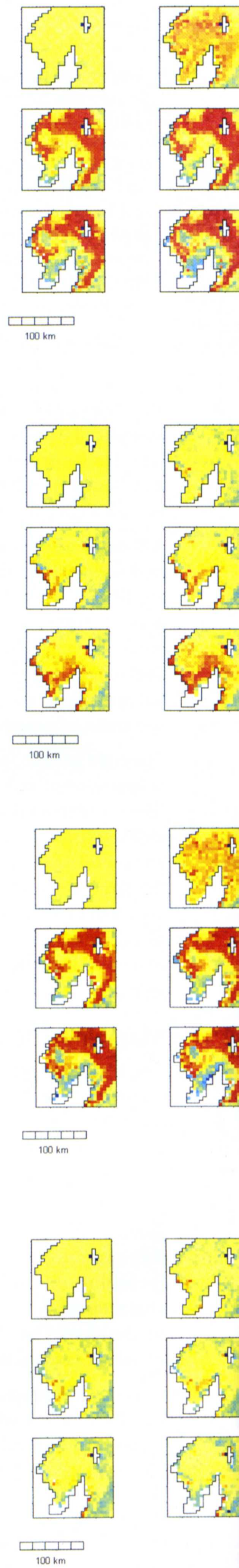
For the past four years, a major PGSF-funded research programme, "Ocean Ecosystems: Their Contribution to New Zealand Marine Productivity", has concentrated on the Hauraki Gulf, and particularly the coastal–oceanic shelf zone. In the initial phase of the programme, NIWA scientists assembled a suite of data relating to both the physical and biological characteristics of the Gulf waters. The physical measurements allowed us to develop and test a model that estimates current velocities in the region. This enables us to predict what happens to "biologically inert" material. For example, the model could be used to predict where intruded oceanic water will pass, but cannot tell us how much of the associated biologically active materials such as nutrients and algae will remain within this water.

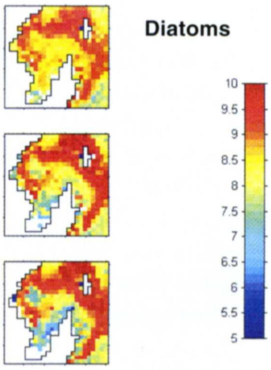
Model in three dimensions

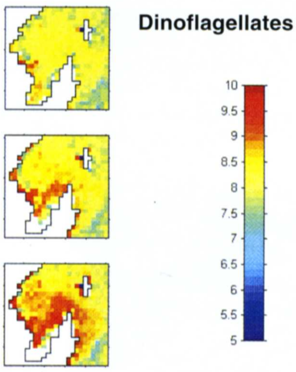
To remedy this situation, NIWA is now developing a three-dimensional biological model of the Hauraki Gulf region. At present the model includes two types of nutrient (nitrogen and silicon), suspended organic detritus and two types of phytoplankton (diatoms and dinoflagellates). As a general rule, diatoms are fast growing and favour turbulent waters; in contrast, dinoflagellates are slow growing and prefer the more stable conditions which tend to develop during summer. There are also many toxic dinoflagellate species. Unlike diatoms, dinoflagellates do not require silicon to grow.

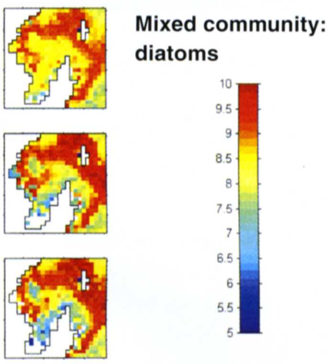
The model is a three-dimensional extension of one described in *Water & Atmosphere* 7(1): 20–21. In the model, the algal populations are represented using many thousands of individual particles. In one sense each particle is considered to represent a single algal cell (a "characteristic cell") and the model keeps a track of the location, size and physiological status of each of these. Of course, in reality there are usually millions of algal cells in a single cubic meter of water. Consequently, the few thousand particles in the model represent only a very small "sample" of the true algal population. Therefore, in a second sense each particle actually represents a large number of algal cells, all of which share similar histories. The model keeps track of the number of true algal cells that each "characteristic cell" might represent.

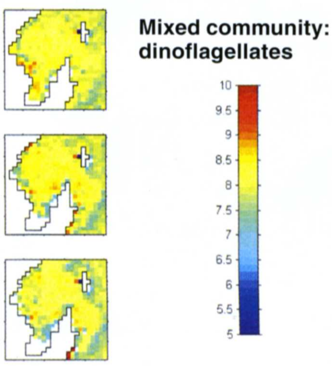
The particles draw nutrients out of the surrounding water at rates determined by factors such as water temperature, external nutrient concentration, and physiological











status (for example, the internal stores of nutrients and energy) of the characteristic cell. When a characteristic cell reaches an upper threshold size, it divides into two equal daughter cells. Consequently, the particle to which it belongs is now considered to be representative of twice as many true cells. When an algal cell dies, its contents are passed into the local pool of organic detritus. In turn, this slowly decays back into free nutrients. Detritus, nutrients and algal particles are transported around the Gulf region by the currents.

To run the model we need time-series of current velocities, and water temperatures for a grid of points covering the area of interest, together with a specification of the sea-floor's bathymetry. These are provided as output of the hydrodynamic model that NIWA has already developed. Algal growth depends upon the amount of light available, and this can be supplied either as a time-series of observations, or from equations that reproduce the average daily and seasonal patterns.

Finally, we need to specify starting values for all the variables in the model and, equally important, "boundary conditions". The latter specify the abundances of nutrients, detritus and algae along the edges of the model's spatial "domain" – the area being modelled.

Early results

The model has yet to be tested rigorously against historical field data; however, some preliminary simulations are discussed. These simulations were made with a horizontal spatial resolution of 5 km and a vertical resolution of 20 m for the currents. In principle, any resolution could be used. In practice, however, the amount of computer memory needed and the time taken to run the model increase disproportionately as the model's spatial resolution is improved. Thus, there is likely to be a trade-off between spatial resolution and the total area covered by the model.

The top two series of figures (left) illustrate how purely diatom or purely dinoflagellate populations might behave within the Gulf. It is especially interesting that diatom populations are greatest in the deeper parts of the Gulf. In contrast, dinoflagellates tend to be most abundant in shallower regions. Even there, however, the dinoflagellate population never becomes as concentrated as the diatom population does in the deeper water.

Simulated cell concentrations (log_{10}(cells/m^3)) plotted at 5-day intervals (left to right, top to bottom) in the surface waters (0–20 m depth) of the Hauraki Gulf under persistent north-westerly wind conditions and low initial surface water nutrient concentrations.

from top to bottom: *diatoms only; dinoflagellates only; mixed communities of diatoms and dinoflagellates.*

Dinoflagellates shallow, diatoms deep

Why do the spatial distributions of the two types of algae differ? In comparison with turbulent water velocities close to the sea-surface, neither diatoms nor dinoflagellates are very mobile. However, turbulent velocities are lower at the sea floor and dinoflagellates can escape contact with the sea floor by swimming upwards. In contrast, diatoms are, at best, neutrally buoyant. Nutrient-depleted diatoms are known to sink, so they are more likely to end up deposited on the sea floor than are dinoflagellates.

It is not clear what happens to deposited algae. In the worst case, they may quickly be buried, or consumed by bottom-living animals. Alternatively, they may merely sit on the poorly lit sea floor – as we have assumed in our model. Here they can grow only slowly, and may even starve to death unless resuspended. Regardless of the details, a shallow sea floor operates as a selective filter against diatoms. The impact of this filter is augmented by the fact that algae that are imported over the external walls of the domain quickly incorporate the imported nutrients. This fuels algal population growth, but leaves less nutrient to fuel growth further "downstream" (i.e., within the Firth of Thames).

So, we have an explanation for the rarity of diatoms close to the coast, but why are the dinoflagellates rare in very deep waters? In order to grow, dinoflagellates need more light than diatoms, and whilst their swimming abilities may keep them off the sea-floor, they are not always sufficient to prevent the cells being mixed to depths where there is not enough light.

The lower two series of figures (left) illustrate the dynamics of a mixed diatom–dinoflagellate algal population. Once again, there are more diatoms in the deeper water. The dinoflagellates are more abundant in the shallower regions but, in comparison with the mono-specific case, they are generally rarer. This is because the diatoms intercept nutrients that enter over the seaward boundaries before these can reach the coastal areas and fuel dinoflagellate growth.

Further reading

Broekhuizen, N. 1999. Balancing the books: dinoflagellate persis-tence in the oceanic environment. *Water & Atmosphere* 7(1): 20–21.

Broekhuizen, N. 1999. Simulating motile algae using a mixed Eulerian–Lagrangian approach: does motility promote dinoflagellate persistence or coexistence with diatoms? *Journal of Plankton Research 21*: 1191–1216.

Zeldis, J., Sharples, J., Uddstrom, M. and Pickmere, S. 1998. Fertilising the continental shelf: biological oceanographic studies on the northeastern New Zealand continental margin. *Water & Atmosphere* 6(1): 13–16.

The future: expanding the model

In the future we plan to use the model to determine how much of the nutrients that enter the Hauraki Gulf system is incorporated into phytoplankton, and where in the Gulf most of this incorporation takes place. This provides one estimate of the productive capacity of the Gulf. With suitable care, such estimates could help to determine where shellfish farms might be most successful.

Many features are still absent from the model: for example, riverine inputs of nutrients have yet to be included. Nonetheless, the model already reproduces many of the observed distribution patterns of the Hauraki Gulf's phytoplankton, such as the dominance of diatoms in the deeper waters, and the greater standing stocks of algae on the western side of the Gulf. In the future we hope to develop a better understanding of the reasons for these patterns. In the meantime, the model has highlighted the need to develop a better understanding of the processes that influence the fate of algal cells which are on, or very close to the sea-floor. ■

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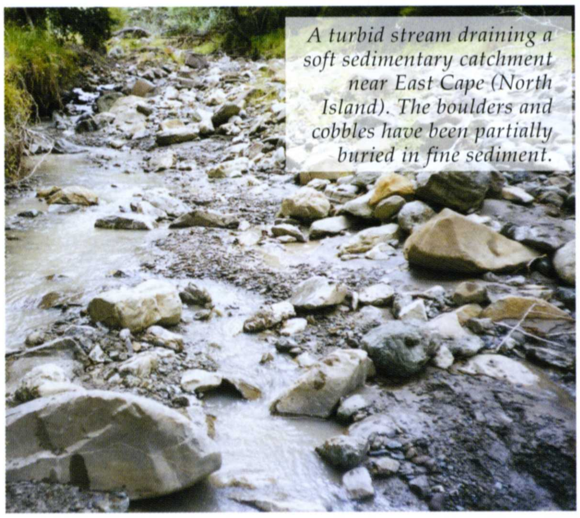
STREAM ECOLOGY

Nowhere to hide:

effects of high sediment loads on instream habitat for fish

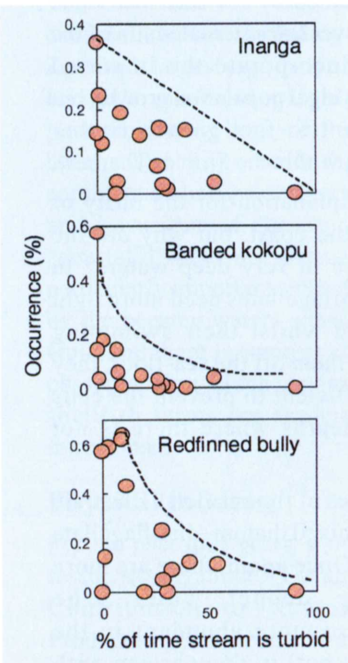


A turbid stream draining a soft sedimentary catchment near East Cape (North Island). The boulders and cobbles have been partially buried in fine sediment.

Ian Jowett

Nelson Boustead

Experiments have confirmed that bullies will move on if hiding places become scarce – even if there is plenty of food available.



The occurrence of inanga, banded kokopu and redfinned bullies falls with the % of time suspended sediment concentration exceeds 120 mg/l.(from Rowe et al. *in press)*

HOW DO FISH in a stream respond to changes in the stream environment?

This is a question that might be asked when assessing the impacts of water use or of other developments that affect a waterway. To help find some answers NIWA has been studying the in-stream requirements of fishes.

One issue is the effect of suspended sediment and deposition of fine sediments in streams and on their fish inhabitants. This is relevant in cases such as the Opuha Dam collapse in South Canterbury, in studies below major river diversions such as the Moawhango Dam in central North Island, and in resource consent applications for developments that result in sediment discharge into streams.

Fewer fish in turbid streams

Information in the New Zealand Freshwater Fish Database (left) indicates that turbid streams contain fewer native fish than clear streams. Why?

High sediment loads make the water in streams "dirty". Two reasons why this affects fish populations are:

- fish tend to avoid dirty water (as shown by Boubee *et al.* 1997);
- turbid water reduces the ability of fish to feed (see experiments by Rowe and Dean 1998).

Turbid water also deposits fine gravel and sand on the stream bed, filling in the spaces between larger cobbles and making a smoother bed. The bed's "hydraulic roughness" is reduced and water velocities increase. This has a two-fold effect on fish: (1) there are fewer places where fish can shelter from the current or hide; (2) at the same time, the increase in water velocity makes shelter from the current more necessary. So increasing fine sediment deposits on the stream bed affects fish populations by:

- reducing the amount of suitable physical habitat (depth and velocity) (see Jowett and Richardson 1995);
- reducing the amount of cover.

In a natural stream all these effects happen together and the various laboratory experiments noted above have helped to identify individual effects.