Vol.5. No.1, March 1997 ISSN 1172-1014

WATER & ATMOSPHERE

NIWA

Taihoro Nukurangi

IN THIS ISSUE • Marine biodiversity • Tides around New Zealand

Cover

The sea anemone *Cricophorus nutrix*. This is one of many species of anemone photographed during a recent survey of the sea anemone fauna of New Zealand. As a result of the survey the number of species listed for the New Zealand region has increased by well over 50%. It is likely that many more will be added to the list following further studies.

For further information about the sea anemone survey refer to pages 6–7 of this issue.

(Photo: Oscar Ocaña Vicente)

Produced by Think Design

NIWA, the National Institute of Water and Atmospheric Research Ltd, is a New Zealand Crown Research Institute. Our mission is to provide a scientific basis for the sustainable management of New Zealand's atmospheric, marine and freshwater systems and associated resources.

NIWA's Maori name *Taihoro Nukurangi* – where the waters meet the sky – describes our work studying the waterways and the interface between the earth and the sky. Our rainbow logo also reflects the intersection of air and water.

More information about NIWA is available on the World Wide Web at the NIWA homepage: http://www.niwa.cri.nz/

Water & Atmosphere is published quarterly by NIWA. Its aims are to publicise and promote research undertaken by NIWA.

Water & Atmosphere is distributed free of charge. Requests for multiple copies may incur postal charges. All circulation enquiries, including requests for additional copies, should be directed to:

Water & Atmosphere
Private Bag 99940
Newmarket, Auckland
New Zealand
Telephone: 09 375 2090
Fax: 09 375 2091
email:k.brown@niwa.cri.nz

We welcome comment on articles in *Water & Atmosphere* and on any matters relating to NIWA's research endeavours.

All correspondence and editorial enquiries should be directed to:

The Editor
Water & Atmosphere
NIWA
PO Box 8602, Christchurch
New Zealand
Telephone: 03 348 8987
Fax: 03 348 5548
email: c.kilroy@niwa.cri.nz

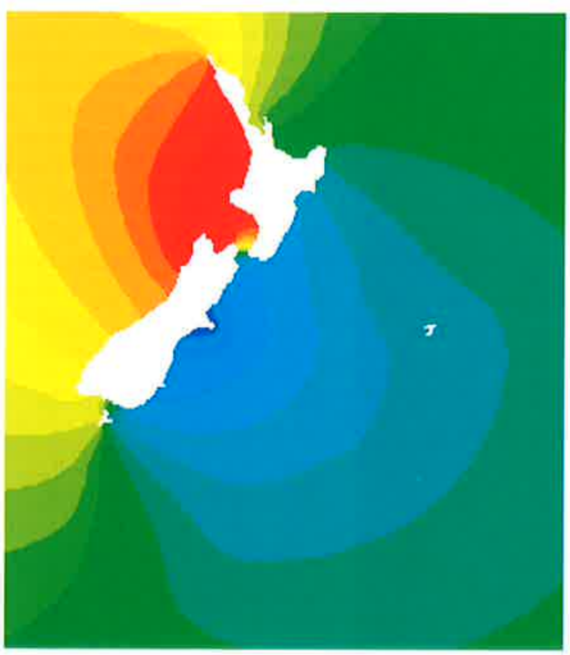
or:

Research Director
NIWA
PO Box 11 115, Hamilton
New Zealand
Fax: 07 856 1710
email: r.pridmore@niwa.cri.nz

WATER & ATMOSPHERE

CONTENTS

Vol. 5 No. 1 March 1997



The tide on video

This illustration is one of a continuous series which shows the progression of the lunar semidiurnal tide — the main component of tides — around New Zealand. The series is produced using a specialised modelling programme and consists of many successive frames covering the whole tidal cycle.
When displayed sequentially on a vdu the effect is of continuous motion.
The different colours represent deviations in sea level height from a known "datum" level. For more information about tides, the modelling technique and these series, refer to the article on pages 13–16 of this issue.

NIWA NEWS FORUM

Waitangi Day

NIWA IS actively forging relationships with iwi to ensure that the environmental work that we do in their rohe is understood and culturally acceptable. As an outcome of these efforts, Ngaati Te Ata honoured NIWA, Hamilton, with an invitation to participate in their 1997 Waitangi Day (6 February) observances at the Tahuna Marae near Waiuku on the southern Manukau Harbour.

Led by Regional Manager Bryce Cooper, seven staff attended with a display of NIWA research in the Manukau, answering questions and distributing information ranging from leaflets to NIWA Annual Reports to copies of *Water & Atmosphere*. The display featured three research programmes that have appeared previously in these pages — benthic ecology, toxicity testing, and boundary-layer processes (ALICE) — all of direct interest to those living on the Manukau. People of all ages stopped by to question and comment.

A young visitor gets an eyeful of the display on marine ecology.

The atmosphere was that of a gala day, with performances by a children's aerobics team, raffles and an auction, a hangi and other food stalls, foot-races and a tug-of-war. NIWA's positive contribution to the proceedings was confirmed by our hosts' insistence that we run in the afternoon sprints and appear in the group photo.

Visitor Hemi Peita indicates where he has helped collect intertidal shellfish for research.

Visiting Scientist works on marine invasions

DURING MARCH and April 1997, Dr Greg Ruiz will be visiting NIWA (Hamilton, Wellington and Christchurch) to work in two different research areas: nonindigenous species invasions and host–parasite interactions.

Greg has a broad background in marine ecology, focusing primarily on estuarine and soft-sediment systems. His work examines predator–prey and host–parasite interactions as well as invasion processes by nonindigenous species (NIS). Based at the Smithsonian Environmental Research Center on Chesapeake Bay (Maryland, USA), Greg has developed a major research programme on the transfer, introduction and consequences of NIS in coastal marine ecosystems. This work includes measuring rates and fates of NIS delivered in ballast water of commercial and military vessels, examining effectiveness of various management and control strategies to reduce risk of invasions, and testing for patterns and consequences of NIS invasions. Although much of this research is centred in the Chesapeake Bay region, some comparative research is also underway in other regions of the US and overseas.

In addition to NIS research, Greg has been involved in long-term research that examines the distribution and impact of predators (shorebirds, crabs and fish) and parasites (primarily protozoans and trematodes) in soft-sediment bays and estuaries in Maryland, Florida and California.

Greg helped to develop a current NIWA programme which examines factors affecting survival of NIS in ballast tanks during trans-Tasman voyages. During his visit to NIWA Greg will be working with the NIWA scientists involved in that study to compare their data with data collected from trans-Atlantic voyages. He will also be discussing current NIS research in the US and potential comparative/collaborative research with NIWA scientists. In addition, Greg will be exploring the potential significance of molluscan parasites (trematodes and protozoans) in soft-sediment habitats around Auckland.

Barbara Hayden
NIWA, Christchurch

USA collaboration on Marine Natural Products programme

NIWA, WELLINGTON, is currently hosting Dr Shirley Pomponi and Robin Willoughby from Harbor Branch Oceanographic Institute (HBOI), Florida, USA. They are working with NIWA's Marine Natural Products programme on sponge cell culture feasibility experiments targeted at producing cell cultures which will generate biologically active (anti-tumour) metabolites.

Shirley is Director of the Biomedical Division at Harbor Branch and she and Robin are world-renowned for their pioneering research in sponge cell culture.

While Shirley is here she will also be setting up a proposed Submersible Expedition for 1998. This is a multi-national, multi-disciplinary research effort organised under the major theme of marine biodiversity research and biotechnology applications. The main feature of the voyage will be the use of a manned submersible for research purposes, from the HBOI research vessel *Edwin Link*.

NIWA and HBOI are the major collaborating institutions. Other participants include UNITEC Institute of Technology, Auckland, the Natural History Museum, London, and the Smithsonian Institute, Washington.

The expedition is scheduled to conduct operations in New Zealand for at least three months beginning in January 1998.

Proposed projects for the voyage include geological and fisheries research as well as some bioprospecting for new biologically active compounds from marine invertebrates which have pharmacological interest.

Chris Battershill
NIWA, Wellington

Stream ecology news: Visiting Scientist

PROFESSOR WILL CLEMENTS from the Department of Fishery and Wildlife Biology, Colorado State University, Fort Collins, is based at Hamilton for four months from mid-January on NIWA's Visiting Scientist programme.

Will is working with Chris Hickey, John Quinn and Kevin Collier, introducing some new techniques for investigating impacts on riverine invertebrate communities and for using recirculating experimental artificial streams or "mesocosms" to study ecological responses.

A major advantage of mesocosms is that they simulate flowing-water ecosystems and facilitate holding complex community assemblages, thus providing increased realism over the commonly used single-species laboratory toxicity test measurements. Will also will be comparing our field impact data for heavy metals on invertebrate communities with US data to determine similarities and contrasts.

Will's research group has also recently undertaken studies of the influence of ultraviolet-B radiation on the drifting response of river invertebrates. They found increased drift with UV which has the potential to influence decisions regarding the importance of riparian vegetation and to affect the design of manipulative experiments with invertebrates. During this visit preliminary experiments will be designed to assess the susceptibility of New Zealand species to UV responses.

Chris Hickey
NIWA, Hamilton

...and an expanding permanent team

Dr Ian Boothroyd, formerly Manager of Environmental Monitoring at Hawke's Bay Regional Council in Napier, has recently joined NIWA in Hamilton where he will establish a programme of research into New Zealand freshwater biodiversity. Ian will focus first on the Chironomidae (midges) which were the subject of his PhD research at the University of Waikato whilst in tenure of a Hilary Jolly Fellowship.

Since 1987 Ian has worked in local government as a scientist with the Hauraki Catchment Board, Environment Waikato, and Hawke's Bay Regional Council. Ian has been involved in a number of Ministerial Working Parties, and has hosted several workshops in Hawke's Bay. He organised the most recent New Zealand Limnological Society Conference in Napier and is currently President of the Society.

Prior to his PhD, Ian gained a BSc in Zoology (University of Manchester) and an MSc in Applied Hydrobiology (University of Wales).

Another new stream ecologist is **Dr Liz Bergey**, who joined NIWA in Christchurch in November 1996. Liz's areas of interest are stream disturbance ecology and insect–algal interactions. She received her PhD from the University of California–Berkeley and most recently worked for a Native American tribe as a wetland ecologist. ■

NIWA in Antarctica

There were two parts to the 1996/97 Antarctic field programme, based from NIWA, Christchurch.

December saw NIWA represented at an international research camp at Lake Hoare in the Taylor Valley where we were undertaking research into the ecophysiology of benthic communities. Later in January, staff went to Bratina Island to continue research into the metabolism of cyanobacterial mats under extreme conditions. The January trip coincided with the 40th anniversary of Scott Base. Dignitaries at Scott Base for the celebrations made a visit to Bratina Island giving us the opportunity to explain our research (see photo).

Anne-Maree Schwarz
NIWA, Christchurch

Dr Clive Howard-Williams (centre, back to camera) addresses an informal gathering of visitors at one of the Antarctic ponds being studied as part of NIWA's Antarctic research programme. Prime Minister Jim Bolger is standing immediately to Clive's right.

Tuapapa Putaiao Maori Fellowship

ERICA WILLIAMS of NIWA, Hamilton, has received a two-year Tuapapa Putaiao Maori Fellowship to support her MSc studies at the University of Waikato. The fellowship scheme, administered by the Foundation for Research, Science and Technology, was established in 1996 to assist and enable the development of talented Maori scientists, to increase Maori participation in science as a career option through positive promotion of role models, and to encourage more Maori students to take up science at secondary and tertiary level.

Erica, whose tribal affiliations include Te Whanau a Apanui, Te Arawa, Ngati Whakaue and Ngati Pikiao, wants her career to include an active role in the preservation and maintenance of New Zealand's unique environment. Her particular interest is ecotoxicology, an area which combines aquatic biology with pollution control technology. Erica has worked as a technician in the NIWA ecotox lab since 1995.

NIWA Science and Technology Series

Two new publications in the series are now available:

Porteous, A. and Thompson, C.F. (1996). *The climate and weather of the Rawaki and Northern Line Islands of Eastern Kiribati.* NIWA Science and Technology Series No. 42. NIWA, Wellington. 60 p.

Price: $38.00 + GST + postage

Available from: Publications, NIWA, PO Box 14901, Kilbirnie, Wellington (Phone: 04 386 0300; Fax: 04 386 0341).

Rowe, D.K. and Deans, T. (1996). *Effects of suspended solids on the feeding ability of five native fish species.* NIWA Science and Technology Series No. 43. NIWA, Hamilton. 25 p.

Price: $15.00 + GST

Available from: Publications, NIWA, PO Box 11-115, Hamilton (Phone: 07 856 7026; Fax: 07 856 0151).

MARINE BIODIVERSITY

New Zealand sea anemone survey reveals high diversity

Oscar Ocaña Vicente

A diving and intertidal survey of the New Zealand sea anemone fauna reveals that it may be one of the richest in the world.

above: Epizoanthus *sp. (Milford Sound).*
upper right: Diadumene neozelanica *(Milford Sound).*

SEA ANEMONES are well known to New Zealanders of all ages who are familiar with the sea shore. So it is surprising to realise that the New Zealand sea anemone fauna is not well known scientifically. Many species are still undescribed and details of their biology are sparse. A recent compilation by Wellington naturalist Elliot Dawson of all known species in the New Zealand region from the published literature tallied about 70 species. In fact the true diversity may be more than twice this number.

New sea anemone collection

In winter 1996, using a campervan as a mobile laboratory, I made a representative collection of intertidal and shallow-water sea anemones (or "soft hexacorals" — see panel below) from several localities in both North Island and South Island, assisted by students or staff of universities and marine laboratories. An important part of the project was photographing live animals because their colour fades rapidly in preserving fluids. I also made notes on habitat, substratum, reproductive state and other details helpful in making formal descriptions of the species. Additionally, I studied museum collections in Auckland, Wellington, Christchurch and Dunedin.

A preliminary assessment of these field collections, museum specimens and the literature has resulted in a new list of about 110 species. All five orders of soft hexacoral are represented (see panel), including the Ptychodactiaria which has not previously been recorded in New Zealand. After further field visits and completion of the survey of the huge NIWA collection, at least 50 more species could be added. This means that the soft-hexacoral fauna of the New Zealand region may be one of the richest in the world, paralleling the trend indicated by some other groups of marine organisms (e.g., Bryozoa, stylasterid and azooxanthellate corals, and glass sponges).

Why study soft hexacorals?

Species of sea anemones, like other plant and animal groups, are liable to become extinct through, for example, pollution or habitat destruction. But we cannot avoid species extinctions unless we know that they existed in the first place — hence the importance of an inventory. Some marine species have very small ranges so are susceptible to total extermination. Others are patchily distributed over a wide area and may be liable to local extinction, and this can have a wider impact on food webs and the ecosystem.

Worldwide there may be only 1500–3000 soft-hexacoral species, ranging from intertidal to deep sea habitats and showing diverse ways of feeding and reproducing. Some species can be useful indicators of environmental quality, some play an important part in seafloor ecology, and others have significant potential in medicine and pharmacology owing to the biochemicals they produce. The latter is a growing field of study that requires accurate identification of species, hence the need for competent taxonomists. Finally, anemones and corals are of considerable evolutionary interest because the Class Anthozoa to which they belong is considered by some authorities to be ancestral to jellyfish and hydroids.

An improved classification scheme

Gwyneth Parry, a New Zealand actinian specialist, pointed out in the 1950s that actinians were a neglected group in the New Zealand fauna, mainly because of inadequate descriptions in historic literature and the lack of a reliable classification scheme — problems not unique to New Zealand.

Of all the sea anemone species recorded in New Zealand up to the first decade of this century, the internal anatomy had been described for only one. These days an anatomical description is crucial for proper systematic placement, and some species recorded in those early days are currently unrecognisable. The 1924–50 studies of Australasian soft hexacorals by Danish specialist Oscar Carlgren, however, provided a good foundation for Parry's 1951/52 compilation, which summarises the contributions of other minor contributors along with her own new discoveries. Since then other papers have appeared sporadically, slowly adding additional species to the fauna.

Unfortunately there are still major problems in actinian taxonomy resulting from inadequate or inappropriate descriptions and little discussion on the systematic relationship between species. As a result existing soft-hexacoral systematics is somewhat chaotic and many of the suborders of

What are sea anemones?

SEA ANEMONES and corals together make up a class (Anthozoa) in the phylum Cnidaria whose members are characterised by their radial symmetry, amongst other features. Technically, the sea anemones belong to five orders of "soft hexacorals":

- Actiniaria (commonly known as Actinians) are sea anemones in the strict sense, from the Greek word for ray, *aktis, aktinos,* referring to the radiating neck region of the animal;
- Ceriantharia are sea anemones which have a burrowing habit;
- Corallimorpharia are somewhat coral-like but completely uncalcified;
- Ptychodactiaria are "aberrant" anemone-like forms;
- Zoantharia are colonial anemones.

Actiniaria may become invalidated.To improve this situation it is crucial that, where possible, studies of live and properly preserved material be undertaken. Morphological and anatomical information can be supplemented later by biochemical and molecular data.

Why such high species diversity?

There is no simple explanation for New Zealand's high diversity of soft hexacorals. The following may be contributing factors.

- New Zealand spans a wide latitude range in which a number of biogeographical provinces have been recognised. Overall, the distribution of actinians may match that of some corals for which there are two main areas: from 34°S in the far north to approximately 45°S, and from around 45°S to 50°S. Certain actinian species occur only in one or other of these areas. Also there may be species groupings associated only with archipelagoes within the larger areas, e.g., there are striking differences between the sea anemone fauna of the cold-temperate Bounty, Antipodes, Auckland, Campbell and Macquarie islands and that of south-east South Island. These are not easily explained by latitude but rather by the isolation between the two areas.
- Some genera are extremely widespread. For example, the viviparous genera *Actinia* and *Cricophorus* occur on the mainland and the cooler offshore islands; both also occur in southern Australia. *Actinia* also occurs in South Africa and South America. This suggests that either these genera are very old or their young are long-lived and dispersible on seaweeds and other floating material. Such vectors could explain the wide but localised distribution of *Cricophorus nutrix* and *Gonactinia* sp. Generally, actinian larvae disperse passively by ocean currents and shipping. The latter may explain the distribution of certain environmentally tolerant species like cosmopolitan *Haliplanella lineata* found in ports and harbours.
- High species diversity can result in areas of high habitat diversity where reproduction by anemones in one habitat occurs in isolation from that in neighbouring habitats, resulting in a high degree of endemism (species found only in that area). New Zealand has a long coastline with many different habitats — mangrove, *Zostera* beds, rock pools, reefs, estuarine muds and gravels, boulder beaches, black coral trees, etc. A high diversity of seafloor relief should also be correlated with a significant number of continental-shelf species, which appear to be well represented in the NIWA collection. The huge variety of seafloor features in the New Zealand region arises from New Zealand's position across a major plate boundary and from its long geological isolation. The latter certainly appears correlated with the occurrence of some archaic faunal types among the Bryozoa, Mollusca, Brachiopoda and sponges.

A centre of diversity

Of particular interest to soft-hexacoral specialists is the high vicariance of the New Zealand species, i.e., many belong to genera found in other parts of the world widely separated from New Zealand by natural biogeographical barriers. This was recognised early this century for several genera and I have found additional such genera during my visit.

On the other hand, there are some interesting novelties in this part of the world. For example, around the world the common *Actinia equina* (*sensu lato*) has a range of colour (red, blue, green, brown), whereas the New Zealand *Actinia* is always red. Newly recorded *Ptychodactis* species clasp to gorgonian stems by a ring-shaped clasping arrangement of the basal disc, a phenomenon previously unknown in soft hexacorals. The common wandering sea anemone, *Phlyctenactis tuberculosa*, closely related to the family Actiniidae, has the bodily form and behaviour of the Aliciidae, a good example of evolutionary convergence. *Cricophorus nutrix* is the only member of its family to incubate live young.

It is difficult to speculate on the origin and diversity of any actinian faunas because of the lack of a fossil record, but if supposed centres of diversity are characterised by high species richness, then New Zealand may be one.

The number of soft-hexacoral species currently recorded in New Zealand is double or more that in other regions such as the Mediterranean, northeastern Atlantic, northwestern Atlantic, Caribbean, central Macronesia (Canary Islands and Madeira), Japan and the northwestern Pacific.

So, either New Zealand is a speciation centre or, more plausibly, part of one that included the adjacent lands of former Gondwana. The present Gondwana-wide distribution of *Bolocera kerguelensis*, *Condylanthus magellanicus*, *Corynactis* spp., *Epiactis* spp., *Helianthella* spp., *Parantheopsis cruentata*, and *Phellia aucklandica* support the latter idea.

There is still much to learn about sea anemones worldwide — especially the fascinating relationships between the faunas of the former lands of Gondwana. ■

Dr Oscar Ocaña Vicente was a Visiting Scientist with NIWA in August–September 1996, assisting in the documentation of New Zealand's marine biodiversity through the Marine Taxonomy Programme (see Water & Atmosphere 4*(3): 4.). Dr Ocaña obtained specialist training in sea anemone biology and taxonomy while working for his doctorate at La Laguna University, Tenerife, Canary Islands. Currently based at Ceuta, Spain, he will be working on the formal description of New Zealand's sea anemone fauna in collaboration with Dr Koos den Hartog of the Leiden Natural History Museum in The Netherlands.*

Anthopleura amoradiata *(Leigh Harbour).*

Further reading

Dunn, D.F. 1983. Some Antarctic and Subantarctic anemones (Coelenterata: Ptychodactiaria and Actiniaria). *In* Kornicker, L. (ed.) Biology of the Antarctic Seas XIV. *Antarctic Research Series, American Geophysical Union 39*: 1–67.

Hand, C. 1961. Two new acontiate New Zealand sea anemones. *Transactions of the Royal Society of New Zealand, Zoology 1*: 75–90.

Ottaway, J.R. 1975a. Review of *Actinia, Isactinia,* and *Cnidopus* (Cnidaria: Anthozoa) in New Zealand. *New Zealand Journal of Marine and Freshwater Research 9*: 54–61.

Ottaway, J.R. 1975b. *Epiactis thompsoni* (Coughtrey, 1875) and *E. mortenseni* Carlgren, 1924 (Cnidaria: Anthozoa). *New Zealand Journal of Marine and Freshwater Research 9*: 253–255.

Parry, G. 1951. The Actiniaria of New Zealand. A check-list of recorded and new species, a review of the literature and a key to the commoner forms. Part 1. *Records of the Canterbury Museum 6*: 83–119.

Parry, G. 1952. The Actiniaria of New Zealand. A checklist of recorded and new species, a review of the literature and a key to the commoner forms. Part 2. *Records of the Canterbury Museum 6*: 121–141.

RESOURCE MANAGEMENT

Urban stormwater quality problems recognised

Ton Snelder

Bruce Williamson

Research into the effects of stormwater discharges on aquatic ecosystems is still at a relatively early stage and managing stormwater discharges poses difficult resource management questions.

STORMWATER is rainwater that runs off impervious surfaces, such as roofs and roads, in urban areas. In general, stormwater is directed through a system of pipes to a discharge point. The primary purpose of these stormwater systems is to remove water efficiently in order to minimise the nuisances and flood hazards that would otherwise occur. Unfortunately, runoff from urban areas picks up a range of toxic chemicals which can result in long-term environmental degradation.

Where does stormwater go?

Stormwater is often discharged into a natural watercourse, which then flows into a river, lake or coastal sea water. In New Zealand, many cities are near the coast, so the receiving environments are often coastal waters.

Where stormwater discharges into open coastal waters, waves and currents ensure that any toxins present are greatly diluted. There is generally no immediate toxicity to the animals that live in this type of high-energy environment.

However, under some circumstances there may be long-term and insidious effects from stormwater discharges. Receiving environments such as sheltered lakes, harbours or estuaries are likely to trap and accumulate particulate matter carried in the stormwater. Such low-energy water bodies are termed "accumulation zones". The hydrodynamic processes in estuaries and harbours tend to "pump" fine particles towards the head of the estuary, so most of the fine particles discharged become part of the bottom sediments. Accumulation zones are characterised by fine, muddy sediments, such as those found in estuaries and upper harbour areas.

Effects on benthic animals

It is accepted that stormwater runoff can cause a build-up of toxic substances in marine sediments (see panel below). How does this affect marine benthic organisms? Because the changes occur gradually, the impacts are not dramatic. However, increasing contaminant concentrations can cause detrimental long-term changes without directly killing organisms. These are "sublethal" effects.

Laboratory and field manipulation experiments at NIWA and Auckland University have identified a range of responses to sublethal toxicity in estuarine biota. They include:

- Physical impairment:
  - reduced reproduction in oysters
  - retarded growth rates of juvenile shellfish and amphipods
  - physical deformities in flounder and oysters;
- Behavioural changes:
  - avoidance of contaminated sediment
  - migration of juvenile shellfish but not adults
  - reduced burrowing rates of shellfish.

What's in stormwater?

VARIOUS CHEMICALS and materials are found in urban stormwater. A few distinct groups are characteristic: suspended solids, nutrients, toxic substances and micro-organisms. Of these, suspended solids (especially catchment soils eroded during land development) and toxic substances impact directly on the bottom sediments in accumulation zones.

Most of the toxic substances found in stormwater are incorporated on or in suspended particulate matter. Therefore suspension and transport of particles is the principle mechanism of transport of toxic substances through the stormwater system to the receiving environment.

Toxic substances in stormwater are heavy metals, petroleum and other synthetic hydrocarbons, and pesticides. Most of these toxins are persistent (they do not break down but persist in the environment). Therefore their concentration will increase if they continue to be added to an accumulation zone.

Road transport activities are a major source of heavy metals, e.g., copper, zinc and lead (although the latter source is largely from historic use of leaded petrol). Traffic also produces poly-aromatic hydrocarbons (PAH) which are toxic and break down very slowly in the environment.

NIWA scientists, in conjunction with the Auckland Regional Council (ARC), have been developing a model which predicts the build-up of contaminants in the sediments of estuaries which receive stormwater discharges. The work is funded jointly by the ARC and the Foundation for Research Science and Technology.

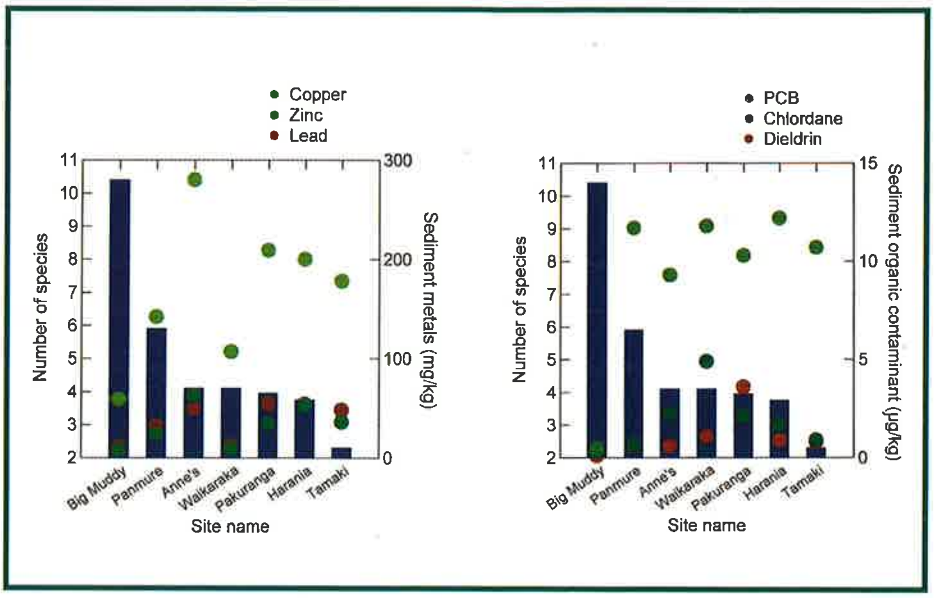
This model assumes that 75% of the suspended sediments discharged in urban stormwater are retained in the estuary and settle in 4% of the catchment area. These assumptions are based on design criteria for stormwater treatment ponds in the Auckland metropolitan area.

The model has successfully predicted the build-up over successive storm events of copper, zinc and lead in two urbanised estuaries. It has yet to be tested for estuaries receiving treated stormwater runoff.

"Flow-on" effects to ecosystem

At present we do not know the extent of sublethal effects resulting from stormwater discharges into estuaries. Neither do we know whether there is a "flow-on" impact to the whole ecosystem. Measuring the ecological impacts in estuaries is difficult because natural populations of animals vary considerably over space and time.

In some of Auckland's estuaries there is evidence that ecosystems have been affected, in some cases very significantly, as a result of human activities. However, Auckland estuaries are subject to a variety of other human perturbations (e.g., boating, dredging, food gathering, past industrial infilling and sewage discharges) and we do not know how much of the impact has been due to urban stormwater inputs.



A comparison of species diversity and (a) sediment metal and (b) organic contaminant levels at seven sites in the Auckland region. Apart from Big Muddy Creek, all sites receive urban stormwater discharges. These sites show increased levels of stormwater-derived contaminants in their sediment and reduced species diversity compared to Big Muddy Creek.

The graphs (above right) illustrate an example of these impacts. Here the diversity and abundance of benthic invertebrates was used to assess the ecological health of different areas. A healthy estuarine ecosystem was assumed to support a wide range of different species and a high abundance of animals. Comparison of the diversity of benthic species from different estuarine and harbour areas in the Auckland region showed a definite correlation between high levels of sediment contaminants such as zinc, copper, lead and organics (e.g., PAH, dieldrin and chlordane) and low numbers of species. By considering the number of species, we could categorise the study sites as polluted and unpolluted. At unpolluted sites the number of species ranged from 9 to 11. Polluted sites had fewer than 6 species present.

Results such as these provide evidence that there are ecological effects, but at present we cannot be confident that these effects are due to pollution alone.

Assessing the long-term impact of the disposal of treated stormwater from which a large proportion of the contamination has been removed is even more difficult.

Mitigating stormwater's effects

Stormwater can be treated to reduce the level of contamination. The most common method uses the processes of sedimentation in stormwater treatment ponds or filtration to remove a portion of the suspended solids load. Because contaminants are associated with the suspended solids, removal of these solids reduces the contaminant load.

The efficiency of a treatment device in removing stormwater contaminants increases with the size of the device. However, after a level of efficiency is reached (around 70%) in a stormwater treatment device, a further increase in size will achieve a proportionately smaller increase in treatment efficiency. Thus stormwater treatment can never be 100% effective.

Current stormwater treatment technology is based on a best practicable option (BPO) approach as defined in the Resource Management Act. Stormwater treatment does not set discharge standards and cannot ensure that a designated environmental objective will be met. The philosophy behind stormwater treatment is therefore to reduce the total quantity of contaminants being discharged to a practical minimum.

Residual contaminants which pass through treatment devices will still accumulate in depositional receiving environments. Recent work by NIWA for the Auckland Regional Council (ARC) shows that indeed the toxicity of stormwater is not completely eliminated by either stormwater filter or retention pond treatment devices. Over time, we predict that contaminant concentrations will increase, albeit at a reduced rate. Stormwater treatment technology therefore only defers the time at which sediment contaminant concentration thresholds are exceeded. Our current understanding is that any ecological consequences of urbanisation of catchments with accumulation zones as receiving environments are therefore only delayed by treatment.

The ARC's demonstration stormwater treatment pond on the grounds of Unitec in Auckland city.

Auckland Regional Policy Statement

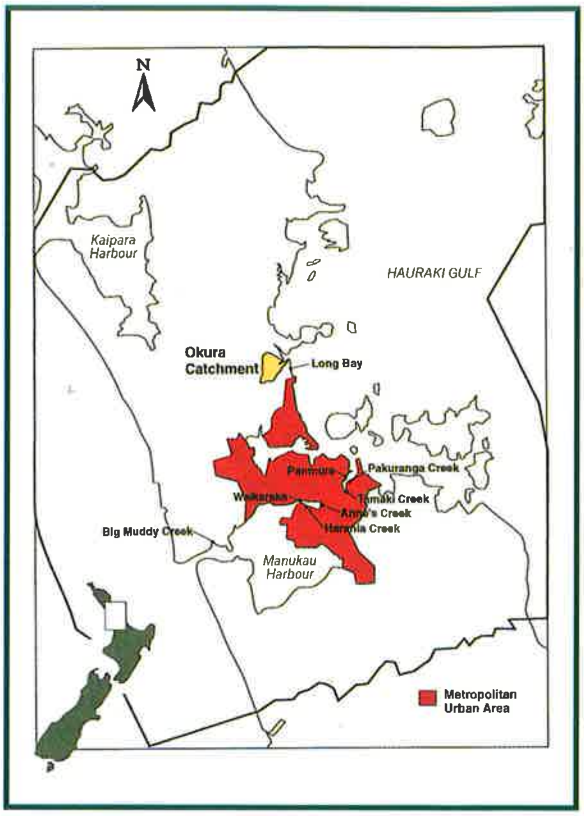
The ARC has implemented a programme of stormwater treatment since the late 1980s. The ARC, however, recognised that preventing urban development in catchments with sensitive and currently unspoilt receiving environments is the only presently available option if stormwater contamination effects are to be avoided entirely. For this, as well as other reasons, the ARC's Regional Policy Statement (RPS), a statutory document required under the Resource Management Act, contains objectives and policies aimed at containing urban development to the existing metropolitan area and excluding it from catchments with unspoilt receiving environments. In particular the RPS identified the Metropolitan Urban Limit (MUL), a line beyond which urban development would not be permitted (see map). Because of Auckland's rapid growth, the ARC accepts that, ultimately, the line will need to be moved — but only after carrying out detailed assessments aimed at minimising environmental effects.

In the north of the metropolitan area, the MUL lies south of the Okura River catchment. The Okura River estuary was identified in the RPS as an unspoilt estuary with high ecological values which deserve protection. This area is within the North Shore City Council area. Subsequent to the publication of the RPS, the City Council proposed an extension of the MUL to meet the increased demand for residential housing. The proposed extension would allow residential expansion into 426 hectares of the Okura River estuary catchment as well as development in the Long Bay catchment which lies between the Okura River and the MUL. The resulting conflict between the objectives of the two Councils was appealed to the Environment Court (previously known as the Planning Tribunal) for hearing.

Appeal before the Environment Court

The appeal of the ARC's RPS by North Shore City Council and a group of landowners and developers with interests in the Okura River estuary catchment was heard during July and August 1996. Ton Snelder and Rick Pridmore of NIWA were amongst those who gave expert evidence for this adjudication.

A crucial aspect of the argument was whether stormwater resulting from the proposed urban development could be treated sufficiently to ensure the protection of the existing estuary ecosystem. On one hand the proposal was to develop only a proportion of the catchment and to install BPO stormwater treatment devices. The developers showed that BPOs could be constructed which would exceed the ARC's treatment efficiency guideline. On the other hand the ARC argued that storm-water treatment BPOs cannot be 100% effective and that despite treatment sediment contaminant levels would increase in the Okura estuary over long time periods.



The Auckland region showing the metropolitan area, the Okura River catchment and the sites where sediment quality and species diversity were measured (refer to diagrams on previous page).

The Environment Court accepted the environmental evidence issues presented on behalf of the ARC. In its findings, the Court focused heavily on section 5 of the Resource Management Act which establishes the Act's purpose. Paraphrased here, the purpose of the Act is to: "manage the use, development, and protection of natural and physical resources in a way which enables people or communities to provide for their social, economic and cultural well being, while safeguarding the life supporting capacity of air, water, soil and ecosystems".

The judgement considered that "applying section 5 involves an overall broad judgement of whether a proposal would promote the sustainable management of natural and physical resources" and that: "Such a judgement allows for comparison of conflicting considerations and the scale or degree of them, and their relative significance or proportion in the final outcome".

A key consideration in the judgement was "it is reasonably foreseeable that future generations of Aucklanders will need accessible experience of an estuary in natural condition". The judgement accepted the probable adverse environmental effect of urban development in the catchment of the Okura estuary and considered that this conflicted with safeguarding the estuary's "life supporting capacity" to such an extent that the proposal was unacceptable in terms of the purpose of the Act. The judgement did not however consider this to be the case for the Long Bay catchment which discharges into an open coastal receiving environment. The Court therefore found that the location of the MUL should be moved to include the Long Bay catchment but not the Okura estuary catchment. ■

Ton Snelder is based at NIWA in Christchurch and Bruce Williamson at NIWA in Hamilton.

Further reading

Williamson. R.B. 1993.
The urban runoff data book.
NIWA, Hamilton

Available from:
Bruce Williamson,
NIWA, PO Box 11 115,
Hamilton
(Phone: 07 856 7026;
fax: 07 856 0151).

FRESHWATER FISHERIES

PITs, CWTs and JUNIPEX

Martin Unwin

Fish tagging has long been used as a fisheries research tool. Two types of internal tag are proving especially useful for a range of NIWA projects.

SCRATCH THE SURFACE of just about any fisheries study and you will find a tagging programme.

Tagging — applying some form of mark to an animal so that it can be recognised at a later date — is one of the most basic field techniques for biological studies in general, and for fisheries science in particular. Tagging is an indispensable tool for studying such diverse topics as population estimation, patterns of movement, growth rates and predator–prey relationships.

Modern technology has led to huge advances in the range of marking techniques available. At one end of the spectrum are high-tech devices such as miniature radio tags which can be tracked by satellite, and the almost unlimited possibilities offered by DNA finger-printing. At the other end lie a host of more mundane but nonetheless useful (and more importantly, cheaper) methods such as external streamer or wire loop tags, and even the humble fin-clip.

Midway between these extremes lie two methods which are an essential part of NIWA's ongoing JUNIPEX study (see *Water & Atmosphere 4*(3): 13–16).

Coded-wire tags

Coded-wire tags (CWTs) have long been used for mass-marking salmon, and were introduced to New Zealand in 1977. CWTs meet the need for an inexpensive mark which can be applied to young hatchery-reared fish as small as 5 g (about the size of your little finger), but will remain in place for the remainder of its life, which may be up to four years.

Each CWT is a 1.25 mm length of fine stainless steel wire, marked with a series of bands like a supermarket bar code. Fish are marked by injecting a tag into the nose cartilage, and also (since the tag cannot be seen once it is implanted) by an external fin clip. Since recovery rates for hatchery-reared fish average less than 1%, CWTs are typically applied to groups of 5 000–10 000 fish, each bearing the same batch mark. Tag recoveries allow us to estimate survival rates and determine homing and straying patterns. Nearly 5.5 million chinook salmon have been marked with CWTs, with over 40 000 recoveries to date.

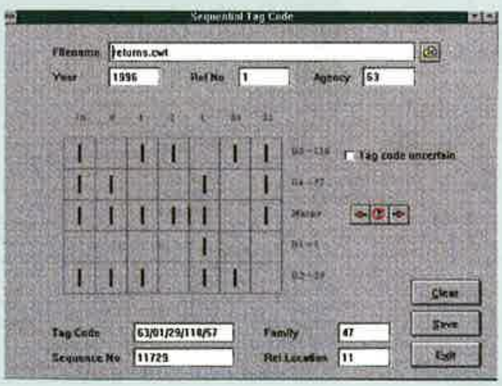
In the course of JUNIPEX we have marked over 130 groups of salmon, some numbering as few as 250 fish. To handle such small batches, we use a special type of individually numbered CWT called a sequential CWT (S-CWT). To help read these tags, which bear a more complex coding pattern than conventional CWTs, NIWA has developed in-house software which greatly streamlines operations in the tag recovery laboratory (see panel).

S-CWTs have allowed us to assign a specific sequence of tags to each of the 83 JUNIPEX families, so that fish can be identified to family level and hence traced back to a specific spawning pair. Ultimately, returns of these fish will allow us to characterise marine survival and growth at both family and population level. Anglers can help this

Sequential coded-wire tags

WHEN VIEWED under a microscope in the tag recovery laboratory, an S-CWT looks like a small metal cylinder engraved with six bands of parallel scratch marks at 60° intervals around the circumference. Each band represents a 6- or 7-bit binary number, with the presence or absence of a mark signifying a binary 1 or 0. However, the code does not necessarily start at one end of the tag, so one of the six bands serves as a master code which identifies both the starting position and orientation of the remaining five codes. Another band is reserved for an "Agency Code" identifying the authority responsible for the tagging programme, leaving four bands available for storing data. In total, over 65 million different codes are possible.

Manually deciphering the tag code requires the reader to determine the value represented by each data bit, and add these together to yield the five numbers which make up the full code. Since this usually involves rotating the tag several times so that each data bit can be lined up and double-checked against the master code, there is plenty of scope for error. To simplify the reader's task and reduce the chance of a mistake, we use a custom-built program which displays a blank template of the tag on a PC screen, as it would appear if we were to cut the tag lengthways and "unroll" the surface so that the master code and the four data bands appear side by side. A key feature of the program is that the template can be rotated and incrementally shifted one bit to the left or right, until the image on the screen corresponds to the image seen through the microscope. Once the correct image has been obtained (in the diagram below the master code has been shifted two bits to the left), the reader fills in successive data bits by clicking with a mouse at the appropriate location on the template. When data capture is complete, the program performs the necessary arithmetic, and passes the full tag number to the appropriate database. Use of this program has greatly streamlined our tag recovery program, with a corresponding improvement in data quality.



For further information, see: Unwin, M.J., Hill, J.T. and Lucas, D.H. An accurate and efficient method for reading sequential coded-wire tags using a PC-based data capture programme. *North American Journal of Fisheries Management*, in press.

programme by keeping a watch for adult salmon missing the adipose fin — the small fleshy fin in front of the tail — and handing the snout in to one of NIWA's 28 Head Depots located near all the major salmon rivers.

Passive integrated transponder tags

A drawback of CWTs is that tag recovery — which involves dissection of the upper jaw — means sacrificing the fish. For adult salmon, which die after spawning, this is not a serious constraint, but other facets of the JUNIPEX study require individual fish to be monitored at regular intervals throughout their life. PIT (passive integrated transponder) tags meet our need for an externally readable tag small enough to be applied to fingerlings but secure enough to remain in place permanently.

Each PIT tag consists of a sealed-glass cylinder about 12 mm long containing a miniature copper wire coil bonded to an integrated circuit chip. When placed within a magnetic field, the chip responds with a characteristic signal specific to each tag. Fish are marked by injecting a tag into the body cavity. Despite the rather intimidating look of the needle (see photo), this operation can be accomplished with over 99% survival.

Tags are read using a hand-held scanner which interfaces to a PC and (using another piece of in-house software) enters the tag code into an Excel spreadsheet, with a date and time stamp. Other relevant details such as length, weight and sex may be entered as appropriate.

In addition to the JUNIPEX study, PIT tags are proving useful in other NIWA research programmes. At our Christchurch laboratory, PIT tags will be used to mark a group of eels which will be reared in the laboratory over the next four years, to allow detailed monitoring of individual growth rates. Staff at NIWA in Hamilton are using PIT tags to identify banded kokopu in cleared and bush-covered streams, in an effort to better understand their individual movements and feeding preferences.

Which tag?

A number of factors need to be considered when choosing a tag for any particular application. CWTs are cheap (about 8¢ per tag), and easy to apply. Using a special tag injector, a four-person crew can mark up to 10 000 fish per day. Tag recovery is time consuming (up to 10 minutes per tag for S-CWTs), and laboratory costs can be a significant part of the programme budget. At up to $14 each PIT tags are comparatively expensive, although larger orders attract substantial discounts. However, an important virtue of PIT tags is that they are reusable, so that recovered tags can be recycled and used again for other studies. Given this asset, we can expect that PIT tags will continue to find plenty of other applications as NIWA initiates new fisheries and aquaculture research programmes. ■

Martin Unwin is based at NIWA in Christchurch.

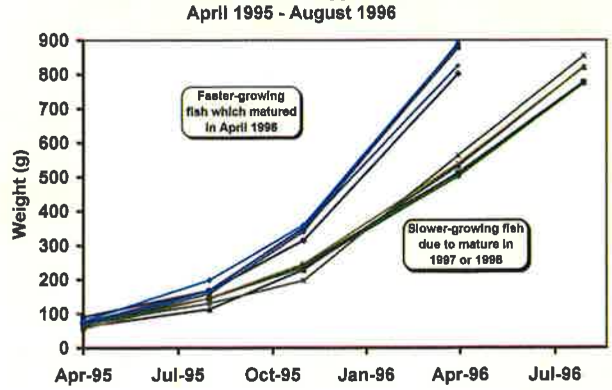
Implanting a PIT tag into a young JUNIPEX salmon. By carefully inserting the tag into the body cavity, between the abdominal muscle tissue and the internal organs, handling mortality can be kept to less than 1%. Three weeks after tagging, the injection scar has healed completely. (Photo: Nelson Boustead)

Individual growth profiles

THE JUNIPEX study involves monitoring 58 families of chinook salmon of Rakaia and Waitaki origin, which are being reared to maturity at NIWA's Glenariffe Research Hatchery, to determine whether the two populations differ at a genetic level. A key part of this study is to rear 50 PIT-tagged fish from each family, so that individual growth profiles can be compared at family and population level. Since these fish were tagged, in April 1995, they have been scanned five times at roughly four month intervals. Fish maturing in April 1996 (at two years of age) were harvested, so that tag records can also be used to compare growth profiles for individuals which did or did not mature in 1996.

The figure below shows growth profiles for 10 fish, all members of the same family, of which five matured this year and five did not. The difference between the two groups showed up clearly in April 1996, when the maturing fish — mostly males with well-developed testes ripe with running milt — were over 60% heavier than their non-maturing siblings. However, by tracing these fish back over the previous twelve months, their growth profiles clearly show that they were starting to pull ahead as early as August 1995 when they were already 20% heavier. This is consistent with results for Atlantic salmon, which show that maturation is strongly linked to springtime fat reserves: fish with the largest reserves are more likely to mature the following autumn.

Growth Profiles for 10 PIT Tagged JUNIPEX Fish, April 1995 - August 1996



HYDRODYNAMIC MODELLING

Tides around New Zealand: a pictorial essay

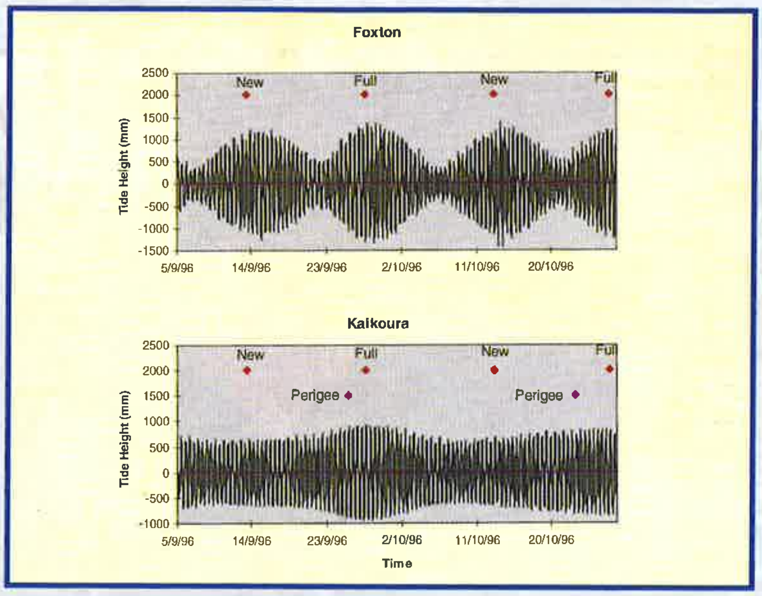
Derek Goring

No-one, not even the legendary King Canute, has been able to turn back the tide. However, we have technology available today to help us understand exactly how tides work.

TIDES are by far the most important factor influencing the variation of sea level on the New Zealand coast. For most of the New Zealand coast, the lunar semidurnal (iM_2) tide, caused by the gravitational attraction of the moon on the earth's waters, accounts for 87% of the variance in sea level. Overall, tides account for 96% of the variance in sea level.

The tides vary considerably from place to place around New Zealand. The most striking difference is that between east coast sites and west coast sites as illustrated (upper right).

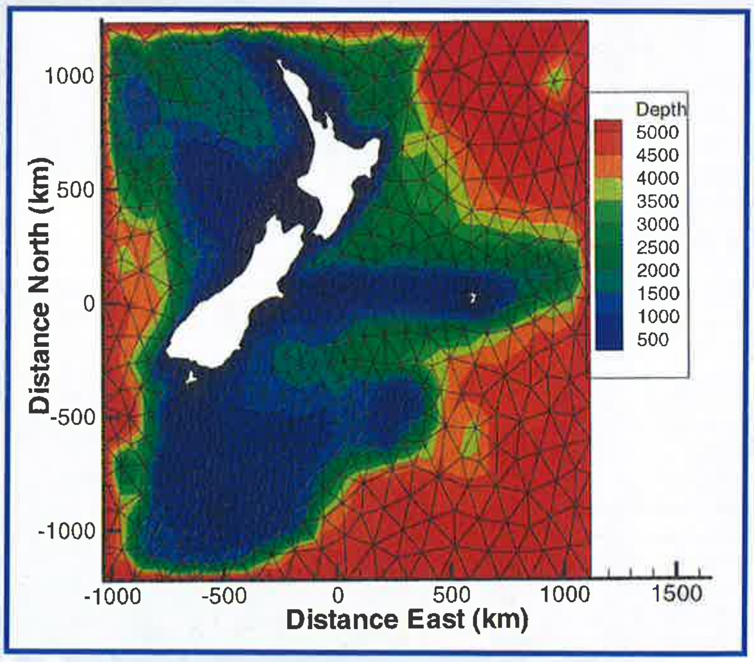
Plots on the following pages show the results of running a mathematical model on a "finite element mesh" (illustrated right) using TOPEX/Poseidon satellite data around the boundaries. The results are in the form of time sequences of sea level through tidal cycles.



Typical tidal records from a west coast site (Foxton) and an east coast site (Kaikoura). The plots show that on the west coast spring tides occur every fortnight, a day or two after new or full moon, and neap tides occur at first and last quarter. However, on the east coast there are essentially no spring/neap tides. Instead, the highest tides coincide with the moon's perigee (the times every month when the moon is closest to the earth). We call these perigean/apogean tides. Every seven months, the full or new moon coincides with the moon's perigee to produce larger-than-normal perigean spring tides.

The mean high water springs (MHWS) level, which in the Resource Management Act is used as the boundary between the coastal marine environment and the land, is defined in the Nautical Almanac *as the mean high tide level over two days following a new or full moon. This plot shows that for east coast sites such as Kaikoura, MHWS calculated this way could vary considerably depending on the closeness of the new or full moon to the moon's perigee.*

With data from the US/France oceanographic satellite TOPEX/Poseidon we can model the way tides propagate around New Zealand using a finite element mesh.



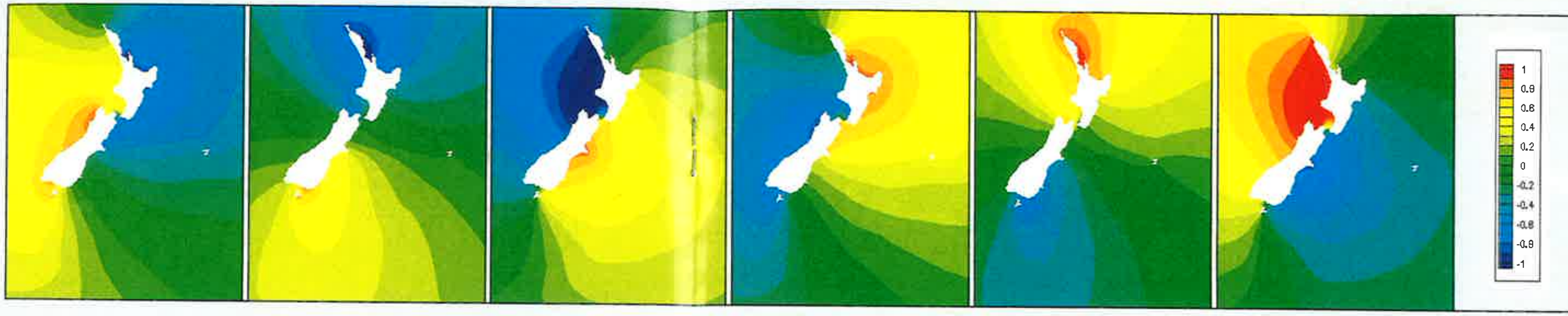
New Zealand's Exclusive Economic Zone (EEZ) with triangular finite element mesh. The triangles are proportioned so that they are close to equilateral and their area is proportional to the depth. This means that in shallow water the nodes at the corners of the triangles are close together, but in deep water they are farther apart.

WATER & ATMOSPHERE 5(1) 1997

The tide consists of around 600 identifiable constituents, each of these resulting from a particular astronomical feature in the gravitational attraction by the moon and sun on earth's waters. Three of the most important constituents are shown here. The colours represent the level above and below mean sea level in metres, as shown in the scales at the far right of each series.

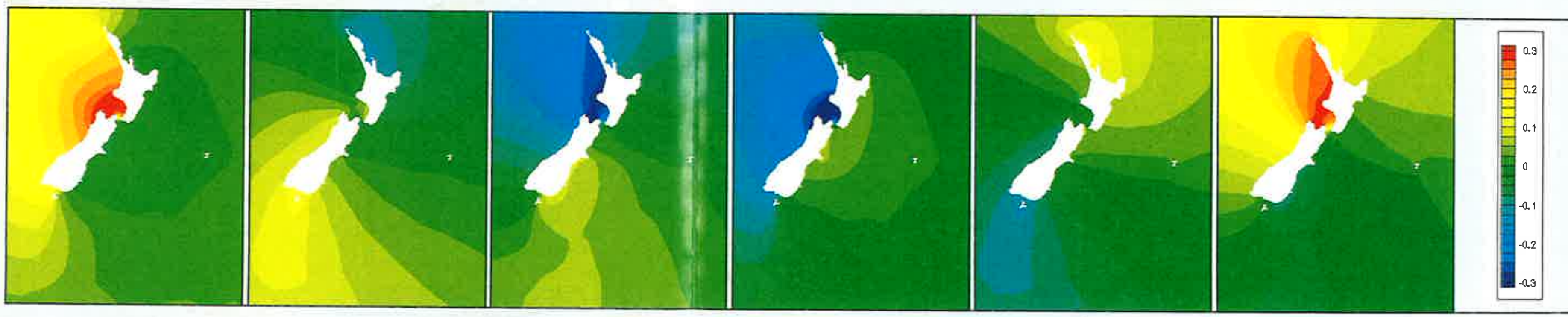
The lunar semidiurnal (M_2) tide

The lunar semidiurnal tide has a complete 360 degree cycle around New Zealand, so that at any given time there is a high tide somewhere on the New Zealand coast. Highest M_2 tides occur in the Cook Strait area from Taranaki to Nelson. Note that the tides are out of phase through Cook Strait, with high tide occurring on one side when it is low tide on the other. This represents a 2 m difference in sea level through the Strait and explains the vicious tidal currents which occur there.



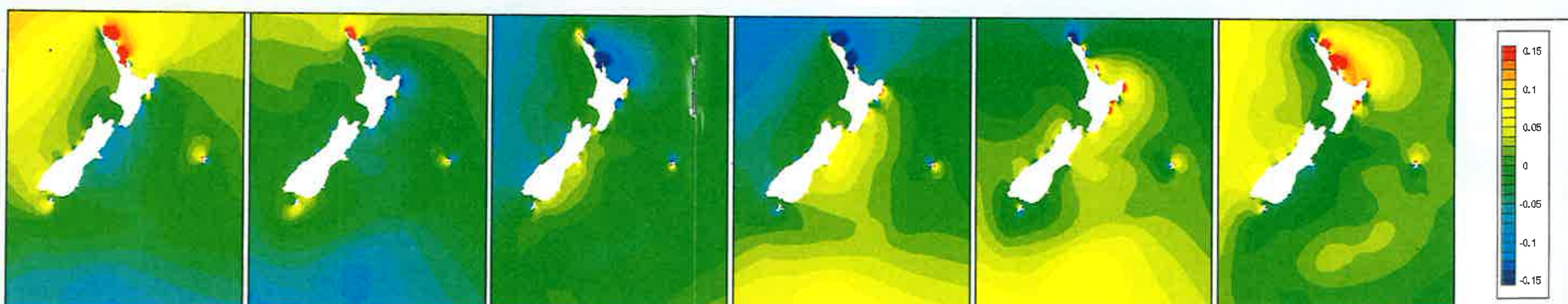
The solar semidiurnal (S_2) tide

In contrast to the lunar semidiurnal tide, the solar semidiurnal tide propagates up and down the west coast but hardly penetrates onto the east coast. This explains the difference between west and east coast tidal records shown earlier.



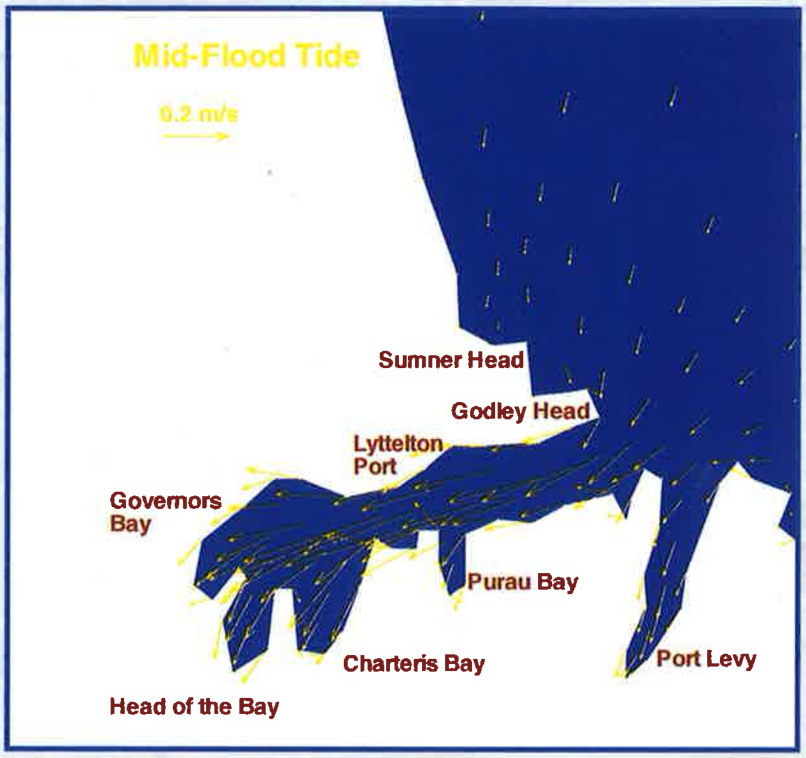
A diurnal (K_1) tide

Diurnal tides are the cause of daily variation in high and low tide heights. These effects are most pronounced in the area from the Hauraki Gulf to North Cape. Notice that at the Chatham Islands this diurnal tide has a complete 360 degree cycle around the island. Other modelling with this grid, using winds and barometric pressure as the forcing function rather than tides, indicates that the natural period of oscillation for the Chathams is about 24 hours.



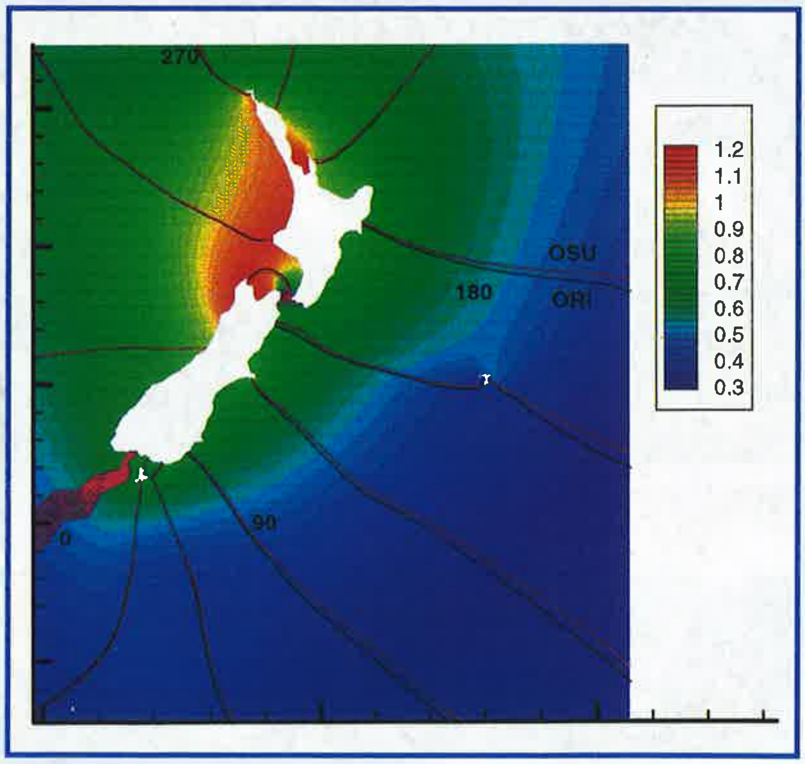
In addition to sea level shown on the previous page, the model also produces velocities at each node.

This enables us to estimate tidal currents and an example is shown in the figure (right) for the Christchurch shoreline and Lyttelton Harbour during mid-flood tide.



Tidal currents at each node of the finite element mesh for the Christchurch coastline and Lyttelton Harbour area. The arrows indicate direction of flow and the length of the arrow is proportional to the velocity of flow, as indicated by the scale arrow (top left).

Patterns of tidal currents such as these can be used to aid navigation and to determine sedimentation and transport of pollutants. Currents in Cook and Foveaux Straits are being calculated as part of a European study into the potential for power generation from tides.



Cotidal chart showing how the amplitude and phase of the M_2 tide vary around New Zealand.

The colours represent the amplitude (the height of the tide above and below mean sea level). Red represents the highest tides (in Tasman Bay and the Firth of Thames), green the intermediate tides (around most of South Island and the east coast of North Island) and blue the lowest tides (in the Southern Ocean and at the Chatham Islands).

Phases (representing the time when high tide will occur) are shown by contour lines, with the numbers representing degrees from a time datum which has been chosen as 0 hours on 1 January 1900 at Greenwich. This datum is used throughout the world for tides. The choice of a universal datum enables researchers to exchange data and results. The different phase lines represent different interpretations of TOPEX/Poseidon data, one from Oregon State University (OSU) and the other from Ocean Research Institute, Tokyo (ORI).

Notice the conglomeration of contour lines at the south-west corner where the phase has passed through a full cycle and jumps from 360 back to 0 degrees. Few contour-plotting programs are capable of handling this jump and bunch the contour lines up in this fashion. Cotidal charts such as this are used extensively by researchers to obtain an overall appreciation of the variation of the various tidal constituents.

This article summarises the initial results of a NIWA project (supported by non-specific output funding from the Foundation for Research, Science and Technology) whose aim is to develop a two-dimensional, hydrodynamic model of New Zealand's Exclusive Economic Zone (EEZ).

In future work the coarse grid shown here will be refined with more accurate bathymetry data, particularly in the region from 200 m depth to the shore. To carry this out, 24 bathymetry charts of the New Zealand coast (produced by the Royal New Zealand Navy) have been digitised. A finite element grid will be developed using these data. Repeating the modelling on this refined grid will produce more detailed results for the area close to the coast. ■

Derek Goring is based at NIWA in Christchurch.

MARINE BIOLOGY

Update on marine toxic algae:

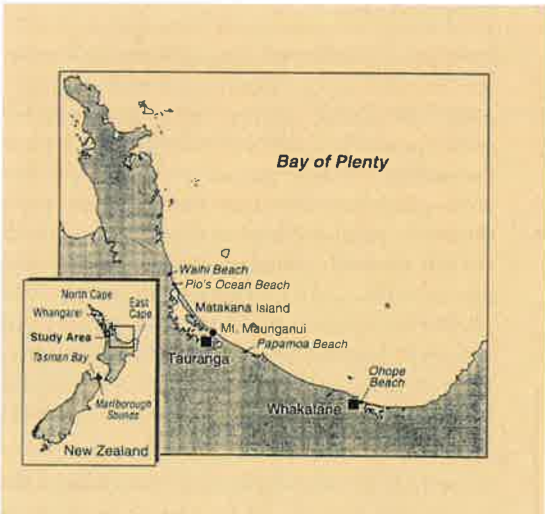
toxin production of two strains of *Alexandrium minutum* isolated from the Bay of Plenty

F. Hoe Chang

The toxic algae responsible for shellfish poisoning in New Zealand over the last few years may have been in our waters all along.

DURING THE 1993 outbreaks of toxic shellfish poisoning, two different strains of a species of planktonic algae, *Alexandrium minutum,* were cultured from shellfish samples collected at both Pio's Ocean Beach and Tauranga Harbour in the Bay of Plenty (see map). Both strains were subsequently found to be toxic in a routine mouse bioassay conducted at the New Zealand Communicable Diseases Centre in Porirua, and were implicated as the source of paralytic shellfish poisons (PSP) detected in the shellfish (see Chang 1994).

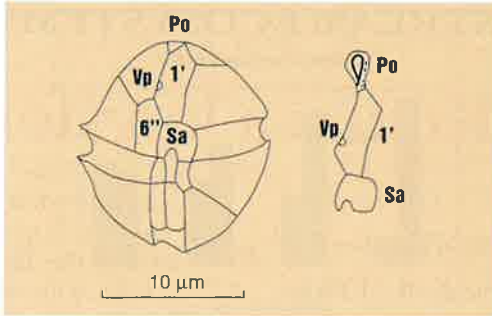
Alexandrium minutum is a small (approx. 0.015 mm in diameter), inconspicuous dinoflagellate species. Cells are almost spherical and usually occur singly, and rarely in pairs, in both cultures and field samples. Positive identification of this species requires careful study of the outer wall of the cell which is made up of distinctive plates as illustrated in the diagram above right. The outer plates can be easily distinguished under both light and scanning electron microsopes.



Study area during the 1993 toxic shellfish outbreaks in the Bay of Plenty, North Island.

This species is known to produce a suite of paralytic shellfish poisons (PSP) which can cause neurological symptoms within 30 minutes of eating contaminated shellfish, ranging from tingling sensation or numbness around lips to pronounced respiratory difficulty. To date, up to four toxin components (mainly gonyautoxin fractions) have been detected in overseas species.

The question of whether the New Zealand strains produce the same suite of toxins as those from overseas has prompted both local and international collaborative efforts. Dr. Don Anderson and his team at Woods Hole Oceanographic Institution, USA, and Desmond Till of the New Zealand Communicable Diseases Centre have worked with NIWA on the toxin production of the two strains of *Alexandrium minutum* found in New Zealand. Toxins were also extracted from several different shellfish (e.g., mussels, pipi, scallop, tuatua) harvested from the Bay of Plenty during the 1993 outbreak and compared with the toxins extracted from the cultures.



Diagrammatic summary of ventral view of cell plates of Alexandrium minutum *from the Bay of Plenty, including details of the apical plate (Po), the first apical plate (1'), the ventral pore (Vp), and the anterior sulcal plate (Sa), which are required for the positive identification of this species.*

Up to six different toxin components were detected in the two *A. minutum* strains cultured from Bay of Plenty. One component known as neosaxitoxin (NEO) was clearly dominant. Toxin profiles of shellfish showed the same six toxin components. Mussels gave the closest match while tuatua matched less closely. Profiles of both scallops and pipi matched least well with those of the *Alexandrium* cultures.

The toxin compositions of the Bay of Plenty strains of *A. minutum* do not resemble any of those characterised to date in overseas strains. Strains from Taiwan, Australia, Portugal and Spain, and a strain which has been described as *Alexandrium angustitabulatum* Taylor and Cassie, isolated by Cassie-Cooper from Whangarei in 1982, all contain gonyautoxins. A strain from France was reported to contain two gonyautoxins and some additional C-toxins. The closest match of toxin composition has been found in several strains of *A. minutum* isolated from Marlborough Sounds by Lincoln MacKenzie (pers. comm.) at Cawthron Institute, Nelson.

This collaborative study clearly established that *A. minutum* from the Bay of Plenty contains saxitoxins, and was responsible for at least part of the PSP toxicity measured in shellfish during the 1993 outbreak. The unique toxin composition detected in strains of this species from the Bay of Plenty weakens the hypothesis that *A. minutum* has been recently introduced to New Zealand waters by ballast water. An alternative theory is that *A. minutum* is native to the area but has not been noticed in the past. ■

F. Hoe Chang is based at NIWA in Wellington.

Further reading

Chang, F.H. 1994. New Zealand: major shellfish poisoning (NSP) in early '93. *Harmful Algae News 8*: 1-2.

STREAM ECOSYSTEMS

Koura: a keystone species?

Kevin J. Collier

Stephanie M. Parkyn

Charles F. Rabeni

Freshwater crayfish or koura have the potential to directly or indirectly influence the structure of benthic invertebrate communities. Work at NIWA has begun to examine the ecological role of Paranephrops planifrons *in Waikato streams, and to evaluate the impacts of land use changes on this possible "keystone species".*

KEYSTONE SPECIES are species whose activities are critical to the structure of the community in which they live. They get their name from the stone at the top of ancient arched doorways — if this stone is removed the whole structure can collapse. Elephants have been considered by some to be keystone species. Their unspecialised browsing on trees and shrubs turns woodland habitats towards open grassland and this encourages the presence of antelope and other grazing ungulates. At the other end of the size scale, recent work both overseas and in New Zealand has suggested that freshwater crayfish can perform a keystone species role in aquatic ecosystems.

Studies on koura

Freshwater crayfish (or koura as we call them in New Zealand) often fall between the cracks in studies of stream invertebrate communities as they are not readily collected by conventional benthic sampling methods. Consequently, we are not sure how many koura there are or how they might influence other stream invertebrates.

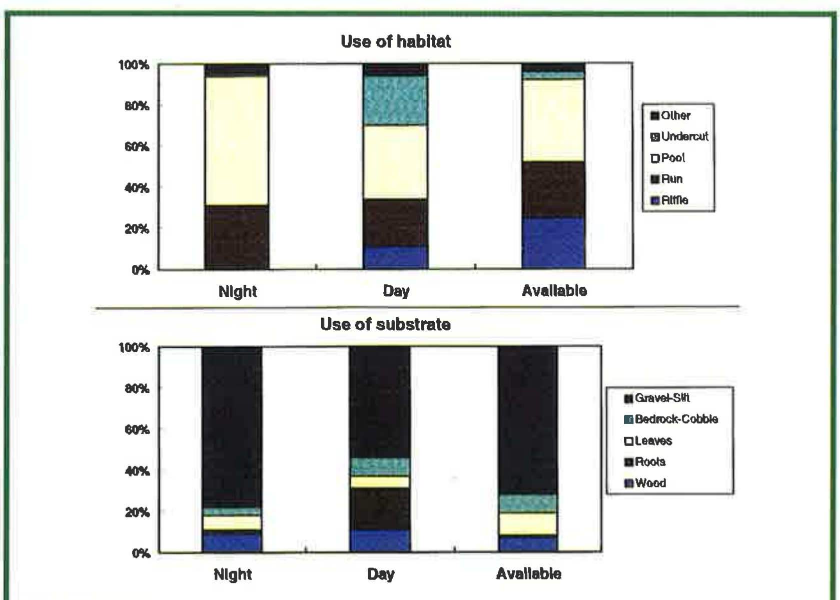
If koura are keystone species then it is of particular interest to know whether these creatures are vulnerable to human impacts such as those brought about by changes in land use. In that case, what would be the follow-on effects of any changes in their abundance on other members of the stream community?

In New Zealand we have two species of freshwater crayfish. *Paranephrops zealandicus* is found on the east coast of the South Island from North Canterbury southwards and in Stewart Island. *Paranephrops planifrons* is found in Nelson, Marlborough, the West Coast and throughout North Island. Work is currently underway at Otago University on the ecology of *P. zealandicus*. NIWA will contribute to this study by funding stable isotope analyses to help identify major food sources of koura in Otago streams.

Studies of *P. planifrons* began at NIWA Hamilton in early 1996 when Dr Charlie Rabeni of the Fish and Wildlife Research Unit of Missouri University arrived as a NIWA Visiting Scientist. Charlie has spent many years studying North American crayfish species and his visit brought a wealth of experience to this New Zealand project. The objectives of Charlie's visit were:

- to develop and test appropriate techniques for measuring the abundance and population structure of koura;
- to conduct density manipulation experiments to see if koura could play a keystone species role.

Percentage of koura in different habitat and substrate types collected during the night by hand-netting and during the day by electric fishing, and the amount of each habitat type available in a 42-m long reach of a native forest stream.



How many koura are out there?

As part of understanding the ecological effects of koura on streams we need to know how many there really are.

Usually, only one or maybe two koura turn up in the occasional benthic invertebrate sample collected using conventional quantitative techniques. Often there are none at all. Part of the reason is that koura are active at night and most spend their days tucked away in burrows in the banks or under logs and large rocks which are not normally sampled in studies of aquatic invertebrates. This is illustrated in the graph (left) which shows that at night most koura were out and about in pools and runs on gravel substrates, whereas during the day they were often found hiding beneath undercut banks and amongst submerged roots of riparian trees.

We tried several different techniques on consecutive days (or nights) to estimate koura abundance in a 42-metre-long reach of a native forest stream with an average width of 2.9 m. The length of each koura we caught was measured (from behind the eye socket to the mid-dorsal posterior edge of the carapace). Large koura — >5 mm carapace length — were marked by clipping certain tail fins so that we could tell which technique(s) had been used to capture them if they were caught again. The techniques we evaluated were:

- direct censusing
- depletion hand-netting
- mark–recapture hand-netting
- depletion electric fishing
- mark–recapture electric fishing
- quadrat (0.5 m^2) sampling.

Direct censusing and hand-netting were done at night. Electric fishing and quadrat sampling were carried out during the day. Baited traps were also investigated but were not considered useful.

All koura caught were returned to approximately the same part of the reach after each sampling. Population size was calculated using formulae based on the rate of decline in numbers caught on one sampling occasion (depletion methods) or the proportion of marked animals that was recaptured on successive sampling occasions (mark–recapture methods).

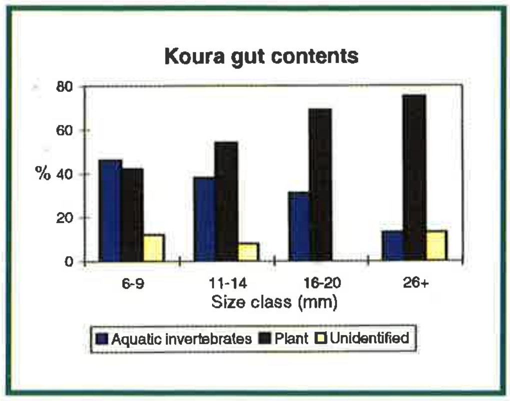
We collected 317 different koura greater than 5 mm carapace length from the reach, or a total of 355 koura if 12% of those caught were assumed to have carapaces less than 5 mm long. Table 1 shows the population estimates, adjusted for small koura, for the different sampling methods.

Method	Population estimate	Number per m² of bed	Number per m of channel
Direct censusing	37	0.3	0.9
Depletion hand-netting	92	0.7	2.2
Mark–recapture hand-netting	306	2.5	7.2
Depletion electric fishing	400	3.3	9.5
Mark–recapture electric fishing	521	4.2	12.4
Quadrat sampling	317	2.6	7.5

Table 1 Total population estimates and estimates extrapolated to densities per square meter and linear meter of stream channel for a 42-m long reach of a native forest stream.

Compared with the number of different koura actually caught in all samples (355), direct censusing and depletion hand-netting gave low population estimates, and both techniques were biased to recording larger individuals which were presumably easier to see. Mark–recapture hand-netting gave a much higher estimate than the depletion technique, but both electric fishing methods yielded even higher estimates. Quadrat sampling gave an intermediate estimate but the confidence intervals were wide and it was biased towards collecting small koura as most larger ones were under overhanging banks during the day.

Overall, it seemed that koura densities in the native forest stream reach we studied were likely to be around 3 per square metre or 10 per metre of channel. Electric fishing provided the most reliable technique for estimating population characteristics of koura.



Percentage of stomach contents classified as containing predominantly aquatic invertebrates, plant matter (including algae), or unidentifiable materials for four size classes of koura collected in November 1995 from the native forest stream.

How do koura affect stream ecosystems?

Preliminary analyses of koura guts from a native forested stream suggested that small koura (6–9 mm carapace length) fed to a much larger extent on stream invertebrates than large koura (>15 mm carapace length), which ate mainly plant material (see graph above). This indicated that koura could potentially influence invertebrate community structure directly through predation and indirectly by increasing organic matter processing rates.

To investigate this further and to address the second objective of Charlie Rabeni's visit we used the artificial stream channels set up at Whatawhata (e.g., see *Water & Atmosphere 4*(2):23) to carry out density manipulation experiments. All channels were seeded with gravel substrates, invertebrate larvae, shelters for the crayfish and pre-weighed packs of wineberry leaves. Koura (10–15 mm carapace length) were introduced to some channels so that we had four replicates each of three densities: no koura (control), four koura ("medium" density) or eight koura ("high" density). At the end of the experiment seven weeks later, we measured:

- the weight loss of the wineberry leaves
- the weight of fine sediments accumulated over the experimental period

Below
left: *Stephanie Parkyn, Jane Rabeni and Charlie Rabeni (left to right) preparing for nocturnal sampling of koura.*
centre: *Electric fishing for koura at the native forest site.*
right: *Using the 0.5 m² quadrat sampler to collect koura.*

- diversity, density and biomass of the benthic invertebrate community.

The patterns observed in this experiment are summarised in Table 2.

Wineberry leaves lost an average of 78% of their weight in the control channels during the course of the experiment. The presence of koura increased this weight loss to 92% in the "medium" density channels. All the leaf material had disappeared from the "high" density channels confirming that koura can have a marked impact on organic matter processing rates.

	Control	"Medium" density	"High" density
Leaf weight (% of initial weight)	22	8**	0**
Suspendable fine sediment (grams per channel)	1412	1159	987**
Surficial fine sediment cover (%)	82	68	41**
Invertebrate density (no. of individuals per channel)	864	1067	859
Invertebrate taxa richness (no. of taxa per 0.02 m^2)	8	7	6**
Invertebrate biomass (grams per channel)	0.4	0.3	0.2**

*Table 2 Summary of trends detected in "medium" density (4 koura) and "high" density (8 koura) channels compared to controls (no koura). **=significantly different from control at* $P<0.05$ (n=4).

Another obvious impact was a reduction in the accumulation of fine sediments in the channels containing koura. Fine sediment levels both on (surficial sediment) and within (suspendable sediment) the channel gravels were significantly lower where koura densities were "high" compared to the control channel. This result indicates that koura can act as ecosystem engineers by stirring up fine sediments and flushing them from the substrate, a process known as "bioturbation".

Reduced levels of fine sediment might be expected to improve conditions for other invertebrates in the channel, but the taxonomic richness (a measure of diversity) and biomass of the invertebrate communities was significantly lower in the "high" density channels than in the controls. This may be because predation by koura on larger invertebrates counteracted any increase in biomass or diversity. While invertebrate densities were not significantly different amongst treatments, changes were detected in the types of stream invertebrate present in the different channels, probably reflecting the interacting effects of bioturbation and predation.

Although densities of koura in the 0.5 m^2 experimental channels (8 and 16 koura per m^2) were greater than our estimates for a native forest reach in Table 1, they are likely to reflect true densities in certain habitat types (e.g., pools at night; see graph page 18). Twelve koura per square metre have been reported in pools of some Otago streams. Our results indicate that high densities of koura can affect the structure of benthic invertebrate communities either directly through predation or indirectly by modifying benthic habitat and organic matter processing rates, at least in experimental stream channels.

The next step is to carry out field enclosure experiments to see if the keystone species effects we recorded in the channels can be detected in a real stream. This will form part of a PhD study by Stephanie Parkyn, formerly of NIWA. Stephanie will also be building on other work begun by Brendan Hicks of Waikato University by examining the effects of land use on koura production, diet and growth (see photo below right), and will be conducting food assimilation experiments and behavioural/ecotoxicological studies to isolate the causal mechanisms of any land-use effects that are detected. This work will help unravel the significance of this poorly understood invertebrate to New Zealand stream ecosystems. ■

Kevin Collier is based at NIWA in Hamilton, Charles Rabeni is with the Fish and Wildlife Research Unit of Missouri University and Stephanie Parkyn is currently undertaking PhD research at the University of Waikato.

Below
left: *A koura and leaf pack in one of the channels.*
centre: *Sampling invertebrates from one of the channels. The different levels of surficial fine sediment accumulation can be clearly seen: the channel on the left has no koura whereas the centre and right channels have koura.*
right: *Marking a koura with coloured elastomere tags so that growth rates can be measured when they are recaptured.*

STREAM ECOSYSTEMS

Bed sediment clusters:

are they a key to maintaining biodiversity in flood-prone New Zealand streams ?

Barry Biggs

Mike Scarsbrook

Steve Francoeur

Maurice Duncan

Many headwater streams which experience frequent, destructive floods also support diverse communities of plants and animals. How do these communities survive the floodwaters? And can we use theories which explain this to help reduce human impacts farther downstream?

MANY OF New Zealand's streams experience frequent, severe flooding. Studies in the lower reaches of rivers in Canterbury have shown that enormous destruction of periphyton, insects and fish may accompany large floods. Nevertheless, diverse communities persist and indeed flourish in the headwater reaches. So, what is it about these headwater habitats which allows biota to survive there? One possible answer has been investigated in a NIWA study jointly funded by the Foundation for Research, Science and Technology and the Department of Conservation.

Stable patches

During floods, water velocities increase dramatically and cause gravels and stones to roll and tumble along the stream bed. All this extra motion makes it unlikely that periphyton and invertebrates can survive simply by their ability to hang on to the sediments. A more likely key to their survival could be the existence of patches on the stream bed that remain stable during floods.

Recent observations in the headwater reaches of rivers on the east coast of the South Island suggest that one source of these stable patches comes from the arrangement of bed sediments into discrete units which stream geomorphologists call "bed sediment clusters". Overseas research has shown that these bed clusters are far more resistant to movement during floods than other sediment types on the stream bed (e.g., gravels and cobbles). It has been shown in some steep headwater streams that between 10% and 90% of the bed may be occupied by bed sediment clusters.

We have investigated the density and stability of such bed forms in twelve South Island headwater streams (six to the west of the Main Divide and six to the east) in relation to a range of geomorphic variables which could be controlling their development. We have also been assessing bed sediment clusters as habitat for periphyton and invertebrates, and as potential refuges during floods.

Our initial observations have confirmed that bed sediment clusters are potentially very important as "refugia" from floods for stream communities. We are currently monitoring their stability, but it is already clear that they are resistant to the small-to-moderate intensity flood events which occur very regularly in these streams. Some of the clusters are staying in place for a year and more. Thus, they offer much more stable places to reside and seek shelter than the rest of the stream bed.

A bed sediment cluster with one large obstacle particle (a boulder) extending above the water and two stoss particles stacked on the upstream side. Flow is from the bottom to the top of the picture.

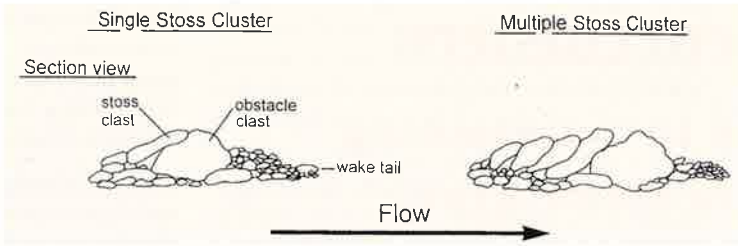
Bed sediment clusters and biodiversity

While carrying out our field work we noticed several other features of the clusters which we believe could also greatly enhance their value as habitat and their contribution to the overall biodiversity of streams.

- The large and complex interstitial spaces (i.e., gaps between particles) of the clustered sediments provide a wide variety of different hydraulic conditions, food resources and an increased surface area for invertebrates and periphyton. This diversity of microhabitats means that different taxa can potentially be catered for within the clusters. This could greatly increase biodiversity not only locally in the clusters, but in the stream as a whole.
- Many of the obstacle particles are large enough so that during low flows they break the surface of the water. Indeed, during one of the field trips we found many discarded larval cases on such rocks indicating that they had been used as sites for the insects to crawl from the water, dry off, and then emerge as adults. Conversely, it is easy to imagine that other adults would also use these rocks for egg-laying. These exposed rocks in mid-stream have lots of interstitial refuges directly below them so the insects would have minimal exposure to predation and high water velocities en route to their emergence or oviposition sites.

What is a bed sediment cluster and how common are they?

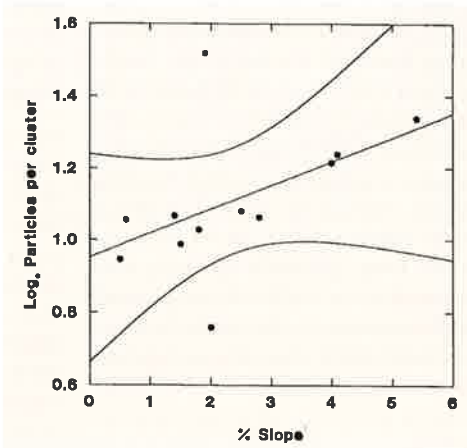
FOR OUR STUDY, we set strict, ecologically oriented, criteria for defining a bed sediment cluster. The arrangement is shown in the diagram. The sediment particle forming the "obstacle" against which the "stoss" particles stacked had to have one dimension of at least 25 cm (i.e., a boulder). The upstream particles had to be stacked up against this boulder to form interstitial spaces. Just adjoining it was not enough.



A stylised bed sediment cluster with a single stoss (or stacked) particle (left) and multiple stoss particles (right).

We found that clusters fitting these criteria occurred at an average density of one every 7.5 square metres with a maximum density of one in 3.6 square metres. The clusters covered an average of 2.3% (a maximum of 4.4%) of the surface area of some stream reaches. Most of the clusters had only two or three particles, but some had up to seven.

We found that the density and cover of a site by clusters were higher where the streambed was already armoured indicating a low supply of sediment to the stream. The frequency of floods had no effect so that there was no difference in the density of clusters between streams on the east and the west of the Southern Alps. One important factor that did contribute to cluster formation was the gradient of the stream reach. As the gradient increased from <1% to >4% the number of particles comprising the clusters increased (see graph left). Catchment geology also appeared to be important. For a given reach gradient, there were many fewer particles per cluster in granite dominated catchments (the sediment particles tended to be more rounded and so did not stack very easily) compared with greywacke, whereas there were many more particles in schist-dominated catchments (where the rocks tend to form more platy sediments which stacked well) compared with greywacke.



The average number of particles comprising the bed sediment clusters at our 12 South Island stream study sites in relation to the gradient of the site. The very high value at a 2% gradient was a site where the sediments were composed of platy schist rocks and the very low value for a similar gradient was a site with rounded granite sediments.

New sampling techniques

To test our predictions of the ecological value of the cluster formations it was necessary to develop new sampling techniques.

- Periphyton sampling is normally carried out by retrieving cobbles from the stream bed and taking them to the bank, where the periphyton sample is scraped off with a scalpel. However, many of the cluster particles and boulders were too heavy to lift so we made a simple new underwater sampler using the head of a toothbrush inserted into the base of a large syringe. An advantage of this sampler was that the clusters could be sampled without disturbing them, thus enabling us to sample the same rocks at many different times over the year.
- Most stream ecologists sample benthic invertebrates using relatively small samplers with frames which enclose, say, half a dozen cobbles and some gravels (e.g., a Surber sampler with a typical sample area of 0.1 m^2). This isn't nearly big enough for studying the groups of large sediments that make up the clusters. This sampling problem probably explains why no data on communities in bed clusters have been collected before. We therefore designed a large new sampler with dimensions of 1 m × 0.8 m — big enough to completely encircle the clusters. A fine mesh cage around the perimeter stops fish escaping and a cloth catch net at the rear allows us to collect all the animals dislodged. (It is possible to electric fish inside the cage prior to scrubbing the invertebrates off the rocks.)

The preliminary results suggest that bed sediment clusters are important "safe-houses" for stream organisms, giving them somewhere to hide from the extremes of velocity and turbulence during floods. The clusters also have other important assets during low flows. These are the diverse array of nooks and crannies they provide for invertebrates to live in during the inter-flood periods. The clusters also provide a more persistent periphyton food resource for invertebrates after floods, resulting in islands of rich biological activity in an otherwise harsh environment of low production. Further, where some of the rocks break the water surface they provide sites close to the interstitial retreats which can be used for emergence of adults and oviposition. It is clear that these areas of organised bed sediments are providing high quality habitat for a

Electric fishing inside the large bed sediment cluster sampling cage.

large range of streambed organisms to survive the harsh conditions of floods and then thrive during interflood periods.

While the benefits of these clusters to headwater streams are clear, it is also possible that these bed forms could be benefiting downstream reaches. It can take many months for communities to re-develop after disturbances in low gradient outwash plain or lowland reaches of rivers where more mobile gravels are the predominant sediments. It is likely that the clusters in the steeper sections of the catchments are playing an essential role in this recolonisation process by providing a rich source of colonists following natural or anthropogenic disturbances.

Management implications

Our results suggest that streambeds are composed of a patchwork of habitats varying in quality. An objective of aquatic resource management in New Zealand is to balance development and the maintenance of biodiversity. This aim warrants giving greater consideration to the preservation of good quality streambed habitat such as that provided by the bed sediment clusters.

There are two major types of development which could affect the formation and stability of these clusters. Firstly, instream activities which reduce bed gradient such as weirs, culverts, road crossings and dams will probably reduce the potential for these bed structures to form. Secondly, catchment activities which increase sediment supply to the streams and/or reduce channel gradient through sedimentation (e.g., through catchment and riparian de-vegetation) and bank destabilisation (e.g., through channelisation and stock trampling) will also decrease the potential for these bed structures to form.

An outcome of this study is that we have identified parameters for defining high quality streambed habitats. Potentially, these parameters could be used to assist in the typing of river systems in New Zealand and the definition of reaches that could have high conservation value. Ultimately, these parameters might be linked with riparian vegetation guidelines to enable the development of a system of "stream reserves". We envisage that such a system could contribute greatly to preservation of the physical integrity and biodiversity of many of our river systems. ■

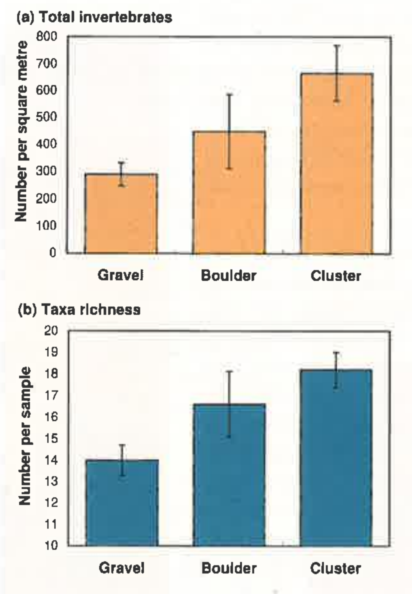
Barry Biggs and Maurice Duncan are based at NIWA in Christchurch, Mike Scarsbrook is at NIWA in Hamilton, and Steve Francoeur, formerly with NIWA in Christchurch, is now at Bowling Green State University, Ohio, USA.

Differences in periphyton and invertebrate communities on gravels, boulders and bed sediment clusters in a headwater stream

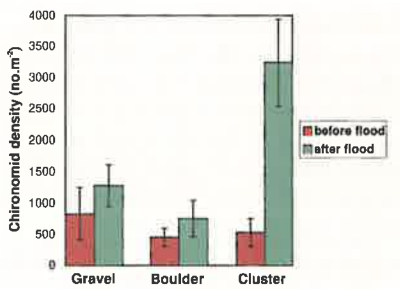
PRELIMINARY RESULTS from one of the streams (Bowyers Stream, South Canterbury) support our hypotheses (see main text). We found that the bed clusters were the best habitat. The histograms (right) show that invertebrate assemblages on clusters were more diverse than those on gravels and solitary boulders and there was a distinct trend of increasing densities from gravels/cobbles to boulders to clusters. Several invertebrate taxa were found only on the clusters and the total number of taxa was significantly greater on the clusters.

We also examined whether the clusters were being used as a place to hide from turbulent flood flows.

Periphyton and invertebrates on the outer surface of the gravels, boulders and clusters were monitored before and after a large flood. Periphyton communities on the clusters were much less affected by the flood. They only lost about 50% of their biomass. However, over 90% of the periphyton biomass was lost from gravels/cobbles. Significantly, the invertebrates (mainly comprising midge larvae) did not change over the flood on the gravels/cobbles and boulders (densities were already relatively low before the flood). However, there was a huge increase in midge densities on the clusters immediately after the flood, as shown in the diagram above right. It is likely that they had accumulated in the remnant periphyton mats on the clusters during the flood. The periphyton then provided an extensive food resource on which these insects could flourish. The midge communities continued to increase greatly in density in the following period of low flows. Midge densities on the boulders also increased dramatically in the subsequent weeks. However, they only increased a small amount on the gravels/cobbles.



(a) The density of invertebrates and (b) the number of species (i.e., taxa richness) on gravel, boulder and cluster bed forms in Bowyers Stream, South Canterbury, March 1996.



The density of chironomid larvae on gravel, boulder and cluster bed sediments before (open bars) and immediately after (closed bars) a moderate to large flood in Bowyers Stream, South Canterbury, June 1995

INSTRUMENTS (OCEANOGRAPHY)

NIWA commissions an ADCP

Nils Oien, Steve Chiswell, Phil Sutton,

Steve Wilcox, Peter Hill, Dick Singleton

The installation of an Acoustic Doppler Current Profiler on the research vessel Tangaroa *significantly enhances the instrument suite on board the ship.*

DURING THE DRY-DOCKING of the RV *Tangaroa* in May 1996 an Acoustic Doppler Current Profiler (ADCP) was installed on the ship. This device emits ultrasound pulses and uses the Doppler shift on the reflected signal (that is, changes in frequency due to the motion of the water) to calculate three-dimensional water velocities beneath the ship. The effect is the same as if a series of current meters were deployed beneath the ship. (See also *Water & Atmosphere 3*(3):5.) The ADCP measures average currents in "bins", or layers of water, underneath the ship. Each bin is 8 m deep. The ADCP can measure currents to a maximum depth of about 250 m.

NIWA's ADCP was manufactured by RD Instruments of San Diego, California. It is one of the first broad-band units to be deployed. In contrast to the older, narrow-band units which emit a single, long pulse, broad-band ADCPs emit a series of short pulses. Overall, the broad-band unit is capable of more precise measurements.

The currents measured by the device include the ship's velocity. In fact, ADCP technology developed from the manufacture of Digital Velocity Logs that measured ship velocity relative to water. To obtain absolute currents, the ship's velocity must be subtracted out of the unit's measurements. To this end a very accurate Global Positioning System (GPS) was installed on the *Tangaroa*. This unit was manufactured by AshTech and gives accurate estimates of ship position, velocity, roll, pitch and heading, all of which are updated twice a second. These measurements are among the most accurate available from civilian GPS systems.

The University of Hawaii has developed software to process ADCP data. The software, known as CODAS (Common Oceanographic Data Access System), provides a means both of storing and processing the data and has been used extensively with narrow-band ADCPs. The loading of broad-band data into CODAS has only recently been achieved. This was the result of a collaborative effort involving Dr Eric Firing (University of Hawaii), one of the originators of CODAS, Dave Senciall (Northwest Atlantic Fisheries Centre, Canada), who developed the loading techniques for broad-band systems, and Nils Oien (NIWA), who ported the loading program to a PC and changed the navigation loading program to cope with the broad band data acquisition system. Eric acted as the final arbiter of code in this exercise and NIWA is deeply indebted to him for doing so.

NIWA is among the first institutions to process fully navigated broad-band ADCP data. A sample dataset processed using CODAS is shown in Figure 1. Although the ADCP collects a fully three-dimensional dataset, the data illustrated have been averaged in the vertical for ease of representation. This is reasonable, as instances of large current shear (the top layer of the ocean flowing in one direction while lower layers flow in another) did not occur on this cruise.

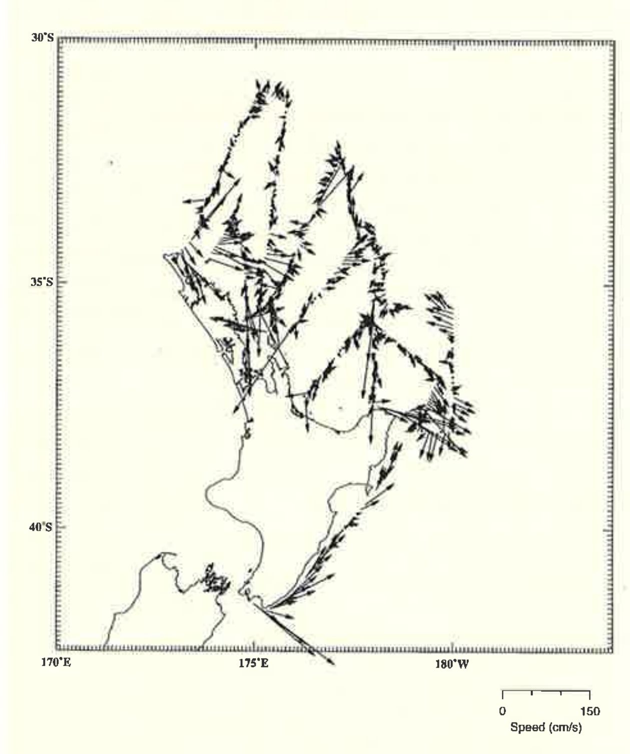


Figure 1. ADCP current vectors. The ADCP currents, averaged in the vertical, are shown here as vectors on a map. These data were collected by the Tangaroa *during a research voyage in October 1996 and have been plotted using the University of Hawaii's CODAS software.*

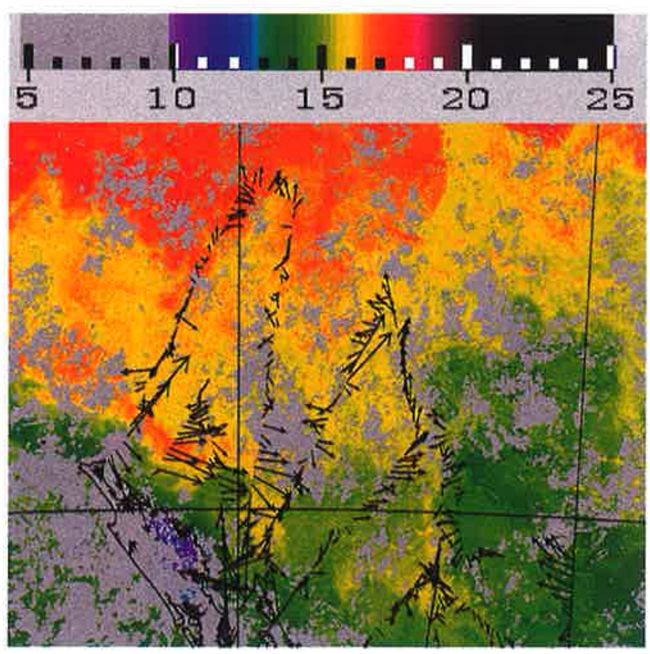


Figure 2. ADCP current vectors overlaid on a Composite Sea Surface Temperature Image generated using NIWA-developed software. This plot is the northern part of Figure 1 and shows the East Auckland Current which delivers warm water (orange/yellow) to the east coast of North Island via a south-east-flowing current. Also visible is the eddy at the extreme north of the cruise track (see Figure 3).

The data shown in Figure 1 were collected by the *Tangaroa* during a research voyage in October 1996. They show the East Auckland current flowing south-east in the region east of North Cape. The current appears here to veer off to the east. The current off East Cape is flowing south-east, but to the north there is a north-west flow, suggesting an eddy. At the extreme north of the cruise track, there appears to be a clockwise eddy. It seems characteristic for most of the energy in the ocean's flow to be associated with short-scale phenomena such as eddies.

The output of CODAS can be overlaid on false-colour sea surface temperature (SST) imagery using software developed at NIWA. The results are shown in Figure 2. The warm water (orange/yellow) correlated with the south-east flow off North Cape suggests that the East Auckland current delivers warm water to the east coast of the North Island. Areas of the image which were masked from the satellite's view by cloud are shown as grey in these images.

The eddy at the extreme north of the cruise track is known as the North Cape Eddy (Figure 3). Basil Stanton (NIWA) deduced from temperature readings made during the cruise that the ship had sailed into the centre of an eddy. It is thought that a south-east flowing current splits in two, some flowing south to form the East Auckland current, and the remainder flowing east into the Pacific. This eddy may be associated with this split in the current.

Other information is collected by the ADCP as a by-product of the current calculation process. In addition to the current vectors, the strength of the returned echo is also stored. This is indicative of the number of acoustic scatterers in the ocean. These are small particles, typically plankton, which reflect the ultrasound pulses. Figure 4 shows the returned-echo strength (backscatter), averaged in the vertical near the surface, as a function of time over a 24-hour period. Note the higher returned signal at night, when the abundance of plankton near the surface increases.

Figure 5 shows backscatter as a function of depth bin (8 m deep) and "ensemble number". Each ensemble represents about 15 seconds, the time required to collect data in this configuration. The strong signal shown in the image seems to suggest that the *Tangaroa* may have sailed over a school of fish which dived down as the ship sailed overhead.

This information is the same as that obtained from an echosounder. Using the ADCP to collect this information may seem to be an under-utilisation of the instrument's abilities, particularly as the unit operates at frequencies optimised for the collection of Doppler-shifted return signals rather than the collection of the returned-signal strength. However, if the ADCP is operated on most voyages of the *Tangaroa*, then the ability to collect returned-signal strength and to obtain the data in digital form (which can be loaded into spreadsheets or processing systems such as Matlab) may be useful as a rough indicator of biomass abundance.

The unit is also fitted with a thermistor (an electronic device that measures water temperature). Figure 6 shows thermistor temperature as a function of latitude as the ship sailed south over the Chatham Rise. The sharp decrease in temperature is consistent with satellite imagery for this region. This temperature can be used to calculate the speed of sound more accurately in the calculation of the current matrix, if desired.

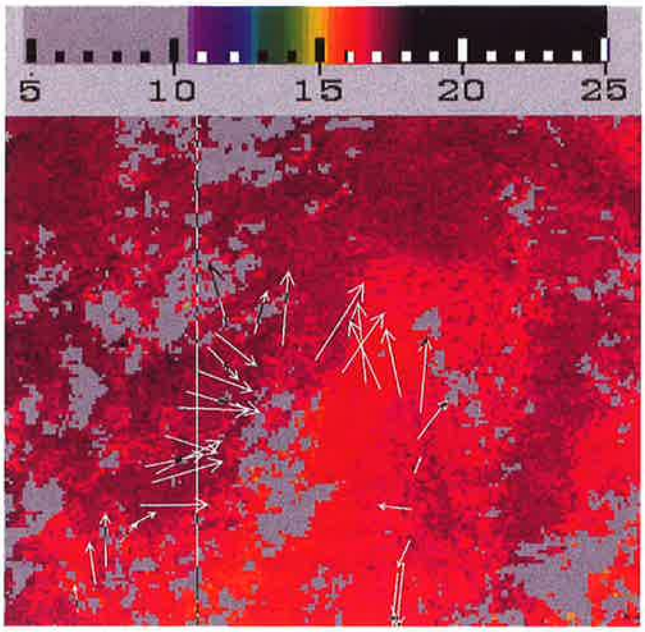


Figure 3. The North Cape Eddy. As warm water (dark red) moves east, cooler water (orange/yellow) is pushed north.

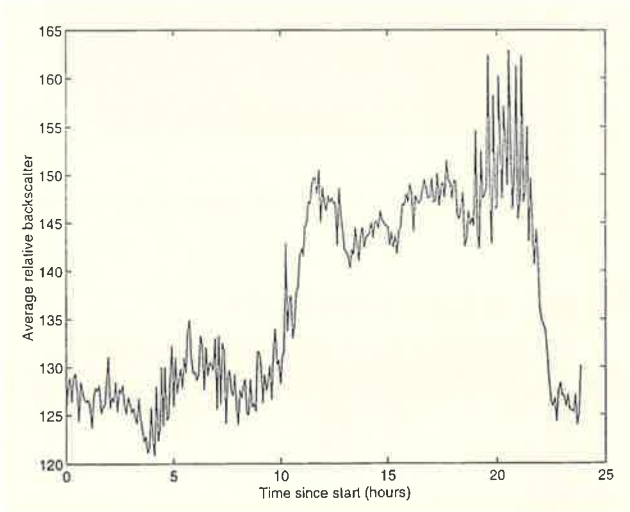


Figure 4. ADCP backscatter plotted against time. This plot shows the average returned echo strength over 24 hours when the ship was stationary in the Marlborough sounds. Note the significant increase at night, when the abundance of plankton increases.

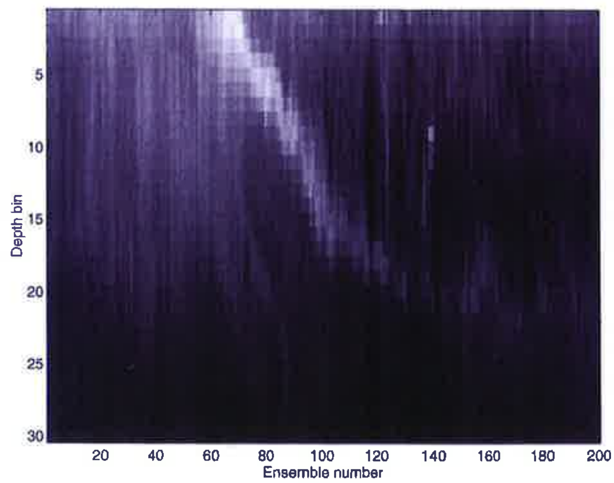
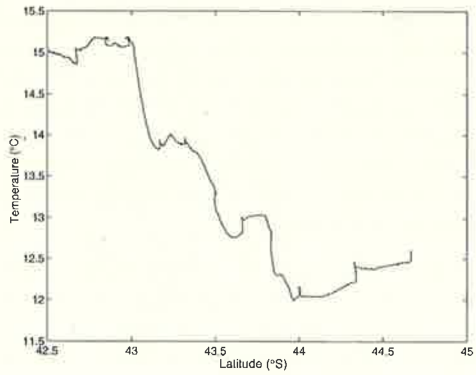


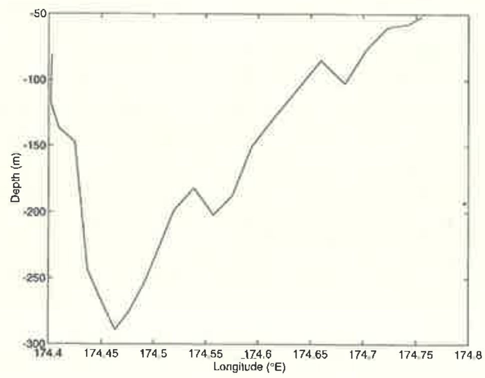
Figure 5. ADCP backscatter plotted against depth bin. The ADCP is here used essentially as an echosounder. The strong white line suggests that the Tangaroa *sailed over a school of fish.*

Another capability is the collection of limited bathymetry information. Figure 7 shows bathymetry across Cook Strait as a function of longitude at a latitude of roughly 41.27°S. Again, the frequency at which the ADCP operates is not optimised for the collection of these data. The unit can only penetrate to about 400 m below the surface. If it does detect the bottom, however, it will determine not only the depth of the bottom but also the speed at which it is moving (i.e., the negative of the ship's velocity). This can be useful in calibrating the ADCP, since a small error in the alignment of the device can result in a component of the ship's velocity appearing in the data. Comparing bottom-tracking data with the navigation data collected by the AshTech GPS is a means of checking the validity of the alignment parameters.

The ADCP can be operated at the same time as NIWA's Nu-Shuttle undulator, a towed instrument which carries an extensive sensor pack. See the following article for more information. Although neither the undulator nor the ADCP have been easy to commission, both have already produced extensive datasets. These instruments together significantly enhance *Tangaroa*'s capabilities as a research ship. ■

Nils Oien, Steve Chiswell, Phil Sutton, Steve Wilcox, Peter Hill and Dick Singleton are all based at NIWA in Wellington.





upper right: *Figure 6. Temperature versus latitude at 178.5° E. The sudden decrease in temperature as the ship sailed south over Chatham Rise is characteristic of this region.*

lower right: *Figure 7. Bathymetry across Cook Strait at approximately 41.27° S. The ADCP collects bathymetry to depths of up to 400 m.*

First successful deployment of Nu-Shuttle

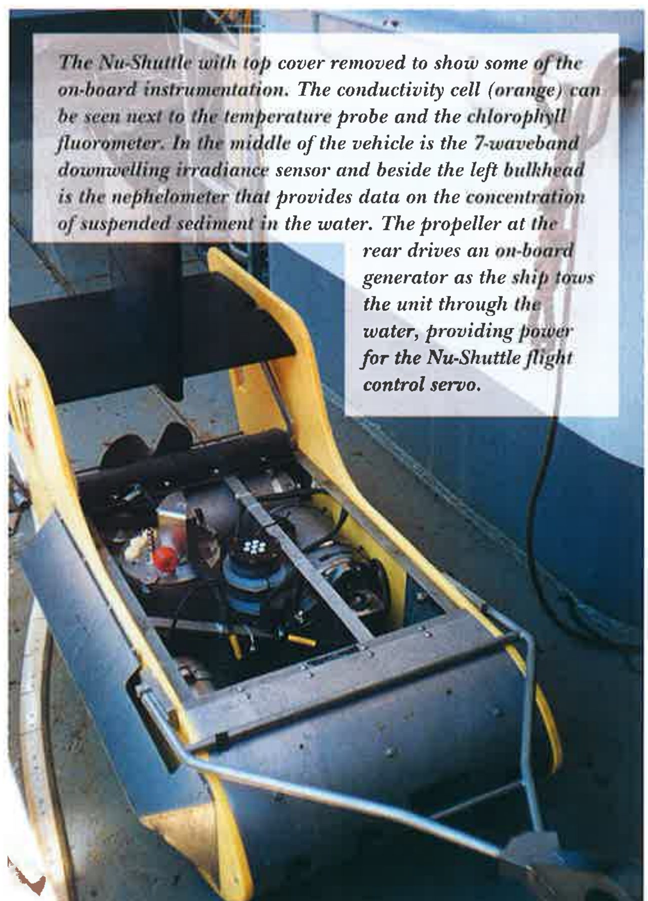
Jonathan Sharples, Rob Murdoch,

John Zeldis, Nils Oien

After two false starts, NIWA's new undulating oceanographic vehicle, "Nu-Shuttle", was successfully used from RV Tangaroa *in October 1996.*

NU-SHUTTLE is a powerful, self-contained suite of instrumentation that measures salinity, temperature, chlorophyll concentration, suspended sediment concentration, light (in 7 wavebands, both upwelling and downwelling), dissolved oxygen, pH, and redox. The system is towed behind the ship and is programmed to "fly" or undulate between specified depths. Data are sent back up the tow-cable at a typical sampling rate of 2 Hz. (See *Water & Atmosphere 3*(3): 5 for a more complete description of Nu-Shuttle.)

Although conventional oceanographic instruments such as the conductivity–temperature–depth probe (CTD) are capable of reaching much greater depths, Nu-Shuttle provides far better horizontal resolution within the upper 100 m of the ocean. This aspect is crucial to many of NIWA's coastal, shelf and upper-ocean studies of physics and biology.



The Nu-Shuttle with top cover removed to show some of the on-board instrumentation. The conductivity cell (orange) can be seen next to the temperature probe and the chlorophyll fluorometer. In the middle of the vehicle is the 7-waveband downwelling irradiance sensor and beside the left bulkhead is the nephelometer that provides data on the concentration of suspended sediment in the water. The propeller at the rear drives an on-board generator as the ship tows the unit through the water, providing power for the Nu-Shuttle flight control servo.

In October 1996 RV *Tangaroa* conducted a research voyage involving two of NIWA's Public Good Science Fund research programmes: Nearshore–Offshore Exchange Processes and Biological Effects of Nearshore–Offshore Processes. Together these programmes investigate the physical processes driving the transfer of water across the shelf edge of north-east New Zealand, and the biological/ecological consequences of these transfers.

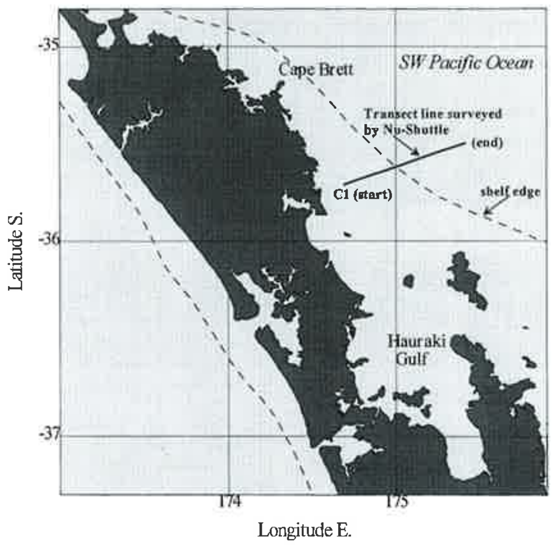
Nu-Shuttle was deployed along several cross-shelf transects during the two-week voyage. For each transect RV *Tangaroa* steamed at a constant speed of 9 or 10 knots along a course approximately perpendicular to the shelf edge, with Nu-Shuttle set to undulate between depths of 10 and 110 m (see map). The diagram (lower right) shows an example of the data collected and highlights two important points about the data shown.

1. The lines of constant temperature do not follow a fixed depth. Instead, they appear to show wave-like behaviour across the shelf. The wavelength of this "internal" wave is approximately 30 km, and it has a peak-to-trough vertical amplitude of about 50 m. The wave is likely to be a manifestation of the "internal tide" crossing onto the shelf from the deeper ocean. The internal tide is caused by the normal tidal currents as they approach the shelf. The steep shelf topography forces these currents upwards. This pushes up the thermal structure of the water. The resulting dome of the isotherms propagates towards the coast as a large-wavelength internal wave that has the same period (12.5 hours) as the normal tide.

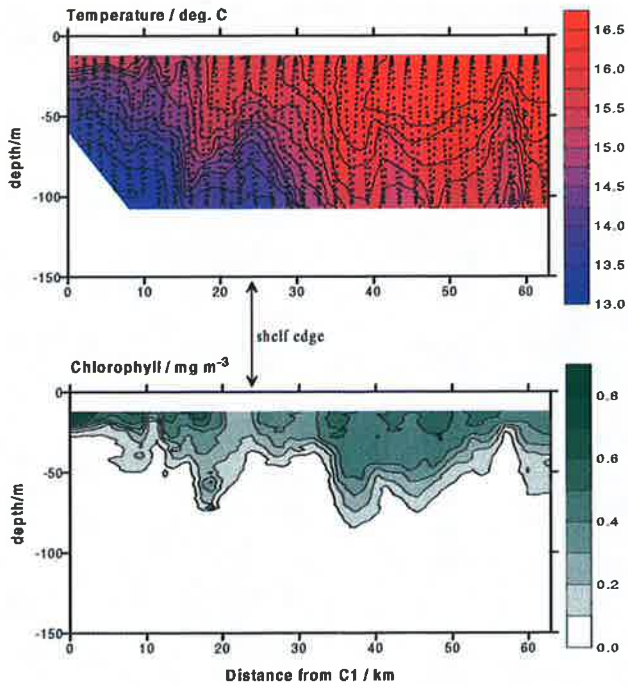
   One immediate result of the internal tide is that the thermocline of the shelf water is observed to oscillate vertically over a tidal cycle. This can be seen in the corresponding chlorophyll data, where the deepest extent of the phytoplankton chlorophyll (a convenient marker for the base of the thermocline) follows the form of the internal tidal wave across the shelf. This illustrates a particularly important consequence of the internal tide for the biology of the area. Phytoplankton productivity depends on the availability of light for photosynthesis. Light intensity decreases rapidly away from the sea surface, so any process that alters the depth of the phytoplankton will affect phytoplankton productivity. These data show that phytoplankton at the thermocline are being moved vertically 50–60 m by the internal tide, which will significantly change the amount of light that they receive compared to a situation in which there is no internal tide.

2. The near-surface chlorophyll measurements show apparently regular patches of higher densities at approximately 10 km intervals. It is not clear what is causing this pattern. It may simply be the typical ubiquitous patchiness that we often observe in the world's oceans. However its regularity does indicate the possibility of a wave-like driving mechanism. One hypothesis that we are considering is that the patches may be concentrations of phytoplankton driven by the weak converging currents at the sea surface that are associated with internal waves. We know from earlier work in the region that the steepness of the shelf causes the internal tidal wave to break as it approaches the coast (in much the same way as surf breaks as it approaches a beach). As the internal tide breaks it generates series of short-period (20–30 minutes) internal waves that could then play a role in concentrating the phytoplankton into the observed pattern.

This first deployment of Nu-Shuttle has provided interesting new insight into the cross-shelf spatial structure of the physics and biology of north-east New Zealand, primarily as a result of the increased horizontal resolution that it is possible to achieve with the vehicle. In our next voyage Nu-Shuttle will be used to address our questions and hypotheses concerning the internal tide and its effect on the biological structure of the shelf-edge waters. As a result of the successful deployment and operation of the Nu-Shuttle, NIWA scientists can now investigate a variety of new questions concerning the temporal and spatial variability of New Zealand's marine environment. ■



Map showing the position of one of the shelf edge transect survey lines.



Data from a single transect survey. Upper panel: cross-shelf water temperature structure; lower panel: corresponding chlorophyll distribution. The dotted line on the density plot indicates the path of the Nu-Shuttle through the water, with each dot representing 15 data points.

Jonathan Sharples was formerly with NIWA, Wellington, and is now based at the University of Southampton, UK. Rob Murdoch, John Zeldis and Nils Oien are all based at NIWA in Wellington.

2493

Recent publications by NIWA staff

The following list includes papers in refereed journals, books and book chapters reported between November 1996 and January 1997. Please note that NIWA staff papers appear in a range of journals and are not published by NIWA. Your local library will be able to obtain copies through interloan if required.

Climatology / Atmospheric sciences

Bouma, W.J., Pearman, G.I. and Manning, M.R. (eds) 1996. "Greenhouse: coping with climate change". CSIRO Publishing, Collingwood, Australia. 682 p.

Diab, R.D. *et al.* 1996. Vertical ozone distribution over southern Africa and adjacent oceans during SAFARI-92. *Journal of Geophysical Research 101(D19)*: 23,823–23,833.

Gayet, J.-F., Febvre, G. and Larsen, H.R. 1996. On the reliability of the PMS FSSP probe in the presence of small ice crystals. *Journal of Atmospheric and Oceanic Technology 13*: 1300–1310.

Keys, J.G. 1996. Studies of reactive and reservoir chlorine and nitrogen compounds in the Antarctic stratosphere, using ground-based observations. *Italian Research on Antarctic Atmosphere 51*: 269–278.

Lassey, K.R., Enting, I.G. and Trudinger, C.M. 1996. The Earth's radiocarbon budget: a consistent model of the global carbon and radiocarbon cycles. *Tellus 46B*: 487–501.

McKenzie, R.L. 1996. Ozone depletion and UV radiation: a health risk to New Zealanders? *NZ Public Health Report 3(10)*: 75–77.

McKenzie, R.L., Bodeker, G.E., Keep, D.J., Kotkamp, M. and Evans, J.H. 1996. UV radiation in New Zealand: measured north to south differences, and relationship to other latitudes. *Weather and Climate 16(1)*: 17–27.

Revell, M.J., Purnell, D. and Lauren, M.K. 1996. Requirements for large-eddy simulation of surface wind gusts in a mountain valley. *Boundary-layer Meteorology 80*: 333–354.

Wright, A.N. and Allan, W. 1996. Are two-fluid effects relevant to ULF pulsations? *Journal of Geophysical Research 101(A11)*: 24,991–24,996.

Wright, A.N. and Allan, W. 1996. Structure, phase motion, and heating within Alfvén resonances. *Journal of Geophysical Research 101(A8)*: 17,399–17,408.

Zheng, X. 1996. Unbiased estimation of autocorrelations of daily meteorological variables. *Journal of Climate 9*: 2197–2203.

Fresh water

Chisnall, B.L. 1996. Habitat associations of juvenile shortfinned eels (*Anguilla australis*) in shallow Lake Waahi, New Zealand. *NZ Journal of Marine and Freshwater Research 30*: 233–237.

Chisnall, B.L. and West, D.W. 1996. Design and trials of a large fine-meshed fyke net for eel capture, and factors affecting size distribution of catches. *NZ Journal of Marine and Freshwater Research 30*: 355–364.

de Winton, M.D. and Clayton, J.S. 1996. The impact of invasive submerged weed species on seed banks in lake sediments. *Aquatic Botany 53*: 31–45.

Graynoth, E. 1996. Determination of the age of brown and rainbow trout in a range of New Zealand lakes. *Marine and Freshwater Research 47*: 749–756

Jowett, I.G. and Richardson, J. 1996. Relative effects of in-stream habitat and land use on fish distribution and abundance in tributaries of the Grey River, New Zealand. *NZ Journal of Marine and Freshwater Research 30*: 463–475.

McDowall, R.M. 1996. Diadromy and the assembly and restoration of riverine fish communities: a downstream view. *Canadian Journal of Fisheries and Aquatic Sciences 53*: 219–236.

McDowall, R.M. and Eldon, G.A. 1996. Threatened fishes of the world: *Neochanna burrowsius* (Phillipps, 1926) (Galaxiidae). *Environmental Biology of Fishes 47*: 190.

Myrlian, N.F., Allard, B., Hakanson, L. and Nikora, V.I. 1996. Lab modelling of copper and zinc migration in the system "soil-water". *Ecological Chemistry (St. Petersburg) 3(5)*: 171–180 [in Russian].

Smith, D.G., McBride, G.B., Bryers, G.G., Wisse, J. and Mink, D.F.J. 1996. Trends in New Zealand's National River Water Quality Network. *NZ Journal of Marine and Freshwater Research 30*: 485–500.

Suren, A. 1996. Bryophyte distribution patterns in relation to macro-, meso- and micro-scale variables in South Island, New Zealand, streams. *NZ Journal of Marine and Freshwater Research 30*: 501–523

Tanner, C.C. 1996. Plants for constructed wetland treatment systems – a comparison of the growth and nutrient uptake of eight emergent species. *Ecological Engineering 7*: 59–83.

Marine biology

Chang, F.H. 1996. Distribution and abundance of *Dinophysis acuminata* (Dinophyceae) and *Pseudonitzschia australis* (Bacillariophyceae) in Kenepuru and Pelorus Sounds, New Zealand. Pp 93–96 *in*: Yasumoto, T., Oshima, Y. and Fukuyo, Y. (eds). "Harmful and toxic algal blooms". UNESCO, Intergovernmental Oceanographic Commission.

Chang, F.H., Sharples, J. and Grieve, J.M. 1996. Temporal and spatial distribution of toxic dinoflagellates in Bay of Plenty, New Zealand, during the early 1993 toxic shellfish outbreaks. Pp 235–238 *in*: Yasumoto, T., Oshima, Y. and Fukuyo, Y. (eds). "Harmful and toxic algal blooms". UNESCO, IOC.

Cole, R.G. and Babcock, R.C. 1996. Mass mortality of a brown kelp (Laminariales) at Goat Island, north-eastern New Zealand. *Marine and Freshwater Research 47*: 907–912.

Cranfield, H.J., Michael, K.P. and Francis, R.I.C.C. 1996. Growth rates of five species of subtidal clam on a beach in the South Island, New Zealand. *Marine and Freshwater Research 47*: 773–784.

Favorskaya, T.A., Gordon, D.P. and Voigt, E. 1996. New Bryozoa (Cheilostomatida, Ascophorina) from the Paleocene of Uzbekistan. *Mitteilungen Geologischen-Palaontologischen Institut Universitat Hamburg 79*: 171–181.

Francis, M.P. 1996. Observations on a pregnant white shark with a review of reproductive biology. Pp 157–172 *in*: Klimley, A.P. and Ainley, D.G. (eds). "Great white sharks: the biology of *Carcharodon carcharias*." Academic Press, San Diego.

Francis, R.I.C.C. 1996. Do herring grow faster than orange roughy? *Fishery Bulletin 94*: 783–786.

Gallegos, C.L., Vant, W.N. and Safi, K.A. 1996. Microzooplankton grazing of phytoplankton in Manukau Harbour, New Zealand. *NZ Journal of Marine and Freshwater Research 30*: 423–434.

Hewitt, J.E., Thrush, S.F., Cummings, V.J. and Pridmore, R.D. 1996. Matching patterns with processes: predicting the effect of size and mobility on the spatial distributions of the bivalves *Macomona liliana* and *Austrovenus stuchburyi*. *Marine Ecology Progress Series 135*: 57–67.

James, M.R., Hall, J.A. and Barrett, D.P. 1996. Grazing by protozoa in marine coastal and oceanic ecosystems off New Zealand. *NZ Journal of Marine and Freshwater Research 30*: 313–324.

Jellyman, D.J., Chisnall, B.L., Dijkstra, L.H. and Boubee, J.A.T. 1996. First record of the Australian longfinned eel, *Anguilla reinhardtii*. *Marine and Freshwater Research 47*: 1037–1040.

McClatchie, S., Alsop, J. and Coombs, R.F. 1996. A re-evaluation of relationships between fish size, acoustic frequency, and target strength. *ICES Journal of Marine Science 53*: 780–791.

McClatchie, S., Alsop, J., Ye, Z. and Coombs, R.F. 1996. Consequence of swimbladder model choice and fish orientation to target strength of three New Zealand fish species. *ICES Journal of Marine Science 53*: 847–862.

Robertson, D.A. 1996. Research as the basis for secure fisheries. Pp 67–79 *in*: Cozens, P. (ed.). "New Zealand's maritime environment and security". Centre for Strategic Studies, Victoria University of Wellington.

Sagar, P.M., Tennyson, A.J.D. and Miskelly, C.M. 1996. Breeding and survival of Snares cape pigeons *Daption capense australe* at The Snares, New Zealand. *Notornis* 43: 197–207.

Sagar, P.M. and Weimerskirch, H. 1996. Satellite tracking of southern Buller's albatrosses from The Snares, New Zealand. *Condor 98*: 649–652.

Thrush, S.F, Whitlatch, R.B., Pridmore, R.D., Hewitt, J.E., Cummings, V.J. and Wilkinson, M.R. 1996. Scale-dependent recolonizations: the role of sediment stability in a dynamic sandflat habitat. *Ecology 77(8)*: 2472–2487.

Turner, S.J., Thrush, S.F., Cummings, V.J., Hewitt, J.E., Wilkinson, M.R., Williamson, R.B. and Lee, D.J. 1997. Changes in epifaunal assemblages in response to marina operations and boating activities. *Marine Environmental Research 43(3)*: 181–199.

Turner, S.J. *et al.* 1996. Patch dynamics of the seagrass *Zostera novazelandica (?)* at three sites in New Zealand. Pp 21–31 *in*: Kuo, J., Walker, D.I., Kirkman, H. (eds). "Seagrass biology: scientific discussion from an international workshop, Rottnest Island, WA. Science Faculty, University of Western Australia, Nedlands.

Vignaux, M. 1996. Analysis of spatial structure in fish distribution using commercial catch and effort data from the New Zealand hoki fishery. *Canadian Journal of Fisheries and Aquatic Sciences 53*: 963–973.

Weimerskirch, H. and Sagar, P.M. 1996. Diving depths of sooty shearwaters *Puffinus griseus*. *Ibis 138*: 786–788.

Marine geology and physical processes

Boon, J.D., Green, M.O. and Suh, K.D. 1996. Bimodal wave spectra in lower Chesapeake Bay, sea bed energetics and sediment transport during winter storms. *Continental Shelf Research 16(15)*: 1965–1988.

Boyd, P.W. and Newton, P.P. 1997. Measuring biogenic carbon flux in the ocean. *Science 275*: 554–555.

Carter, R.M., Carter, L. and McCave, I.N. 1996. Current controlled sediment deposition from the shelf to the deep ocean: the Cenozoic evolution of circulation through the SW Pacific gateway. *Geologische Rundschau 85*: 438–451.

Healy, T.R., Cole, R.G. and de Lange, W. 1996. Geomorphology and ecology of New Zealand shallow estuaries and shorelines. Pp 115–154 *in*: Nordstrom, K.F. and Roman, C.T. (eds). "Estuarine shores: evolution, environments, and human alterations". John Wiley & Sons.

Lewis, K.B. and Marshall, B.A. 1996. Seep faunas and other indicators of methane-rich dewatering on New Zealand convergent margins. *New Zealand Journal of Geology and Geophysics 39*: 181–200.

Morawitz, W.M.L., Sutton, P.J., Worcester, P.F., Cornuelle, B.D., Lynch, J.F. and Pawlowicz, R. 1996. Three-dimensional observations of a deep convective chimney in the Greenland Sea during winter 1988/89. *Journal of Physical Oceanography 26(11)*: 2316–2343.

Murray, P.B., McCave, I.N., Owen, T.R.E., Mason, M. and Green, M.O. 1996. A robust *in situ* settling velocity box for coastal seas. *Journal of Sea Research 36(1/2)*: 101–107.

Parson, L.M. and Wright, I.C. 1996. The Lau–Havre–Taupo back-arc basin: a southward-propagating, multi-stage evolution from rifting to spreading. *Tectonophysics 263*: 1–22.

Wright, I.C. 1996. Volcaniclastic processes on modern submarine arc stratovolcanoes: sidescan and photographic evidence from the Rumble IV and V volcanoes, southern Kermadec Arc (SW Pacific). *Marine Geology 136*: 21–39.

Wright, I.C., Parson, L.M. and Gamble, J.A. 1996. Evolution and interaction of migrating cross-arc volcanism and backarc rifting: an example from the southern Havre Trough (35°20'–37°S). *Journal of Geophysical Research 101(B10)*: 22,071–22,086.

Hydrology

Ibbitt, R.P. 1996. Flood forecasting in Central Vietnam. *Australian Journal of Water Resources 1(2)*: 99–103.

Nikora, V.I., Ibbitt, R. and Shankar, U. 1996. On channel network fractal properties: a case study of the Hutt River basin, New Zealand. *Water Resources Research 32(11)*: 3375–3384.

Nikora, V.I. and Shteinman, B.S. 1996. Turbulence in the Jordan River: a case study. Pp 581–588 *in*: Chen, C.-J., Shih, C., Lienau, J. and Kung, R.J. (eds). "Flow modeling and turbulence measurements VI". Balkema, Rotterdam.

***Water & Atmosphere* is published quarterly by NIWA (National Institute of Water and Atmospheric Research Ltd), New Zealand**
Enquiries should be directed to *Water & Atmosphere*, NIWA, Private Bag 99 940, Newmarket, Auckland