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WATER & ATMOSPHERE

NIWA
Taihoro Nukurangi

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Cover

A phyllodocid polychaete worm *Eulalia microphylla* from Mahunga Bay, Wellington Harbour. This is one of the hundreds of species of polychaete worms currently known in New Zealand.

For more information, refer to the article on pages 7–9 of this issue.

(Photo: M. Marmach)

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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/

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WATER & ATMOSPHERE

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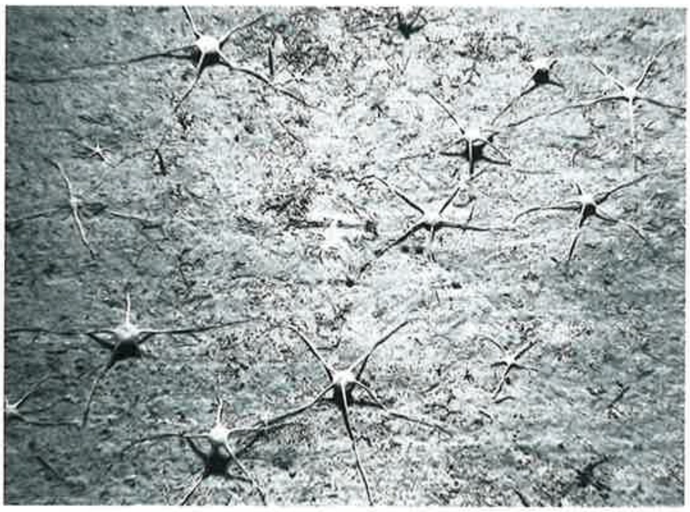


Deep-sea creatures

Ophiuroids (brittle-stars) (Ophiomusium lyani *Wyville Thomson, 1873) on the continental slope at the head of Bounty Trough in 1188 m water depth (NIWA station Q290). The bodies of the larger ophiuroids are approximately 3 cm across. The same species is a conspicuous component of benthic communities on the flanks of the Chatham Rise. Refer to the article on pages 15–18 of this issue.*

(Photo: Lionel Carter)

NIWA
NEWS FORUM

"Year of the Ocean"

1998 HAS BEEN the United Nations' "Year of the Ocean", a major worldwide project promoting awareness of oceans, seas and coastal waters and encouraging their use in a sustainable manner. During the year, NIWA has been involved in a range of initiatives, two of which have directly involved schools in New Zealand: "Ocean Voyage '98" and essay/art competitions. The outcomes of these special events are reported here.

A teacher on the *Tangaroa*

Bu Windsor, recipient of a Royal Society of New Zealand Science Fellowship, reports on six months working with NIWA scientists on the "Ocean Voyage '98" project. Ocean Voyage '98 aimed to foster awareness of the special nature of New Zealand's oceanic environment and focused on 8- to 12-year-olds.

After 20 years as a Primary School teacher, I thought I had a good grasp on most aspects of the curriculum but, after this year, teaching science will never be the same again. Working with NIWA scientists on the International Year of the Ocean-inspired project "Ocean Voyage '98" has seen to that! And why? Because it's taken science teaching away from text book facts and planted it firmly back in the arena of working with real scientists researching real science in real places in real time.

By taking teaching objectives out of the science curriculum and implementing them with the use of information technology, we've offered students the chance to take electronic field trips into the heart of cutting-edge research being undertaken by New Zealand scientists, both here and internationally. That's exciting stuff as it has helped both teachers and children to realise that science isn't a static body of information to be learnt off by heart. Rather, it is a vibrant and on-going series of processes that leads not only to real knowledge being assimilated but asks as many questions as it answers.

left:
Bu Windsor and Julie Hall (left) ready to board the Tangaroa.

Ocean Voyage '98 began when I was granted a Royal Society of New Zealand Science Fellowship to work with NIWA producing resources for schools using the medium of Information Technology. As an educational initiative promoting the International Year of the Ocean, Dr Julie Hall and I have spent several months producing teaching resources on different aspects of oceanography. Our aim is to foster an awareness of the special nature of New Zealand's oceanic environment. The written resources, accompanied by NIWA maps and charts, have been distributed to every Primary and Intermediate School in New Zealand and a group of 30 schools have registered for further classroom support through audio-conferencing and email contact.

Information and communications technologies can transport students into virtually any situation they care to imagine – instantly. And that's what we've done. A special feature of Ocean Voyage '98 has been my participation in voyages in the NIWA research vessel *Tangaroa.*

The first voyage supported units of work investigating plankton dynamics at several stations on the Chatham Rise and human dynamics living in close quarters aboard a ship! During the voyage, daily reports to the Ocean Voyage '98 website provided children with a taste of real science in an interesting context. The reports were based on my observations both of the science and the day-to-day activities on board an ocean-going research vessel. We held an audioconference from the *Tangaroa* to the registered schools. This featured descriptions of their jobs from several of the crew and opportunities for the children to ask them and Julie questions.

The second module of work centred on discoveries on the ocean floor. Drs Lionel Carter and Bruce Haywood provided diaries for the web page. They were part of an international team of scientists carrying out research into ocean bed core samples from the vessel *Joides Resolution* off the coast of New Zealand. A further audioconference featuring answers from Dr Phil Barnes, a marine geologist at NIWA, Wellington, concluded that module.

For the third module of work, entitled "Something Fishy" I rejoined the *Tangaroa* as part of a fisheries assessment voyage to support this module. Again, a series of daily diaries were transmitted to our website and an audioconference was held when we returned to Wellington.

A fourth module, featuring activities and information about ocean currents was run in November. Another NIWA-produced chart, describing the unique current circulation around New Zealand, provides a visual stimulus for interpretation. The addition of a "chat room" where children communicated in real time with scientists concluded the range of communications technology options available through this programme.

With the current emphasis on effective use of Information Technology in schools, this type of partnership between schools and businesses such as NIWA is not only highly popular, it's also highly successful. I can't think of a better way of motivating students and providing our primary school science programmes with the shot in the arm they need to boost them into the 21st century.

Bu Windsor (Principal, Mount Cook Primary School),
Julie Hall (NIWA, Hamilton)

Oceanz '98 art and essay competitions

As part of New Zealand's contribution to the International Year of the Ocean 1998, NIWA organised and sponsored the Oceanz '98 art and essay competition. The art competition with the theme "Images Inspired by the Ocean" and the essay competition with the topic "The Importance of the World's Oceans" were open to all secondary school students throughout New Zealand.
A total of 289 entries from 26 schools were received for the art competition and 182 entries from 40 schools for the essay competition.

The very high standard of entries made the judging an extremely difficult but enjoyable task. The criteria used to judge the art were topic, critical faculty, perception, imagination and skill. The essay criterion was coverage of the major points relevant to the subject supported by associated information, facts and opinions. The judges looked for originality, a demonstration of understanding and a good balance between fact and opinion.

The first prize winners for the different categories were:

North Island Art
Form 5–7: Kirsty O'Hara, Palmerston North Girls High School
Form 3–4: Kirsty Britton, Epsom Girls Grammar School

South Island Art
Form 3–4: Guy Horrocks, Christs College

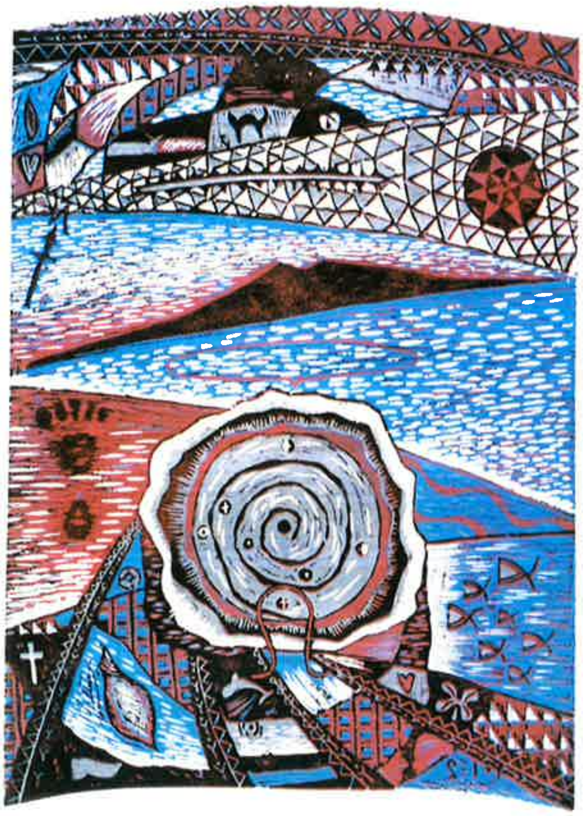
North Island Essay
Form 5–7: Shane Bilish, St Peters College
Form 3–4: Moriz Hartmann, New Plymouth Boys' High School

South Island Essay
Form 3–4: Tim Garlick, Nayland College

All schools that entered went into a prize draw for school equipment. Kelston Girls High School (Auckland) and Ashburton High School won the prize draw for $200 for science equipment. Sacred Heart Girls College, Hamilton and Waimea College, Nelson have both won the prize draw for $200 for art equipment.

All entrants and their schools are to be congratulated and encouraged to continue their excellent work, and commitment to conserving the ocean's resources.

The winning entries (1st, 2nd and 3rd places) can be viewed on the webpage: oceanz98.rsnz.govt.nz



left: *Kirsty O'Hara's print "Pacific Journey" represents symbols and aspects of her life and her ancestors' journey through the Pacific to settle in New Zealand. The Dutch clog, Irish Shamrock and Scottish Tartan pattern portray her mixed heritage, while the traditional Polynesian symbol, the centipede depicts that she is the oldest child in her family.*

Institute of Aquatic and Atmospheric Sciences

IN DECEMBER 1998 NIWA and the University of Auckland launched the Institute of Aquatic and Atmospheric Sciences (IAAS), an initiative designed to enhance educational opportunities for today's students and ensure a stock of high-quality scientists for tomorrow's workplace. Co-directed by Dr Rick Pridmore (NIWA) and Prof. Geoff Austin (University of Auckland), IAAS will enable the two organisa-tions to share facilities and staff. Following a period of organisation and course design, the Institute's teaching activities will begin in June 1999; offices will be maintained at the University's Tamaki campus. The admission of students to IAAS will favour quality over quantity.

With a focus on Masters and PhD-level students, the new Institute will run in conjunction with the University's existing Schools of Biological Sciences, Physics, Geography, Engineering, Environmental and Marine Sciences, Geology and Mathematics, enhancing current courses and offering new study modules. NIWA staff will participate as lecturers and supervisors. Students enrolled in IAAS will have access to NIWA facilities and gear, including laboratories, equipment and the research vessel *Kaharoa*.

NIWA joins forces with US research centres

NIWA has forged formal collaborative ties with three marine and environmental research centres on the East Coast of the United States. The purpose of the new relationships is to enhance the sharing of research expertise and facilitate exchange of staff and students. The research interests these centres hold in common with NIWA include aquaculture, coastal fisheries, oceanography, coastal and urban water pollution, estuarine ecology and invasive species.

The American centres are

- Marine Sciences Department of the University of Connecticut, at Avery Point, Groton, Connecticut [www.uconn.marinesciences.edu]
- Smithsonian Environmental Research Center, Edgewater, Maryland [www.serc.si.edu]
- Virginia Institute of Marine Science, School of Marine Science of the College of William and Mary, Gloucester Point, Virginia [www.vims.edu].

In a press release NIWA Chief Executive Paul Hargreaves made the point that achieving solutions to many global and localised environmental problems requires the combined talents of world class panels of scientists and research experts with diverse skills.

"By joining forces, we and the US centres are better positioned to assemble the variety of multi-disciplined talent and sophisticated instruments required to solve a growing range of complex issues.

"These agreements open the way for extensive research collaboration that will significantly advance our ability to find solutions to New Zealand and world-wide environmental issues. We will be sending our people to join research teams on specific projects in the US, and they will be contributing talent and expertise to our contract work for local authorities, government and industry."

The collaboration was formalised at the end of September 1998 by a signing ceremony hosted by New Zealand Ambassador Jim Bolger at the New Zealand Embassy in Washington.

Coupled atmosphere–ocean climate modelling workshop

TWO WORKSHOPS in Melbourne recently provided an opportunity to get up-to-date in several areas related to NIWA's current and future climate research.

In October 1998 Brett Mullan (NIWA, Greta Point) attended the 10th Annual Bureau of Meteorology Research Centre Modelling Workshop, this year on coupled modelling. This was followed immediately by a two-day workshop on the Coupled Model Intercomparison Project (CMIP) run under the auspices of a major international climate variability programme known as CLIVAR.

Three climate areas were particularly relevant to NIWA current and future research:

- coupled atmosphere–ocean general circulation modelling generally. NIWA is committed to using a model known as the UKMO Unified Model. So far, only the atmospheric component has been used, although future work may involve the ocean component.
- climate variability over decades, including the recently publicised 1976/77 climate "shift".
- scenario development of future regional climates.

Many key research scientists participated in these workshops, representing modelling groups from Europe, the USA and Canada, as well as from Australia.

The coupled global climate models exhibit variations over decades in atmosphere and ocean circulation patterns. Two of the models described at the first workshop showed decadal oscillations very similar to the "Pacific Decadal Oscillation" (PDO) that is implicated in New Zealand's 1976/77 "climate shift" (see *Water & Atmosphere 6(3)*: 3,4). The PDO affects Australia as well. In particular, it appears to modulate the El Niño response. Correlations of the Southern Oscillation Index with Australian rainfall and temperature are much stronger during the negative (or pre-1977) phase of the PDO than the recent positive phase.

One of the presentations emphasised the importance of very-high-resolution ocean global circulation models (e.g., 1 degree resolution is “coarse”). When an ocean model is used to generate climate patterns over a long period, very small regions may be crucial. For example, the creation of deep water to the north of Iceland drives the global thermohaline circulation but this region may only be one or two grid points in a coarse ocean model. High resolution is also required for a realistic simulation of the effect of bottom topography on water masses. This may well be important around New Zealand.

Brett Mullan
NIWA, Wellington

Scientists off for a SOIREE in the Southern Ocean

In late January 1999, 26 scientists from New Zealand, UK, USA, Holland, Australia and Canada will participate in the SOIREE research voyage to the Southern Ocean waters south of the Polar Front at 60 °S). The voyage will be led by Dr Rob Murdoch of NIWA. Ten others from NIWA campuses in Wellington, Hamilton, Christchurch and Dunedin will be on board the NIWA vessel *Tangaroa.*

SOIREE is the acronym for Southern Ocean Iron RElease Experiment. The Southern Ocean is the largest reservoir of unused macronutrients (e.g., nitrate) in the world's ocean, yet puzzlingly it is a region with low phytoplankton stocks and production. Phytoplankton production rates strongly influence both the uptake of atmospheric CO_2 by the ocean and the overall productivity of Southern Ocean ecosystems. There is a need to understand the factor(s) that control phytoplankton dynamics in this region.

Experiments conducted in incubation bottles suggest that the phytoplankton in this region are anaemic, and that if supplied with iron they grow at optimal rates. However, the Southern Ocean with its large waves and strong winds cannot be simulated in an incubation bottle. A large-scale experiment in the ocean itself is needed to test the theory.

In order to carry out SOIREE the international team of scientists will fertilise around 70 km^2 of the Southern Ocean south of New Zealand, with an iron sulphate solution in 7500-litre tanks. It is planned to add the iron solution into the vessel's propellor wash along with a small quantity of an inert chemical tracer detectable at very low levels (SF_6).

This tracer will allow the fertilised patch of ocean to be tracked for the expected duration of the experiment (12 days). The experiment will determine any iron-mediated alteration of phytoplankton growth and stocks and associated changes in ecosystem (bacteria, grazers), chemical (micro- and macro-nutrients, greenhouse gases) and biogeochemical (sedimentation rate) parameters. Results of this study will test whether iron supply controls phytoplankton growth in the Southern Ocean and will provide a better understanding of the role of Antarctic biota in determining atmospheric CO_2 levels in the present and the geological past.

A report on the outcome of this experiment is planned for *Water & Atmosphere* later in 1999.

Philip Boyd
NIWA, Dunedin

Visiting scientist

DR GRAHAM SYMONDS visited NIWA in Hamilton in November and December 1998 to work on beach dynamics with Kerry Black and Karin Bryan. Graham is from the Australian Defence Force Academy, University of New South Wales, Canberra. He is renowned for his seminal papers on infra-gravity oscillations on beaches and for his more recent work on wave-driven currents over reefs and beach sand-bar migration. Graham also operates a long-term beach video monitoring camera at Palm Beach in Sydney and is providing input into a range of NIWA projects, including the Cam-Era study, a New Zealand beach monitoring project funded by the Ministry for the Environment, regional councils and industry.

Water quality short courses

Statistical Methods for Water Quality Studies

8–10 March 1999,
Quality Hotel, Hamilton

Target audience

Technical personnel from regional and district councils and consultants with interests in design, monitoring and interpretation of water quality programmes.

NIWA Short Course

This three-day workshop will increase your ability and confidence in using statistical methods for analysing, interpreting and designing water quality and effluent sampling programmes. A number of modern methods will be included (including nonparametric methods).

Water Quality Modelling

11–12 March 1999,
Quality Hotel, Hamilton

Target audience

Technical personnel from regional and district councils, and consultants with interests in using models as a tool to make predictions of water quality.

NIWA Short Course

This workshop will enhance your understanding of water quality modelling concepts and procedures. Dr Steve Chapra, a world authority and an excellent teacher on the development and application of environmental models, will present the course.

For brochure and registration contact:
Graham McBride, NIWA, PO Box 11 115, Hamilton
Ph: 07 8561726, Fax: 07 856 0151, email: g.mcbride@niwa.cri.nz

Roughness Characteristics of New Zealand Rivers

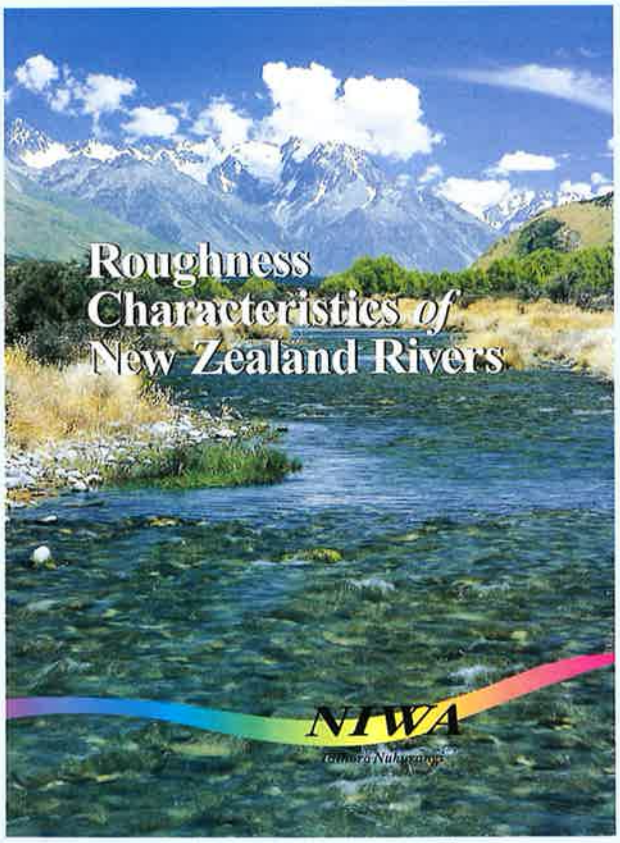
The handbook “Roughness Characteristics of New Zealand Rivers” (D.M. Hicks and P.D. Mason) is available once again.

Published in 1991, the book has been out of print for some time and the recent reprint was prompted by continued requests from individuals and organisations throughout the world. This publication has been referenced in every significant book on fluvial geomorphology and in hundreds of articles published since its original printing.

For further information and orders:

From Australia and New Zealand
contact: NIWA, PO Box 8602,
Christchurch, New Zealand
(Ph: +64 3 348 8987;
Fax: +64 3 348 5548;
email: p.mason@niwa.cri.nz)

From the rest of the world
contact: Water Resources Publications, 7200 East Dry Creek Road, Suite E-104,
Englewood, CO 80112, USA
(USA and Canada: Ph. 800 736 2405, Fax: 800 615 1971;
All other countries: Phone: 303 741 9071; Fax: 303 741 9073)
email: wrp@sni.net



MARINE BIODIVERSITY

Polychaete worms: a diverse yet poorly known group

Chris Glasby

Geoff Read

Polychaete worms, which are related to earthworms, come in an astonishing range of shapes and sizes. It is proving a formidable task for taxonomists to describe the hundreds of species in this mainly marine group in New Zealand waters.

above and inset: *Reef made by the colonial tubeworm* Neosabellaria kaiparaensis *at Oakura, Taranaki. (Photo: G. Read)*

below: *A undescribed capitellid,* Notomastus *sp., from Porirua Harbour; capitellids resemble earthworms because of their lack of parapodia and head appendages. (Photo: C. Glasby)*

POLYCHAETE WORMS are some of the most common animals in the sea. Some are hard to overlook because they live in colonies and build massive reefs, but the rest of the many New Zealand species may escape the casual notice of beach walkers and divers. They are present nevertheless in their thousands, living in burrows in the sand, hiding in rock crevices and colonising almost any structure created by other marine life, in all habitats ranging from the almost-dry margins of estuaries to the abyssal depths.

Why document polychaete diversity?

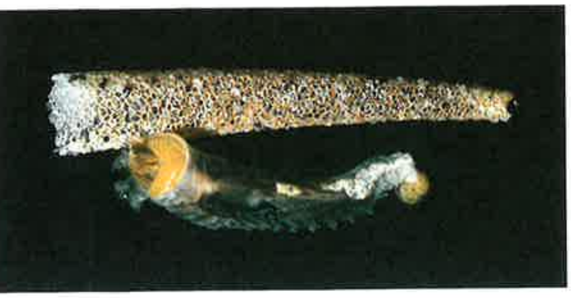
Biologists studying the marine environment for a range of reasons are likely to encounter polychaetes and will need to know what species they are. If accurate identification is not possible the work will be subtly lessened in value because it won't be comparable with other studies.

There are other more specific reasons for studying polychaetes.

- *Polychaetes are abundant and ecologically important.* They are usually a major component of the benthos alongside the molluscs and crustaceans. In the New Zealand region they account for 36–50% of all the larger invertebrate individuals and between 25 and 34% of all species. Sediments may be dominated by natural dense aggregations of tube-dwelling species belonging to the families Spionidae, Sabellidae and Onuphidae. Some New Zealand polychaetes (e.g., the subtidal serpulid *Galeolaria hystrix* and the intertidal sabellariid *Neosabellaria kaiparaensis*) build reef-like structures which provide habitat for other invertebrates.

  Polychaetes play a critical role in the food chain of the sea floor. On one hand they recycle organic matter with in sediments, and on the other they are preyed upon by many species of fish (especially flatfish) and crustaceans. On mudflats, polychaetes are an important food source for many wading birds. Because polychaetes are dominant in soft marine sediments, their distribution patterns often reflect those of the entire benthic fauna. Hence they should always be included in faunal surveys, particularly those of soft sediments.
- *Polychaetes include many invasive and nuisance species.* Several shell-boring spionids may have been inadvertently introduced into New Zealand waters either growing on a ship's hull or as larvae in ballast water. These species colonise shellfish. In oysters, for example, spionids can cause blisters containing foul-smelling sediment to develop and spoil the quality of oyster meat. *Polydora websteri* – an introduced species – has caused problems for intertidal oyster cultivation in Mahurangi Harbour, whilst *Boccardia knoxi* – an endemic species – appears to be the major pest for subtidal oyster cultivations in the Marlborough Sounds. The latter also occurs in paua shell. A boring sabellid polychaete has become a problem for abalone aquaculture in California and South Africa, but fortunately does not yet occur in New Zealand.

  Serpulid polychaetes are common components of hull-fouling communities and several species have been distributed around the world. New Zealand has at least two introduced problem species. For example, *Ficopomatus enigmaticus*, first noticed in 1967, became a nuisance in the harbours of Whangarei and Waitemata and in Hawkes Bay when its encrusting tubes built up on boat hulls, intake pipes and water-control structures.
- *Polychaetes may be useful bio-indicators.* Polychaetes live in both pristine and polluted environments, but certain species are regarded as pollution indicators. For example, dense populations may rapidly colonise oil-contaminated sediments. Many species, including *Capitella capitata* and related species,



top: *The widespread scale worm* Lepidonotus jacksoni *from Shelley Bay, Wellington Harbour. (Photo: M. Marmach)*

below: *The sand-mason worm* Pectinaria australis *(Pectinariidae) from Wellington Harbour. (Photo: M. Marmach)*

and the semi-terrestrial nereids, appear to be highly tolerant of heavy metal contamination. Many species are tolerant of reduced oxygen levels in sediments and can survive in organically polluted conditions not tolerated by other fauna. Capitellids and spionids can reach enormous densities around the "food-rich" (for worms!) discharges from sewage and other waste-water outfalls.

- *Polychaetes are important in studies of evolutionary relationships and biogeography.* Polychaetes are a key group for understanding the evolutionary relationships of all segmented animals (which include the arthropods, e.g., crustaceans and insects). Because the parapodium is a simple "limb" (see panel below), polychaetes may also be useful for studying the fundamental genetic machinery of limb development common to many animals. Polychaetes are thought to be most closely related to the clitellates (earthworms and leeches), with both groups having evolved independently from an annelid ancestor. However, the latest research suggests that the clitellates may have stemmed directly from a polychaete ancestor; that is, they might just be polychaetes in another guise. Certain other worm-like animals might also belong to the class (see below).

Polychaetes have a long evolutionary history with some fossils dated at more than 500 million years old! Research conducted at NIWA has shown that polychaetes, particularly those with limited dispersal capabilities, can be used to investigate ancient relationships between continents and landmasses. Together with biogeographic information from other animal and plant species, it is possible to construct a history of continental relationships that can be compared with plate tectonic theory.

Naming and describing our polychaete fauna: problems and solutions

The number of known polychaete taxa (species and higher categories) is likely to increase by two or three times as we learn more of the New Zealand fauna. Information from the authors' taxonomic database indicates that there are already 586 species, 280 genera and subgenera and 63 families known in New Zealand waters. New species and records are most likely to be discovered from offshore areas and from cryptic intertidal habitats. However, it is also important to redescribe common near-shore polychaetes and to check the names used for them.

Taxonomic studies funded by the Foundation for Research, Science and Technology are under way for some of the larger families including Nereididae, Terebellidae, Trichobranchidae, Spionidae and Maldanidae. Other important families are being studied by overseas experts. However, the research is time-intensive and the proper taxonomic treatment of the New Zealand's 63 families will take many years.

At the heart of these taxonomic studies is the collection of preserved polychaetes held in the NIWA Museum in Wellington. Containing more than 70,000 specimens collected from some 5000 locations, it is by far the largest polychaete collection in the country. It is also significant by

What are polychaetes?

POLYCHAETES are a class of the phylum Annelida (the segmented worms) which also includes the earthworms and leeches. They are mainly marine and extremely diverse with about 80 families, 1000 genera and 8,000–12,000 known species.

Polychaetes differ from other worms in two features:

1. They have structures for "walking": paddle-like parapodia carrying bristles (chaetae – hence the name of the class) on each segment
2. The head carries tentacles and other structures which are feeding, breathing and sensory organs.

The polychaetes are now thought to include the giant deep-sea vent worms (Vestimentifera) and their smaller, spaghetti-like cousins, the Pogonophora, both of which were at one time placed in separate phyla. Pogonophora live in the deep sea around New Zealand waters, and vent worms may be found as more undersea hydrothermal vents are explored in our waters.

Diversity of form and behaviour

Polychaetes display a diversity of body form and behaviour that is, arguably, unrivalled by any other marine invertebrate group. This may explain their success in occupying a great range of environments.

In size, polychaetes range from microscopic species that live in the pore water between sand grains to some beach-dwelling Onuphidae and Eunicidae, over 3 m long. Body form varies depending on whether the species crawls, burrows, makes its own tube or is pelagic (free-swimming in the upper ocean). Some of the most bizarre polychaetes are parasitic and symbiotic forms. Most species are free-living.

The more mobile polychaetes generally have well-developed eyes and other sensory appendages on the head and along the body. They usually have a muscular mouth cavity sometimes tipped with pincer-like jaws which they can shoot out to seize live animals, tear off pieces of algae or grasp dead and decaying matter.

Species that burrow through the sand or mud generally have reduced head appendages and parapodia. They often eat a wide range of sediment sizes, digesting the coating of organic material. Species inhabiting permanent tubes use secretions from their bodies to cement together sediment, or create parchment-like or calcium carbonate tubes. They use special extensible appendages to collect food from the surrounding surfaces or to filter it from the water. Pelagic species are usually delicate with well-developed eyes, paddle-like parapodia and swimming chaetae, and are active predators on other plankton.

Reproductive processes vary. The usual description for the class is reproduction by spawning thousands of small eggs which are fertilised in the water column. They develop into larvae that can remain feeding in the plankton for weeks or months, before settling and metamophosing into juveniles. However, many species brood a few large, yolky eggs that develop directly into juveniles. Others may be viviparous and give birth to young worms. Some reproduce asexually by subdivision of the body and regeneration of the missing parts. Many polychaetes become free-swimming and swarm in the sea at night at time of reproduction. All of these methods of reproduction, and other interesting variations, may occur within a single family of polychaetes.

Some common polychaete families

EUNICIDAE and **GLYCERIDAE**, although not closely related, are both sometimes referred to as blood worms. Species of both groups are commonly used for bait. Eunicids are characteristically iridescent, often have blood-red parapodial gills, which stand up along the back of the worm, and a few short tentacles on a rounded head. They occur on rocky shores in crevices and under rocks. Glycerids have a sharp-pointed head bearing four minute appendages at the tip, strong muscular bodies, and a huge eversible proboscis – the perfect shape for burrowing into the soft sediment of mud and sand flats. Both groups have impressive sets of jaws which they can evert and use to seize prey (or careless fingers!).

MALDANIDAE (bamboo worms) construct brittle sand tubes, which can extend slightly above the surface. They have a blunt head, lacking appendages, very long body segments and reduced parapodia. They are bulk-ingestors of sand and live on sheltered sand flats between and below the tides.

NEREIDIDAE (ragworms) are active scavengers found under rocks and in crevices on the shores as well as in the soft sediments of estuaries and bays and at great depths. One group occurs in and alongside freshwater streams. This includes *Namanereis tiritene*, described from specimens collected from Turitea Stream, Massey University, North Island.

ONUPHIDAE are long and slender with seven head appendages (two very small) and gills on the back like eunicids. They build various types of tube including sand-encrusted, parchment-like and quill-like ones (in the case of *Hyalinoecia tubicola*, a species which crawls around with its tube, on the surface of offshore sediments). Other onuphids occur on beaches between the tides. Most are scavengers.

PHYLLODOCIDAE include one of the most familiar New Zealand polychaetes, *Eulalia microphylla*, which inhabits narrow crevices of rocky shores; other species are found on the surface of sheltered mud and sandflats. Most phyllodocids are predators of small invertebrates. Like nereids they have well-developed tentacles and move using a similar sinusoidal motion but are usually less robust and have distinctive leaf-like lobes atop each parapodium.

POLYNOIDAE (scale-worms) are often colourful and highly ornate as a result of the thin oval scales, or elytra, which cover their upper surface. They are short, flattened polychaetes perfectly suited to living under stones and in crevices, where they prey upon other invertebrates.

SABELLIDAE and **SERPULIDAE** are "fan worm" polychaetes, so called because of their delicate and spectacular filter-feeding crowns (single or double, sometimes spiralled), which they can withdraw rapidly when disturbed. Sabellids construct a flexible, parchment-like tube whereas the tubes of serpulids are calcareous and can be stoppered by a tentacle-like operculum. Both groups are common on the lower levels of rocky shores; sabellids also occur in soft sediments at various depths.

SABELLARIIDAE construct colonies of characteristic cemented sand-grain tubes on intertidal and shallow sub-tidal rocks. Like fan worms, sabellariids are filter feeders, but instead of a feeding fan they use two groups of ciliated tentacles to filter food from the water. They also have an operculum which can be used to plug their tube, formed by the stout, golden chaetae of the first two segments.

SPIONIDAE are abundant, but usually small, tube-dwelling polychaetes with a characteristic pair of long feeding tentacles which they move about actively above their tube in search of food particles. Many species live in soft sediments, often in large aggregations; species of *Polydora* and related genera bore into calcareous surfaces, including mollusc shells.

TEREBELLIDAE and **TRICHOBRANCHIDAE** are closely related tube-dwelling polychaetes with numerous long extensible head-end tentacles, which are often the only visible part of the worm. The tentacles are used to search for food particles on the surface of the sediment. Both groups have a small cluster of blood-red gills behind the head. Terebellids are commonly found under stones and in crevices on rocky shores; both groups occur on sheltered sand and mud flats and in offshore sediments.

left: *The New Zealand endemic terebellid* Pseudopista rostrata *from Wellington Harbour. (Photo: M. Marmach)*

world standards, having a particularly good representation of deep-water species. In addition, the collection contains some valuable material from early voyages around New Zealand (e.g., *Galathea, Alert, Kotuku*), as well as inshore and estuarine material from surveys by the former Estuarine Research Unit, University of Canterbury (donated by Professor Emeritus George Knox). Over the last few years most of the collection has been identified to family and the results stored on a database.

Major impediments to polychaete taxonomic research in New Zealand are the high proportion of undescribed species (ranging from 30 to 70%, depending on the group and area) and the lack of experts available to describe them. This situation exists despite the demand for accurate names for species by ecologists and government. It has encouraged a somewhat maverick approach to identification of polychaetes. Thus, inappropriate names are sometimes used, including "cosmopolitan" species, which do not occur here, or arbitrary systems of species codes (like "nereid sp. 5") may be adopted that make it difficult to compare the results of different surveys. As a consequence, biologists and managers remain largely ignorant of the wider ecological and geographical distribution of New Zealand polychaetes.

To provide a system of standard taxonomic names for immediate needs, as well as contributing to ongoing taxonomic studies, we are preparing descriptions for each species in the common families in New Zealand waters. These descriptions are based on preserved material in the collections at NIWA, the Museum of New Zealand, and other institutions. We plan to identify synonymous species between collections and create a single system of species names, either the traditional Linnean names or temporary species codes. Each description will include distribution and ecological notes.

The descriptive data are currently being encoded in DELTA format, a taxonomic standard adopted by the International Taxonomic Databases Working Group. This will enable the preparation of high quality species descriptions and fully illustrated keys to families, genera and species. Interactive versions of the keys will be distributed as software, either on CD ROM or via the NIWA webpage. Classical taxonomic studies, involving family revisions, are proceeding in concert with this other, more urgent, effort. At any time we are willing to advise on the most up-to-date names to be used for New Zealand Polychaeta. ■

Chris Glasby and Geoff Read are based at NIWA in Wellington.

Further reading

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COASTAL PROCESSES

Sedimentary micro-surgery at Napier

Kerry Black
Chris Vincent
John Radford
John Hawken
Malcolm Green

A new system of instruments is providing first-hand evidence of the mechanisms that result in either erosion or deposition of sand on our beaches.

DELICATE MICRO-SURGERY is about to be performed as a highly technical optical glass probe is quietly moved into place by a computer. As it moves closer to its target, images suddenly come into focus on a high-resolution television screen. These allow the "surgeon" to complete the exact positioning of the instruments. Once this is done, a button is pressed and sonic beams ring out to complete the dissection.

Strangely enough, the above scene is not from an operating theatre in a hospital. It is a description of new micro-technology developed in the Centre of Excellence in Coastal Oceanography and Marine Geology, a joint educational and research centre at NIWA and the Department of Earth Sciences at the University of Waikato. The surgeons are sediment transport scientists dissecting the complex natural phenomenon of sand movement under the combined action of waves and currents. They are studying the inner space of single sand grains. The delicate micro-surgery is needed because, just as DNA is a basic component of living organisms, the movement and interactions of the grains form the building blocks for our beaches and coastal sedimentary systems. The combined movement of sand grains ultimately determines the state of our beaches and controls matters as diverse as the impacts of sand extraction or the best coastal protection solutions.

The sedimentary instruments are collectively known as the sediment micro-probe system (see panel opposite for a technical description). Such technology has previously been the reserve of surgeons or industry but, with some careful research and development, a system customised for the marine environment has been developed for beach research.

Field application

The system was the cornerstone of experiments conducted at Westshore Beach in Napier in November 1997. Napier was chosen for its suitable medium-intensity wave climate and mobile beach sediments.

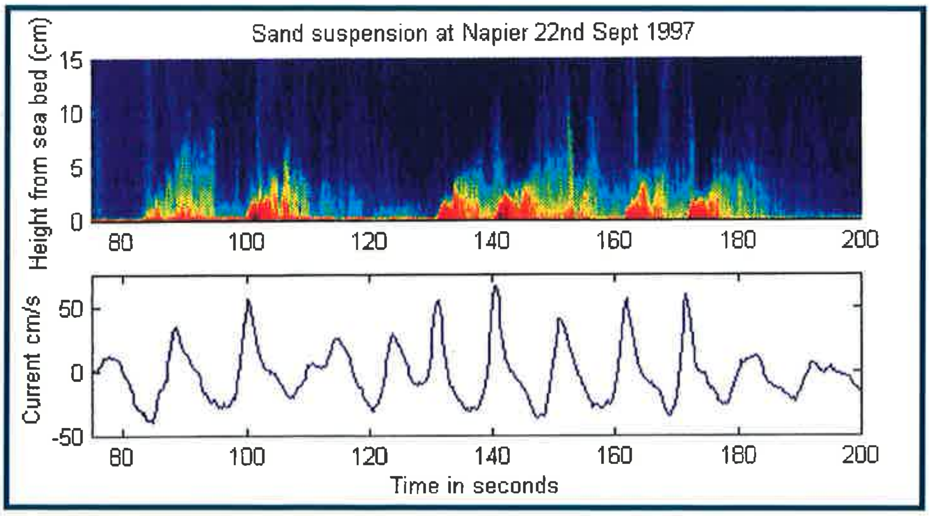
We were rewarded with a range of unprecedented measurements. The instruments provided world-first views of the micro-scale dynamics at the sea bed under natural waves. But we were additionally fortunate that the sea bed went through all of its motions, from planar sheet flow at low energy where the bed is smooth, through rippled where the bed is undulating and back to smooth under energetic wave conditions. In each case, the way in which sediment is lifted above the sea bed is different, and in each case we were able to watch and record its intricate behaviour.

Initial analysis of the data has shown sand grains of all different shapes rolling over their neighbours and breaking free of the sea bed to be ejected into the water column. We then observed that the boundary layer in the bottom few centimetres above the sea bed simply "collapses" after each wave crest passes (see diagram below left). This collapse raises the turbulence levels and changes the complex mechanisms that cause sediment from the bed to be forced upwards. The timing of the collapse during a single wave is critical. If the sand comes up around the crest of the wave, then it will be carried shorewards and may be deposited on the beach. But if the sand rises in the trough of the wave, then the offshore currents at this time will ultimately lead to beach erosion.

We already knew that both processes occur but our measurements showed the variability and complexity of one of nature's delicate balances. This balance between opposed processes, some causing erosion and some causing deposition, results in the coastal geomorphology that we have all seen but have never fully understood.

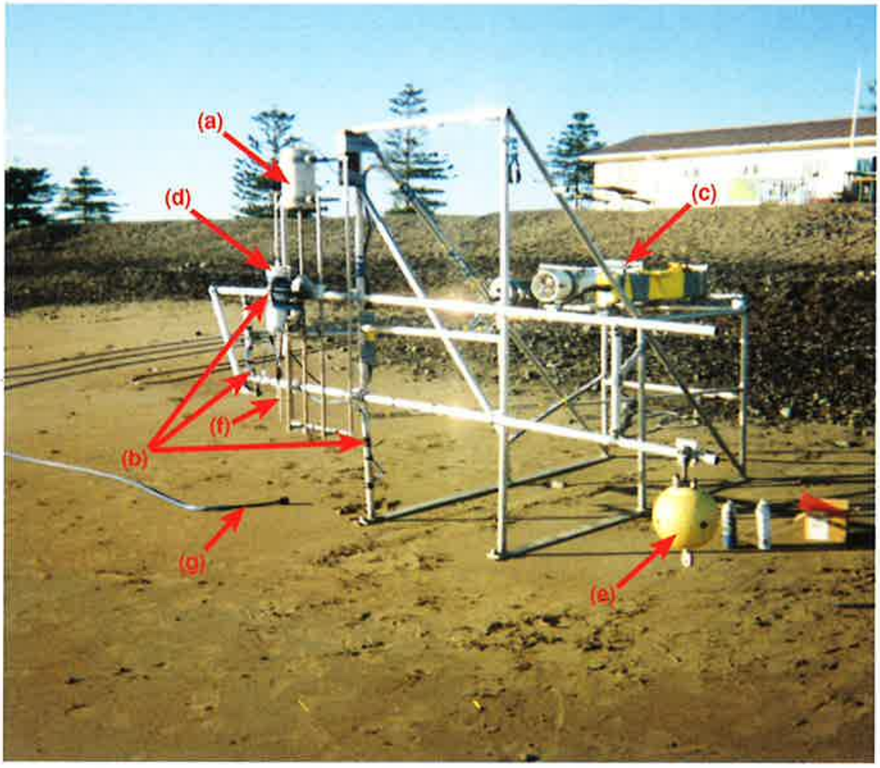
With the combined power of the different components of the sediment micro-probe system, the sedimentary micro-surgeons were able to probe the inner space of sediment transport and watch it in action at high resolution on a natural beach. With these insights, the computer takes over and accurate computer models of the micro-scale processes are used to predict the sediment suspension. An

below: *Output from the sediment micro-probe system during the measurements at Napier. The upper panel shows the vertical suspension of sand close to the sea bed. The suspended sand concentration scale is logarithmic extending from 0.001 g/l (dark blue) to 10 g/l (dark red). The lower panel shows measured currents at 7 mm above the bed (lower panel) at Napier. The sand is lifted upwards as each wave passes, as shown by the complex patterns which evolve through time.*



Sediment micro-probe system: technical description

The sediment micro-probe consists of a 600-mm long stainless steel rod filled with optical glass fibres. The rod is attached to a small video camera which receives the images passing up the optical fibres. The images from the camera are relayed to the beach via a cable with low electrical impedance and which can also withstand the considerable force of the waves in the surf zone. A high-intensity light source is fed into the optical fibres and travels down the fibres to illuminate the images. The reflected light then returns along the same route and into the camera. At the base of the optical rod, a mirror reflects the light at 90° so that the instrument looks sideways across the sea bed, giving a better perspective. The field of view is about the size of a 10 cent coin (22 mm diameter) and a single sand grain is about 5 mm diameter on the television screen, giving high resolution images of each grain.



The system ready for deployment on Westshore Beach, Napier. The instruments consist of: (a) vertical profiler unit; (b) three acoustic backscatter sensors; (c) instrument housings; (d) micro-video unit; (e) S4 electromagnetic current meter; (f) acoustic doppler velocimeter; (g) umbilical cord to the shore.

The camera is suspended on a vertical profiler unit which was custom made for the micro-probe. The heavy duty profiler consists of a carriage for camera mounting, which is attached to a threaded rod. In response to commands from the "surgeon's" portable computer, the stepper motor rotates the thread by an exact number of revolutions, which causes the carriage to move up or down the rod by a precisely known distance. The mechanical components were built to the Centre of Excellence specifications by a specialist engineering company (Neil Precision) in Hamilton.

Also on the profiler unit is a highly sensitive current meter called an acoustic doppler velocimeter (ADV, Sontek Instruments Ltd.; see *Water & Atmosphere* 5(3):22–24 for more details about the ADV). It sends out sound wave pulses which reflect back off the tiny particles found in all water bodies and deciphers water currents in three directions up to 25 times per second.

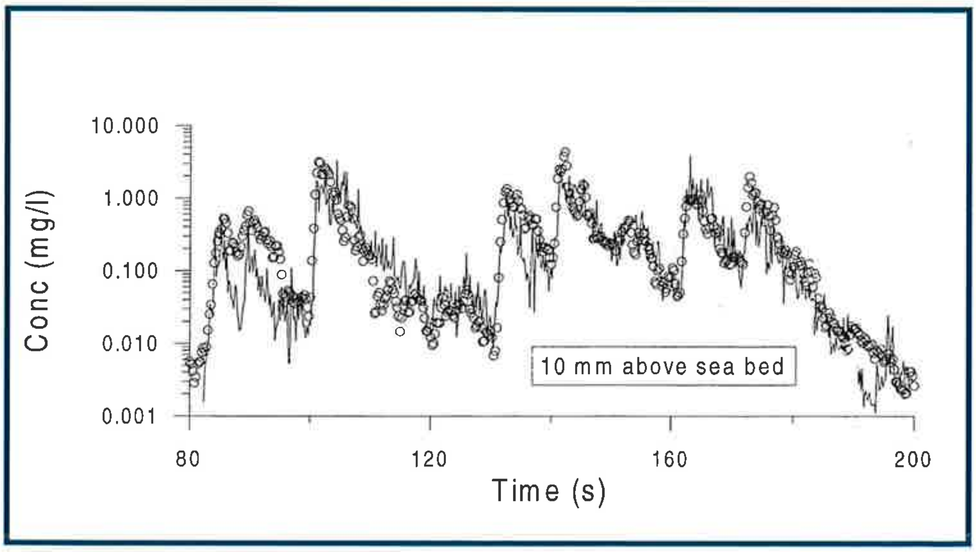
Another technically advanced instrument on the profiler is the acoustic backscatter system or "ABS". The ABS sends a sound beam towards the sea bed and, the intensity of the returned signal reflected off the sand grains in suspension is used to determine the concentration of sand lifted off the sea bed by waves and currents. This instrument records the sand concentrations in thin bands, each only 5 mm thick. It does this in 60 bands above the sea bed 10 times every second. This sort of high-resolution technology has only recently become available for natural beaches. Three ABS's were brought to the Centre of Excellence by Dr Chris Vincent from the University of East Anglia (United Kingdom) for the experiments at Napier.

The Napier experiments were conducted under the auspices of the research programme "Wave and Sediment Dynamics in Coastal and Estuarine Systems", funded by the Foundation for Research, Science and Technology. Wave and Sediment Dynamics underpins a range of applied studies and provides the framework for refinement of our comprehensive computer simulations which forecast outcomes for coastal management.

example is shown to the right. Only with this level of technology can the fundamental processes which cause either erosion or deposition on a beach be resolved and comprehended. ■

Kerry Black, John Radford, Malcolm Green and John Hawken are based at NIWA, Hamilton. Chris Vincent is from the University of East Anglia in the United Kingdom.

right: *The concentrations measured at 10 mm above the sea bed (circles) are closely predicted by the numerical computer models (solid line).*

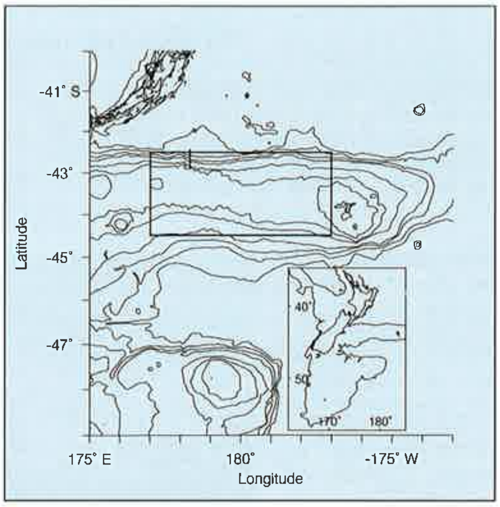


OCEANOGRAPHY

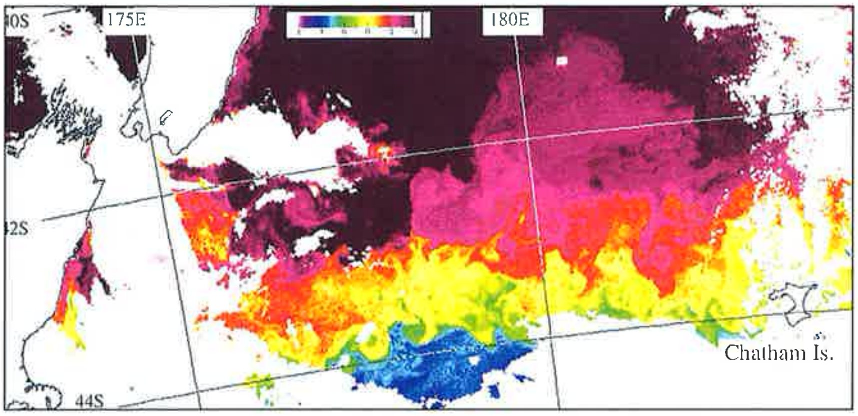
Scaling the Chatham Rise

Sam McClatchie
Stephen Chiswell
Laura Richards
Michael Uddstrom
Nils Oien

Strong swirls where warm water meets cool over the Chatham Rise could explain the patchy distribution of plankton and even fish in that area.



above right: *Map of the study area showing 250-m interval depth contours. The box encloses the region for the large-scale study based on sea surface temperature. The bold north–south line is the transect for the towed undulating vehicle. The inset shows the 1500-m contour.*



below: *A single pass of SST data derived from a NOAA satellite on 11 October 1997 showing the Subtropical Front over the Chatham Rise east of New Zealand. Warmer, salty subtropical water is separated from the cooler, fresh subantarctic water by a highly variable frontal zone dominated by instabilities. Colour coding for temperature (° C) of the surface of the water is shown by the bar at the top of the image. Grey areas indicate land or clouds.*

THE SUBTROPICAL FRONT (STF) is an oceanographic feature that girdles the globe in the Southern Hemisphere between 40 and 45°S. The frontal zone separates warm, salty subtropical water from cooler, fresher subantarctic water and is a region of strong physical gradients and high biological variability. It is clearly visible in satellite images of sea surface temperature (SST data) (see *Water & Atmosphere 6*(1): 17–20 and figure below).

The New Zealand landmass deflects the STF southwards. To the east of New Zealand the front lies parallel to the Chatham Rise, a relatively shallow ridge over which the water is only 250–500 m deep. Because of the STF the water masses over the Chatham Rise itself and to its north and south are distinctly different in terms of nutrients, biomass, species composition and size composition of the plankton and seasonality of these factors (see Bradford-Grieve, in press).

The front and fisheries

The Chatham Rise region is one of New Zealand's important fishing areas. The major fisheries are hoki (50,000 t in 1995/96), orange roughy (12,500 t), oreos (6800 t) and ling (4600 t).

On a large scale, the distribution of deep-water fish stocks on Chatham Rise is indirectly related to the regional distribution of water masses. For example:

- orange roughy are mostly found north of the frontal zone beneath subtropical water. This fishery – the most valuable in the region – is now restricted to seamounts (undersea mountains) at depths of 700 to 1200 m;
- the oreo fishery is located on the southwest margin beneath subantarctic water. Oreo populations occur at depths of over 700 m.

For both these species the concentrations found in different areas are more likely to be related to differences in productivity (through movement of food material to the sea bottom), bathymetry and bottom type rather than to the temperature of the water masses near the surface (see McClatchie *et al.*, 1996).

The Chatham Rise between 200 and 600 m deep is also an important nursery for juvenile hoki (age 2–4 years).

At small scales, variability in the currents affects the transport of fish eggs. For example, orange roughy spawn at depths of about 1000 m along the northern margin of Chatham Rise. The eggs are released at about 850 m and ascend rapidly. They are carried around by tidal and background currents. Their distribution is affected both by small variations in flow and by differences in temperature that affect both their rate of rise and their rate of development (see Zeldis *et al.*, 1995). This means that knowledge of physical variability in the spawning area is relevant to our understanding of recruitment variability in one of New Zealand's most valuable fisheries.

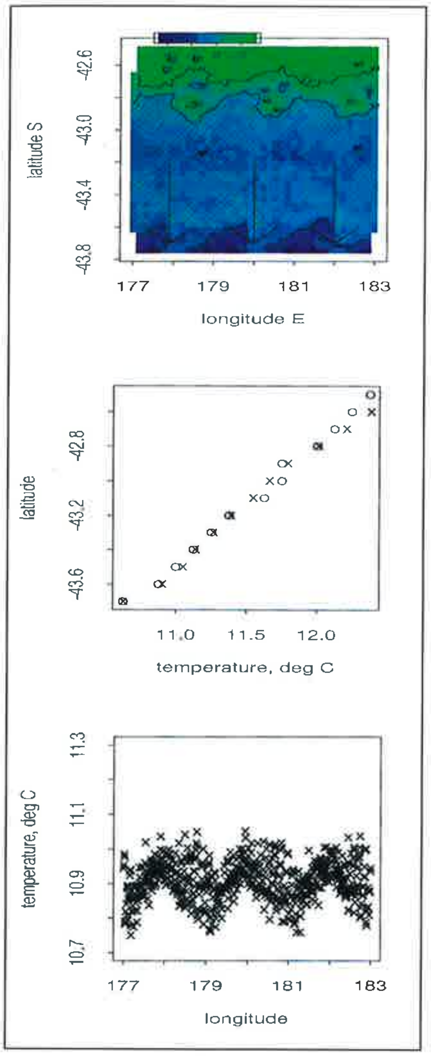
Little research has been done on the variability of physical or biological properties across the STF off New Zealand, and studies that have been carried out have considered only large-scale variability (for example, Chiswell, 1994). We know very little about small-scale gradients in temperature, salinity and water density, or about the biological patchiness of fish and plankton across the Rise. Even less is known about how the small-scale gradients and the intensity of patchiness vary over space and time. The idea of this study was to determine the characteristic scales for the variability for fish and plankton in relation to the strong physical gradients across the STF over Chatham Rise.

Two scales of variability

The map (above) shows the areas in which we investigated two scales of variability.

1. Large-scale variability across the STF

Large-scale variability was obtained from SST data, bearing in mind that SST describes only the surface patterns of temperature. We do not yet



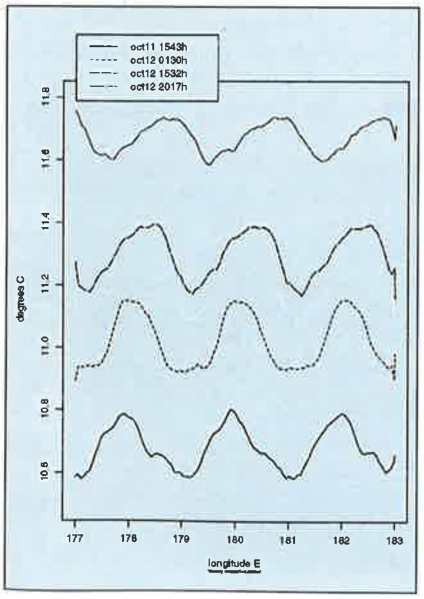
above: *Slicing the SST data between 42.5°S and 43.8°S for a single image (top) by latitude and longitude averaged by 0.1° intervals shows a periodicity in the temperature signal caused by warm and cool intrusions at about 43.6°S (bottom).*

have a clear picture of correlation between the surface patterns of temperature and subsurface (mixed layer) properties on the Chatham Rise. The images from SST data showed a sequence of "meanders" in a zone between about 42.5 and 44.5°S. We asked three questions about large-scale variability:

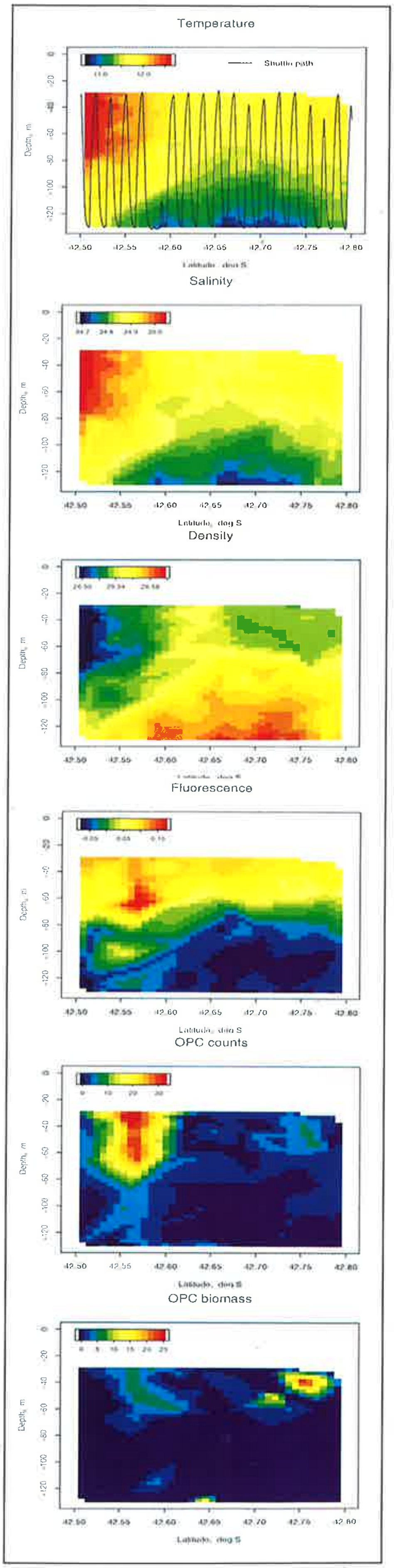
1. What are the sizes of the meanders in the frontal zone?
2. What is the distance between them?
3. In which direction do these features move?

The approximate size of the meanders in single-pass satellite SST data between 11 and 13 October 1997 (during the October 1997 voyage) was 40 to 80 km. The spacing of features was obtained by estimating the mean temperature in "bins" of 0.1° latitude and longitude in the box marked on the map. When these mean temperatures were plotted against longitude, a clear cyclical signal emerged that has an amplitude (i.e., half the height from peak to trough) of 0.125°C (see diagrams, left). This periodicity in the averaged temperature signal is caused by intrusions of warmer and cooler water associated with rotation of the features. The temperature signal has a period of about 2° longitude, suggesting that the centres of the features are separated by about 160 km.

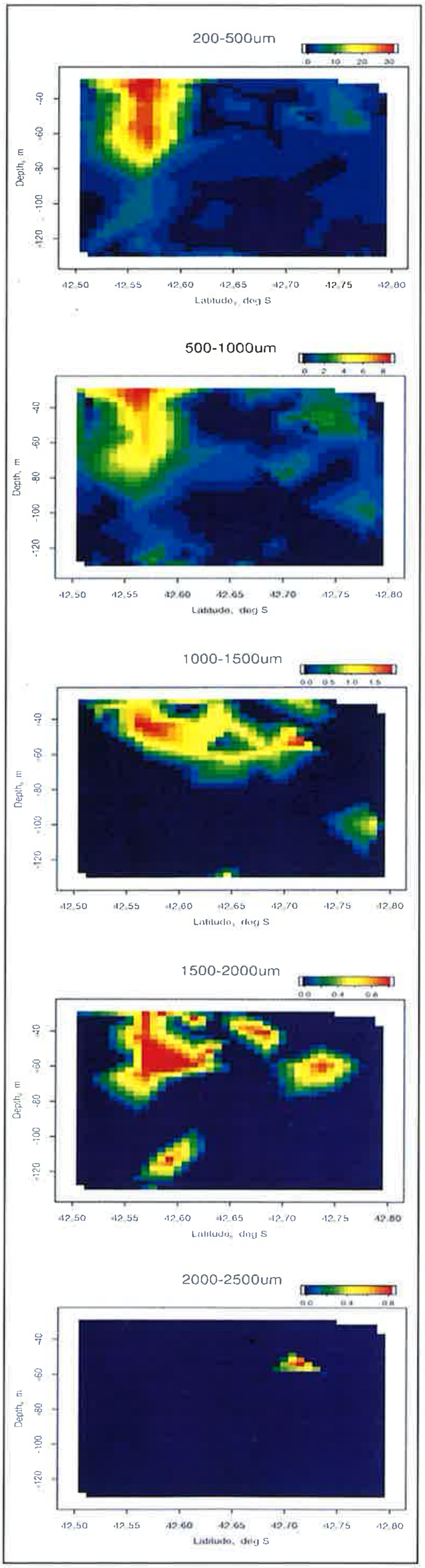
Movement of three features over 30 hours was detected by plotting the mean temperature in 0.1° bins from each of four single-pass images of SST data for a narrow band of latitude (43.6 to 43.8°S) (see graph, lower left). Maximum temperature values shifted to the east in successive images, even over this short period, suggesting eastward movement of the meanders. The temperature profiles in the graph also indicate warming of about 0.9°C over 30 hours. The observed warming may represent a northward movement of the features, but we cannot rule out warming of the surface of the ocean during the day as the cause.



left: *Sea surface temperature from 43.6 to 43.8°S, 11–12 October 1997. The longitudinal shift in the maximum temperature suggests movement of the features to the east, while the warming of the features over 30 hours by about 0.9°C suggests either movement to the north or surface warming over two clear days.*



right: *Small-scale patchiness of phytoplankton (measured as fluorescence) and zooplankton (measured as particle counts in the 0.05 to 250 mm equivalent spherical diameter size range resolved by the Optical Plankton Counter, or OPC). OPC biomass is a summed particle volume estimated by multiplying each particle count by its size using the internal size calibration of the instrument. Data were collected along an 18 km north-south transect along 178.5°E over the vertically undulating track of the nu-shuttle between depths of 30 and 130 m (shown in the top panel).*



far left: *Size distribution of zooplankton counted by the OPC. Sizes are equivalent spherical diameters (ESD, µm). ESD is the cross-section of a sphere that has the same volume as a non-spherical object.*

2. *Small-scale variability of temperature, salinity, fluorescence and zooplankton over a 33 km North–South transect on the front*

Temperature, salinity and fluorescence were measured from a towed undulating vehicle, the nu-shuttle (for more information see *Water & Atmosphere* *3*(3):5 and *5*(1):26–27). Fluorescence measures the plant pigment chlorophyll and indicates phytoplankton concentration.

The figure representing a section of nu-shuttle data (previous page) shows small-scale patchiness of fluorescence and optical plankton counter (OPC) data along the frontal zone collected during October 1997. The OPC data provide information about the amount and type of zooplankton present. A patch of higher fluorescence centred 60 m deep at 42.57°S 178.5°E was associated with higher OPC counts at the same location. Both patches were on the edge of a warm, saline, low-density tongue of water up to 80 m deep. Both phytoplankton and zooplankton patches were about 7 km across and they extended downwards from less than 30 to 80 m deep. A second patch of zooplankton was 22 km south of the main patch. Because the zooplankton here were larger, the biomass was higher then that in the first patch, although the total number of zooplankton counted was lower.

The size distribution of particles measured by the OPC showed that the spatial distribution of zooplankton differed with their size (see illustration left). Copepods with equivalent diameters smaller than 1000 µm (= 1 mm) made up most of the counts and were concentrated in the phytoplankton patch. Larger zooplankton (mainly bigger copepods) were more widely distributed and also occurred in areas of low phytoplankton. The largest zooplankton (over 2000 µm = 2 mm across) were localised into the single patch to the south of the phytoplankton patch. Compare the two figures.

Conclusions

The Subtropical Front over the Chatham Rise is dominated by energetic meanders, generating a complex spatial field. The dynamics are likely to be creating much of the strong patchiness that we observe in the biology at small space scales.

At large space scales (about 200 km), preliminary results from SST data suggest:

- the latitudinal cross-section of the meanders was ~ 40–80 km;
- the separation distance between meanders was ~ 2° longitude (160 km);
- meanders may be moving to the northeast.

At small space scales (about 10 km):

- copepod-sized zooplankton were positively associated with phytoplankton in low-density water;
- the distributions of phytoplankton and zooplankton were not simply a result of mixing.

Our future work involves addressing some of the mechanisms by which this patchiness is created. ■

Sam McClatchie, Stephen Chiswell, Laura Richards and Michael Uddstrom are based at NIWA in Wellington; Nils Oien is now at NCAR, Colorado, USA.

Further reading

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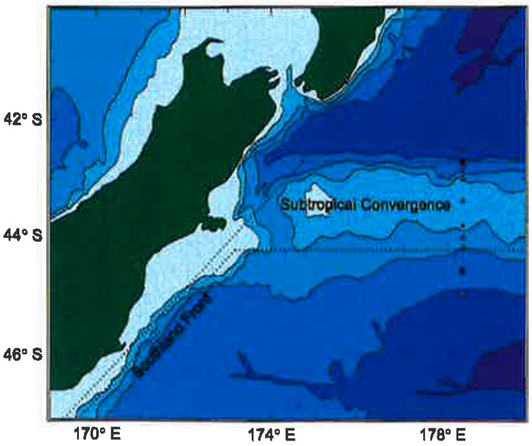
OCEANOGRAPHY

From the sea surface to the abyss: food supplies to the deep ocean sea floor east of New Zealand

Scott Nodder
Conrad Pilditch
Keith Probert
Don McKnight
Julie Hall

The inhabitants of the deep-sea floor depend on a food supply of particles that sink through the water from the productive upper ocean. But is this food supply enough? Not always, according to some recent NIWA measurements. In some areas perhaps other processes, as yet unmeasured, are contributing to maintaining the surprisingly rich life in the abyss.

Location of benthic sampling stations (red circles) during April–May 1997 and deep ocean sediment trap mooring sites (black crosses) occupied from May 1996 to May 1997.



THE DEEP OCEAN SEA FLOOR, in human terms, is a truly inhospitable place. It is perpetually dark and cold and creatures living down there must be able to withstand extremely high pressures. The food supply from the overlying ocean is irregular and could be anything from a whale carcass to a "rain" of particles only a millimetre across. Contrary to the popular view that the abyss is a realm of relative calm and quiescence, we now know that the deep ocean environment is influenced periodically by abyssal "storms" and sediment resuspension. In spite of all this, many organisms are adapted to live in these conditions. And although they may seem isolated from the rest of the planet, they are entirely dependent on what happens in the upper ocean and play an important role in the global carbon cycle.

Carbon cycling in the deep ocean

Because of the difficulties of deep-water sampling, inhabitants of deep-ocean benthic environments (near the sea floor) remain much less well known than their contemporaries living in the surface waters above. In fact, of a possible 270 million km^2 of deep-sea floor, only about 500 m^2 have been sampled using quantitative methods (Gage 1996).

But we do know that several of the most important steps in the global carbon cycle occur below the sunlit surface layers of the ocean. These steps include the export of carbon-rich organic material out of the upper ocean, the decomposition and transformation of organic matter as it sinks through the deep ocean, the partitioning of energy and mass within benthic communities and the burial of carbon in deep-sea sediments.

Once carbon has left the upper ocean it is effectively removed from further exchange with the atmosphere except on the time-scale of ocean water mass turnover, which is hundreds to thousands of years. When carbon reaching the sea floor is incorporated into deep ocean sediments as organisms die, it is removed from cycling processes on even longer geological time-scales.

Very little of the carbon produced in the upper ocean actually reaches the sea floor – only about 1–3% of biological primary production. Most of this organic material – food – is rapidly used up by deep-ocean benthic communities.

Research beneath an ocean front

Certain areas of the ocean are known to use up organic material especially quickly. For example, at oceanic "fronts" (areas where large water masses merge) primary productivity and plankton biomass are usually much higher than elsewhere (e.g., see *Water & Atmosphere* 6(3): 9–12). Consequently NIWA's largest biological oceanographic research programme "Ocean Fronts" focuses primarily on carbon cycling by pelagic and benthic communities within and beneath the Subtropical Front (STF).

The STF is an oceanic front that circles the Earth and, to the east of New Zealand, lies along the Chatham Rise. This front is recognised as a zone of high biological productivity and appears to be a place where CO_2 is "lost" from the atmosphere and global circulation. The Chatham Rise region of the STF is also important in supporting several of New Zealand's largest deep-water fisheries (see this issue, pages 12–14). The fish prey on animals that live near or on the sea floor, and these organisms, in turn, depend upon food sinking down from the upper ocean. Therefore there may be a close relationship between annual recruitment to fish stocks and variations in the supply of sinking organic matter.

We are investigating the links between the sea floor and sea surface (known as benthic–pelagic coupling) across the STF in the Chatham Rise region, using measurements made during recent NIWA research voyages in the area. Two sampling approaches were used:

- direct sampling of the sea-bed material (including sediments and organisms);
- sampling of sinking material at different depths in the water.

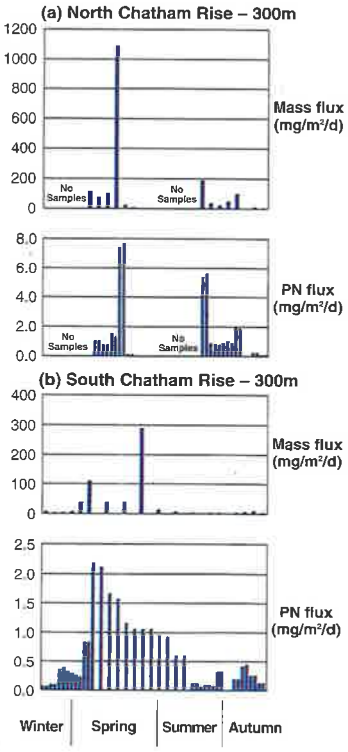
The panel on page 17 gives more details of the sampling methods.

By combining results from these two sampling approaches, we hope to gain a better understanding of how benthic communities function beneath the STF and the role they play in regional oceanic carbon cycling.

North/south differences

Our sampling showed that the larger animals (>0.42 mm across – the "macro-benthic community") living on the deep-ocean floor are usually dominated numerically by various worms. Other groups include crustaceans, bivalves, gastropods, sea-stars and single-celled animals with calcium carbonate shells (foraminifera). Smaller organisms (generally <0.42 mm across) are collectively known as the "meiofauna" and small worms, foraminifera and tiny crustaceans typically dominate this community.

Initial results from the sediment samples (see graphs right) show that the upper flanks and crest of Chatham Rise tend to be sandier than other places. Also, there is more sand on the southern flank at 1000 m depth compared to the same depth on the northern side. Clay and silt contents are always quite low (<40% dry weight), except at the deepest sites (2300 m) and at the 1000 m station on the northern flank of the rise. At 2300 m depth on the southern side of Chatham Rise, the sediment is a carbonate-rich (70%), white, deep-sea ooze, compared with the organic-rich (7%), clay-dominated (55%), grey–green sediment found at the same depth on the northern side. At other sites, sediments are "silty sands". Organic and carbonate contents range from 3 to 5% and 15 to 40%, respectively.



left: *Annual sediment fluxes at 300 m from deep ocean sediment trap deployments: (a) northern Chatham Rise; and (b) southern Chatham Rise. In each case, the upper panel depicts total mass fluxes and the lower, organic particulate nitrogen (PN) fluxes in mg per square metre per day. Note that duplicate values for PN fluxes are shown for each corresponding sampling period for mass flux.*

The largest concentrations of both the larger and smaller animals were found on the crest and on the southern flank of Chatham Rise. The measurements of benthic metabolism (measured as the amount of oxygen used up in the sediment) also suggested higher rates of organic matter turnover with metabolism 85% higher on the southern flank.

It has been suggested that there are more animals on the sea floor to the south of Chatham Rise because more food reaches the sea floor there than on the northern flank (see Probert and McKnight 1993). But the results from our year-long sediment trap moorings (from May 1996 until May 1997) do not support this theory. In fact, we found that in the subtropical waters on the northern flank, two to three times more particles (by weight) reached depths of 300 m than in the subantarctic waters to the south.

So perhaps food *quality* rather than food *quantity* is making the difference in the benthic communities.

Sedimentation differences

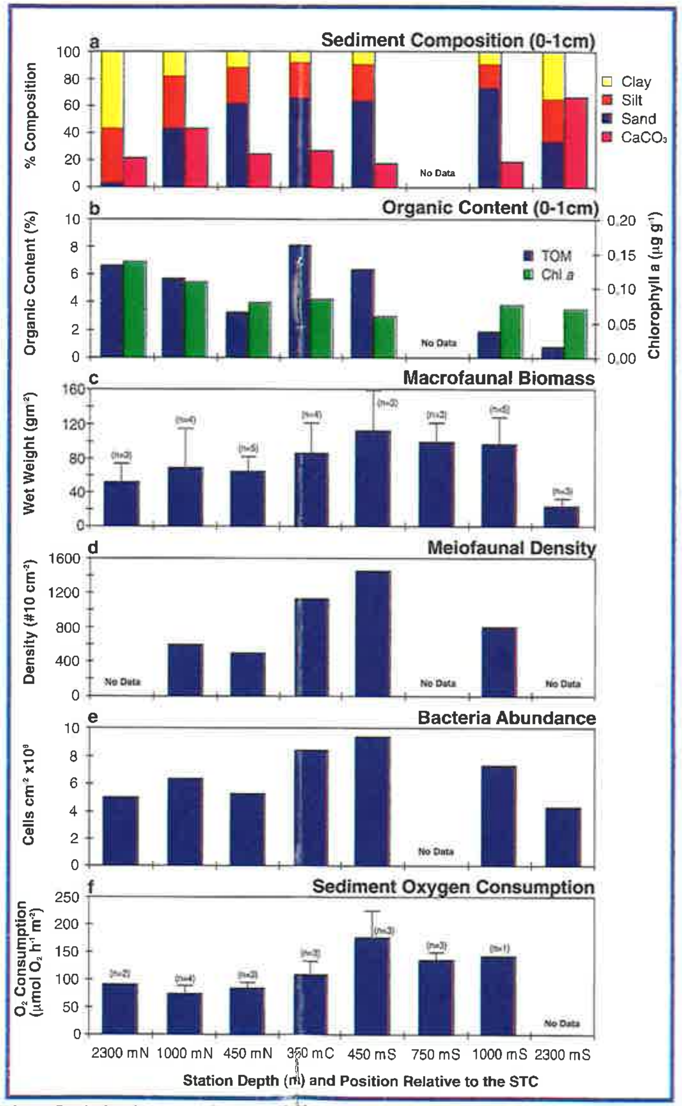
The diagram (left) shows that at the northern sediment-trap mooring there was a spring peak in the amount of sinking organic material with most of the flux occurring within one 7-day period. We assume that this is a result of the spring phytoplankton "bloom" in the upper ocean. Compare this with the more persistent rain of organic-rich material over the whole of spring observed at the southern mooring site.

The sediment traps near the sea bed (in water 1000 m deep) also recorded clear pulses of sinking material coinciding with the spring phytoplankton bloom. The material probably consists of dead algal cells, marine aggregates and herbivorous animal faecal pellets. These deep traps also recorded other pulses of particles, possibly associated with resuspended material moving into the area.

Other food sources?

Combining the benthic community and sediment-trap data enables us to compare deep-sea community size and metabolism with the amount of organic-rich food material reaching the sea floor during the time of this sampling. We can then make some inferences about how the benthic community might respond to variations over time of inputs of material to the deep ocean.

Calculations using the results from the sediment-trap moorings show that slightly more of the organic material produced in the



above: *Results from benthic sampling in April–May 1997 on a transect across the Chatham Rise.*
(a), (b) Sediment parameters for the upper 0–1 cm of sediment. (a) Grain-size (sand >63 µm, silt 4–63 µm, clay <4 µm) and calcium carbonate ($CaCO_3$) percentages. (b) Total organic matter (TOM) and chlorophyll a contents.
(c) – (e): Benthic biomass (averages). (c) macro-fauna, (d) meiofauna and (e) bacteria.
(f) Sediment oxygen consumption (a measure of the rate at which the benthic community converts food into energy, i.e., benthic metabolism).

Sampling the sea bed and the water column

Sea-bed samples

Sampling deep ocean sediment (and the associated benthic communities) involves using coring devices lowered on a wire from a ship to the sea floor.

In April–May 1997, sea-floor samples were collected at eight stations on a transect along 178°30´E across central Chatham Rise. Water depths ranged from 300 m on the crest of the rise to 2300 m beneath Subtropical and Subantarctic waters that lie north and south of the STF, respectively.

We used a "box corer" to collect replicated macro-benthic samples. A box corer comprises a stainless steel box that is pushed into the sediment using weights attached to the corer. The sediment is retained in the box by a pivoting arm that snaps an attached flat "spade" under the box. The sediment collected was screened through a 0.42-mm sieve, and then we weighed the animals (wet weight of living material) left after screening. Smaller organisms – "meiofauna" and bacteria – that live adhered to and in the spaces between sediment grains were sampled using a "multi-corer" (see photograph) which preserves intact the geochemically and biologically active sediment–water interface.

Replicated sub-cores to 5 cm sediment depth were taken from multi-core samples and we used these to determine the meiofaunal biomass and bacterial abundance and productivity.

To obtain information about the physical properties of the sediment we vertically sectioned multi-core samples at 0.5 and 1-cm intervals. These were analysed (at NIWA laboratories onshore) for grain size, organic content (as carbon and chlorophyll) and calcium carbonate percentages. The rate at which the benthic community in the sediment converts food into energy (benthic metabolism) was estimated using a sediment incubation technique: sediment sub-cores were extracted from box core samples, and these cores incubated at bottom water temperatures. The rate at which oxygen concentration declined in the water overlying the sediment core was used as a measure of benthic community metabolism. Shipboard incubations provide reasonable estimates of metabolism when cores are collected from <1000 m water depths, but at greater depths pressure changes damage benthic organisms, thereby reducing the reliability of such measurements.

Sediment in the water column

During 1996 sediment traps were deployed in water depths of 300 and 1000 m on two 1500-m long wire moorings north and south of central Chatham Rise. The traps sample sinking particles by rotating a series of bottles at specific intervals beneath a collecting funnel, thereby recording seasonal variations in the flux of organic matter to the deep sea. Using the samples collected, we measured the total mass fluxes and organic particulate nitrogen (PN) fluxes in mg per square metre per day. These fluxes can be converted to carbon fluxes by assuming a carbon-to-nitrogen ratio of seven in sinking marine particles (see Nodder 1997). Actual carbon flux samples are presently being analysed in one of NIWA's laboratories.

below: *The multi-corer being deployed over the side of RV* Tangaroa. *The corer is lowered over the side of the ship from a thick wire cable. Once the corer is on the sea floor, a dampening piston regulates the passage of the transparent sampling tubes into the sediment so as to minimise any disturbance across the sediment–seawater interface. Sediment is retained in the tubes by a combination of suction (the tubes are capped tight by upper lids), sediment cohesion and by bottom plates. These plates are snapped into position over the open lower end of the tubes as the corer is pulled up from the sea floor by the wire cable.*

spring subantarctic surface waters is sinking out, compared with subtropical waters. On the other hand, the organic carbon flux required to fuel benthic metabolism at depths of between 450 and 1000 m is almost twice as high on the southern flank of Chatham Rise than on the northern flank.

Overall, it seems that the benthic community on the northern flank gets all the food it requires from the organic material that sinks through surface subtropical waters. However in the south, where benthic metabolism is much higher, the food supply sinking through subantarctic waters may be 60% lower than that required. The figures are summarised in the table.

Estimates comparing food production, flux (as sinking particles) and estimated food required by the sea-bottom communities north and south of Chatham Rise. All the figures are expressed as carbon-equivalent units.

	Northern flank (subtropical waters)	**Southern flank** (subantarctic waters)
Upper ocean primary production (from published data – Bradford-Grieve et al., 1997) (mg carbon/m^2/day)	990	250
Carbon flux at 300 m (estimated from sediment trap measurements) (mg carbon/m^2/day)	50	15
Benthic biomass at 450 to 1000 m depths (converted from measured values and corrected for remineralisation and burial) (mg carbon/m^2)	3110	4720
Calculated sedimentation required to sustain benthic biomass (mg carbon/m^2/day)	20.4	37.9

So how do the benthic communities on the southern flank of Chatham Rise sustain the metabolic rates that we measured? Is there is another source of food? Perhaps this source is from the horizontal advection of organic material from the Southland Front, since near-bottom currents on the southern side of the rise came persistently from the west. Alternatively, it is possible that the rapid processing of organic material on the southern flank might support a secondary system of benthic production, perhaps involving microbial processes. Or it may be that the difference arises because there is a persistent "rain" of food material out of subantarctic surface waters on the southern flank of Chatham Rise over the entire spring/early summer period. Compare this to the northern side where we found that the food supply to the deep ocean varied much more over time.

Our work on connections between the deep ocean and surface waters continues within the framework of the "Ocean Fronts" programme. This should eventually lead to a better understanding of how food supplies to the deep ocean communities affect the highly productive deep-water fisheries of the Chatham Rise. ■

Scott Nodder and Don McKnight are based at NIWA in Wellington; Conrad Pilditch is at the University of Waikato; Keith Probert is in the Department of Marine Science, University of Otago; and Julie Hall is at NIWA in Hamilton.

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Acknowledgements

The expertise of many NIWA staff is acknowledged in the "Ocean Fronts" deep ocean benthic programme. Bill Main provided technical help with coring deployments and sediment sampling methods, Lisa Northcote with sediment parameters and trap analyses, Mark Gall with pigment determinations, Faye Richards with particulate nitrogen analyses, Lisa Reed and Tracey Edwards with bacteria enumeration and Richard Rayner with computer assistance. The officers, engineers and crew of RV *Tangaroa* are also thanked for their valuable contributions.

NATIVE FRESHWATER FISH

Lampreys suck – but where do they live?

Don Jellyman, NIWA, Christchurch

NEW ZEALAND has a single species of lamprey, *Geotria australis*, which we share with south Australia and South America. Known by Maori as piharau in the North Island and kanakana in the South Island, lamprey were trapped by Maori at specially constructed weirs or hand-picked off rocks below waterfalls as they migrated upstream during spring to spawn. Traditional fishing is still carried out at weirs in the Whanganui River, and at falls on the Mataura and Waikawa Rivers in Southland.

Lampreys spend most of their lives at sea where they parasitise large fish and even whales. They return to fresh water to spawn, entering rivers during winter/spring – interestingly, previous research by NIWA (*Water & Atmosphere 3*(2):20–21) has shown that they remain in fresh water for a further year before spawning in summer. During their upstream migration and their preparation for spawning, adults are secretive and seldom seen. As little is known about this phase of their life-history, NIWA has commenced a two-year radio-tracking study. During the first year, lampreys are being tracked in the Okuti Stream, a small stream entering Lake Forsyth (Wairewa) in Canterbury. In the second year, the tracking will shift to the Mataura River.

Twelve freshly arrived lampreys were electric-fished in the lower Okuti Stream on 1 September 1998. Wairewa is periodically artificially opened to the sea and at that stage had been open for only a week, so the fish had covered the 10 km from the sea within that time. Specially designed radio transmitting tags were fitted to the lampreys before they were released, and their subsequent movements were tracked using a hand-held receiver. After an initial period of activity, lampreys settled down and showed little inclination to move upstream, even after a substantial flood. To contrast movements of these newly arrived lampreys, a batch of 20 adults which had been collected the previous winter and held in the laboratory for a year, were tagged and released into the Okuti Stream in November. We anticipate that, as these fish are showing signs of sexual development, they will move upstream rapidly. With luck the tags will stay attached long enough for us to determine likely spawning areas and condition, something which is unknown but important if the species is to be sustainably managed.

Incidentally, one of our tagged lampreys was eaten by a black shag within an hour of being released – fortunately the shag regurgitated its catch some distance downstream and we were able to retrieve the tag and reuse it!

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ATMOSPHERIC RESEARCH

Automated all-sky imaging at Lauder

Richard McKenzie

Jill Scott

Greg Bodeker

Ian Boyd

Alan Thomas

Chuck Long

Daily measurements of the clouds in Central Otago provide a valuable data set that is being used to study the effects of clouds on UV radiation.

Alan Thomas checking the roof-mounted all-sky camera at NIWA Lauder, Central Otago (45.04° S, 169.7° E, 370 m a.s.l.). (Photo: Otago Daily Times, 3 April 1998)

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WHAT ARE THE SKY CONDITIONS over Central Otago at the moment? Was the sun shining at 2.45 p.m. on Christmas Day?

Not everybody cares, but answers to questions like these can be highly relevant for atmospheric researchers.

This sort of information is now available from a new all-sky imaging system at NIWA's atmospheric research laboratory in Lauder, Central Otago. While the results will be useful for future climate-change questions, or for real-time decisions on remote operations (such as balloon launches), the main motivation for installing it was to understand the effects of clouds on ultraviolet (UV) radiation.

Clouds and UV

The intensity of UV radiation received in New Zealand is high compared with that in corresponding northern latitudes because of our lower ozone amounts, the closer Sun–Earth separation in the Southern Hemisphere summer months (when most of the UV arrives), and our unpolluted atmosphere.

Clouds also play an important role in regulating the UV reaching the Earth's surface. Although clouds generally reduce UV radiation, they can also cause increases in UV when sunlight is scattered from the clouds to the ground. Of course, other regions shaded by the clouds at the same time receive less radiation. A similar effect is clearly seen in the visible region where, when we look up, the clouds appear brighter than the blue sky. However, care must be taken in the analogy between visible radiation and UV radiation. Visible sunlight is dominated by a direct beam from the sun, whereas UV radiation is dominated by the diffuse component from the sky and clouds.

The effects of clouds on UV radiation have been investigated previously at Lauder using both satellite estimates of cloud cover and ground-based measurements with a conventional 35-mm camera with a fish-eye lens (McKenzie *et al.*, 1998). The conclusions from this study were that:

1. more frequent cloud observations are required, and an improved objective analysis method is needed to derive cloud parameters;
2. the effects of clouds on UV radiation are correlated much better with their effects on total radiation than they are on simple measurements such as the fraction of sky covered by cloud. Total radiation might be, for example, global data from a broad-band pyranometer – an instrument used to measure the combined intensity of incoming direct solar radiation and diffuse sky radiation.

The close correlation between the effects of clouds on UV and on total radiation is the basis of NIWA plans to develop a UV Atlas for the New Zealand region (see Bodeker and McKenzie 1996).

Measuring the clouds

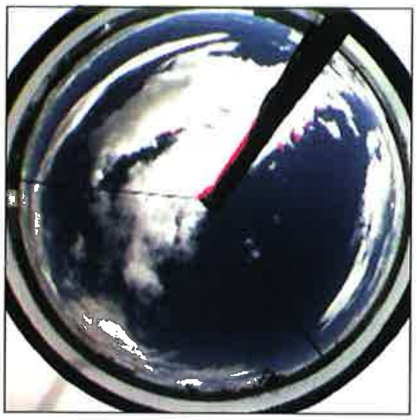
An automated all-sky imaging system was set up at NIWA Lauder in March 1998 in order to generate detailed information for future studies. The system is based on a prototype developed by Dr Chuck Long of the US National Oceanic and Atmopsheric Administration, Air Resources Laboratory (NOAA/ARL), Surface Radiation Research Branch (SRRB), who visited Lauder to help with the installation and set-up of analysis software.

The system is a compromise between costs and data storage requirements. At the same time it must have high enough resolution over time and space to capture the effects of clouds. It consists of a digital CCD camera that is programmed to take an all-sky image every minute throughout the day between dawn and dusk. The full-sky field of view is achieved by mounting the CCD camera above a convex mirror (see photo, left). The mirror rotates under stepper motor control so that direct sunlight is blocked from the camera field of view by a shading band.

This automated system saves each image as a jpeg file at 320 x 480 pixel resolution, which usually requires 10–15 kBytes per file (see figure). Thus, approximately 700 images and 10 Mbytes of data are stored in a separate directory for each day. These data are archived on CD-ROM (about six CDs per year).

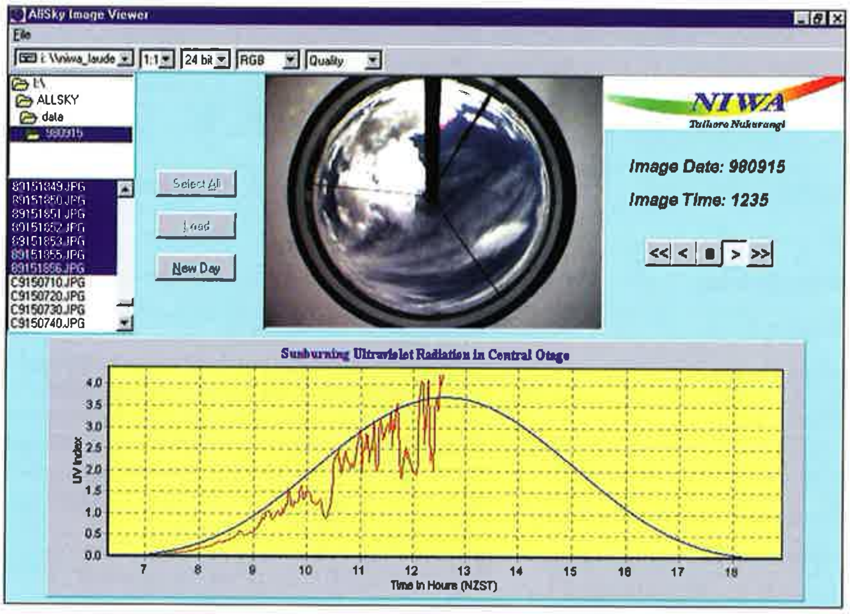
Routine analysis

At the end of each day's observations, the imaging system automatically carries out a series of analyses. For each image it determines the fraction of sky covered by cloud, the cloud fraction in the zenith sky (i.e., the portion of the sky that is directly overhead), the thin cloud fraction, cloud edge-to-area ratios, whether the sun is unobscured by clouds, and other parameters. The processing each night produces a set of "cloud-decision images" and a daily file summarising information about the cloud cover.



above, top: *Typical all-sky image taken at 1100 hrs NZST on 21 October 1998.*
above, lower: *Cloud-decision image created during the automated processing procedure for the image above.*

below: *Time series of total cloud fraction (CF), thin cloud fraction (TCF) and periods of unobscured sun based on an analysis of all-sky images for 21 October 1998. The time of the images above is indicated by the vertical broken line.*



right: *Sample screen of the "movie loop" display, showing an example of cloud-enhanced UV irradiance.*

The processing procedure makes use of the red/blue ratio at each pixel. The clear sky is blue because the molecular atmosphere scatters shorter visible wavelengths (blue light) far more efficiently than longer wavelengths (red light). Clouds, on the other hand, scatter visible wavelengths about equally. Hence the ratio of red to blue is higher for clouds than for clear blue sky. So, large values in this ratio imply cloudy skies, and pixel red/blue values falling below a set limit are deemed clear.

The analysis carried out currently extends to within 10 degrees of the horizon. Some problem regions, including areas masked by the shadow band and areas near the sun are omitted from the analysis. These are the areas outlined in green in the figure above left.

The results are quality-assured by daily inspection of sky images and cloud-decision images. Questionable data are flagged.

Each image is analysed to determine the fraction of cloud cover and, using these, the system generates plots showing time series (at 1-min resolution) for the previous day (see figure below). The plots also indicate periods when the sun is unobscured by clouds.

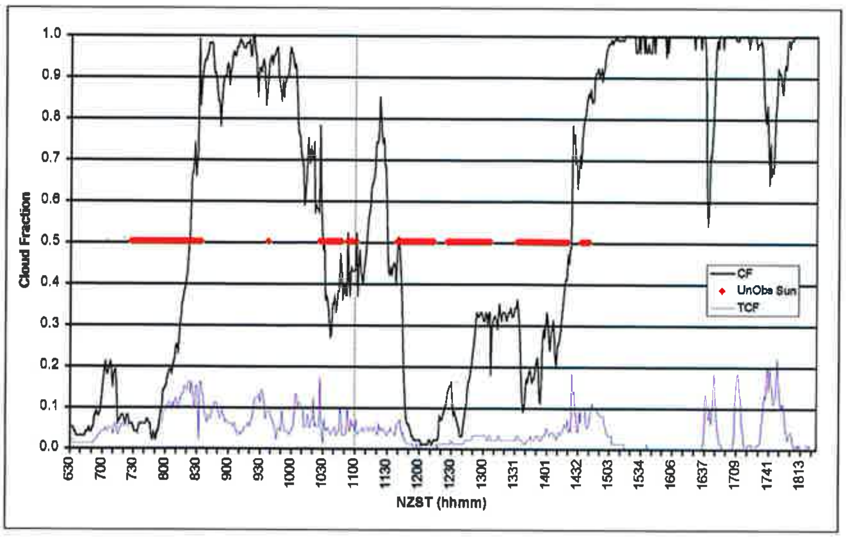
The original 35-mm all-sky camera will operate until the end of 1998, taking photographs once per day to build up a database for assessing the long-term accuracy of the new system.

Post processing

So we have a system for measuring clouds. But how is the information produced converted into usable information about the intensity of UV radiation?

A new software package has been developed as an aid to identifying the cloud conditions that lead to enhancements in UV. The software sequentially displays individual sky images and at the same time updates a plot of measured and calculated UV radiation in a "movie loop" display. A sample screen from this display is shown above.

At 10-minute intervals the most recent image from the sky imager is posted on the Internet (http://www.niwa.cri.nz/lauder/oz_uv02.htm). Time series of cloud parameters for a previous day's analysis are also available. This cloud information supplements other UV Index products (Marks and McKenzie 1997) which have been available on the web since last year. ■



Richard McKenzie, Jill Scott, Greg Bodeker, Ian Boyd and Alan Thomas are based at NIWA, Lauder, Central Otago. Chuck Long is at Penn University, USA (formerly at NOAA, SRRB Boulder, Colorado, USA)

Further reading

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STATISTICAL METHODS

When differences are equivalent

Graham McBride

Traditional statistical tests may not provide satisfactory answers to questions of environmental impact because they may not be asking the right questions. A new procedure – equivalence tests – may do so. Equivalence tests recognise that while differences always occur (e.g., between upstream and downstream sites), they may be small enough to be considered "equivalent". The required calculations are no more difficult than those used in traditional tests.

MOST DISCOURSES on statistics start from the general and then go to the particular. This article inverts that order, in the hope of making the material more digestible! A number of calculations are referred to as we go along. These have been performed using standard functions in a Microsoft Excel spreadsheet. A one-page summary of the calculation procedure is available from the author.

Gold mining impacts

My ecologist colleague John Quinn and his co-workers examined benthic (streambed) invertebrate communities upstream and downstream of alluvial gold mining operations on six streams on the South Island's West Coast (Quinn *et al.* 1992). The effect of the mining was to increase the cloudiness of the stream water and the accumulation of bed sediment.

In each stream, the survey team collected seven upstream replicate samples of invertebrates and seven downstream replicate samples. Each sample was taken from a bed area of 0.1 m^2 at a site in a "run". A run is a stretch of steadily flowing, unbroken water, intermediate in depth and velocity between a "riffle" and a "pool". The upstream and downstream sites on each stream were chosen so that they were similar in character.

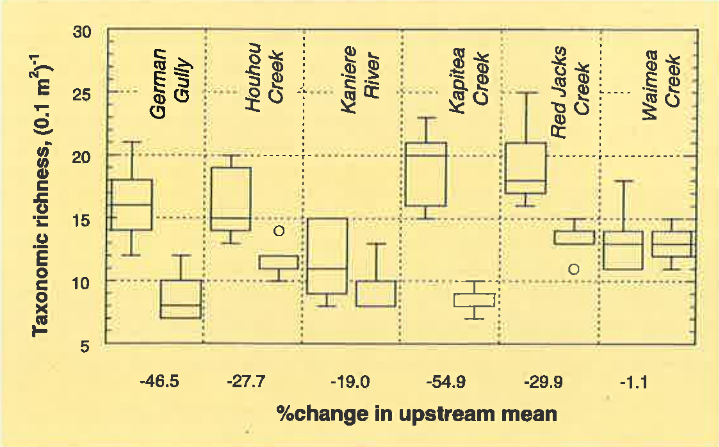
From their surveys the ecologists were able to calculate, among other things, the "taxonomic richness" at each site. This is the number of invertebrate species recorded in the 0.1 m^2 measured at each site, averaged over the seven replicates. As shown on the figure (below) a reduction in the average taxonomic richness from upstream to downstream was measured in all streams, although in Waimea Creek the reduction was very small. Of course the samples are only a small fraction of the benthic invertebrates of the stream, so we can never know whether these results truly represent the mining impact. We need to be aware of this uncertainty when addressing the important question: in which streams is the change in taxonomic richness really different and in which streams is it not?

above: *John Quinn sampling invertebrates in Kapitea Creek, downstream of the mining operation (13 April 1989). (Photo: Rob Davies-Colley)*

This is where statistical "hypothesis testing" comes in – because it deals with the uncertainty.

Traditional null hypothesis test

An hypothesis is a proposition that we make as a starting point for our investigations. A traditional null hypothesis test examines the hypothesis that there is no difference at all (not to the zillionth decimal place!) – hence "null" – between the things we are comparing. The hypothesis is tested by calculating the probability of getting results at least as different as those measured, merely by chance, *if this hypothesis were true.* Statistical theory enables us to calculate this probability quite simply. If the probability is small (usually taken as less than 5%) we reject the hypothesis and say that we have found a "statistically significant" difference.



left: *Boxplots of taxonomic richness data for six streams (from Quinn* et al. *1992). The first of each pair of boxplots is for the upstream site. The boxes contain half the data and the line through each box is that site's median value. The crosses are the site mean values and the circles are outliers. The boxes and whiskers indicate the spread and skewness of the data.*

Outcomes of difference and equivalence tests for upstream/downstream benthic invertebrate taxonomic richness data

German Gully	Houhou	Kaniere	Kapitea	Red Jacks	Waimea
*Null hypothesis test (*denotes "statistically significant" result)***					
*	*	-	*	*	-
*Tested hypothesis is "equivalence" (i.e., true difference is less than 20% of upstream value) ***					
Inequiv.	Equiv.	Equiv.	Inequiv.	Equiv.	Equiv.
*Tested hypothesis is "inequivalence" (i.e., true difference is greater than 20% of upstream value)***					
Inequiv.	Inequiv.	Inequiv.	Inequiv.	Inequiv.	Equiv.
Bayes' probability that then change in taxonomic richness is within 20% of the upstream value (%)					
0.3	14.0	53.3	0.01	7.7	97.1

**The significance level for all comparisons is α = 5%. For further discussion on this and on the calculation methods (including their application to the Waimea Creek data), refer to the explanatory sheet available from the author.

Using that test on John's data shows that the differences in upstream/downstream taxonomic richness at four of these six sites are statistically significant. The exceptions are Kaniere River and Waimea Creek (see the Table above). This finding would often be interpreted to mean that a "real difference" has been detected between upstream and downstream sites on the other four streams.

No impact at all?

But why would you believe that the null hypothesis could actually be true – that there is no difference, none at all? Surely a mining operation could be expected to have *some* impact? And environmental factors alone could be expected to cause differences between sites, even if there were no mining operation.

So, is the right question being asked? Are the differences in invertebrate animal communities detected on the four streams ecologically significant? The answer is "not necessarily". It can be shown that finding a statistically significant difference becomes ever more likely with increased numbers of replicates, and that this is because we are testing a null hypothesis. That is, the detectable difference tends to become smaller with a larger number of samples. So a "statistically significant" difference is not necessarily "ecologically significant". Perhaps the wrong question is being asked.

Similar questions arose in drugs-testing some years ago. In this area of research it is now largely agreed that testing a null hypothesis is not appropriate. Why should one believe that two drugs could have exactly the same effect? It has become common practice for drugs-testing (e.g., Chow and Liu 1992) – but for practically no other field – to test whether or not a difference might be within or beyond some prescribed interval, rather than futilely imagining that it might be exactly zero. The size of the interval is set by the drugs licensing agencies and is set small enough to provide appropriate health protection to patients. Testing for differences falling within a given interval is generally known as "equivalence testing".

For benthic invertebrate data, the equivalence interval should correspond to differences judged by ecologists or regulators to be "ecologically significant". If we conclude that the true difference is within that interval we would say that the sites are "equivalent"; if not, we would say that they are "inequivalent", and so infer that there has been an impact. This language avoids the use of the term "different": after all, everything is different to some degree. A major advantage of this approach is that increased sampling can strengthen the support for a true hypothesis (see the "Power curves" panel). In contrast, support for a null hypothesis is weakened by increased sampling.

Acknowledgements

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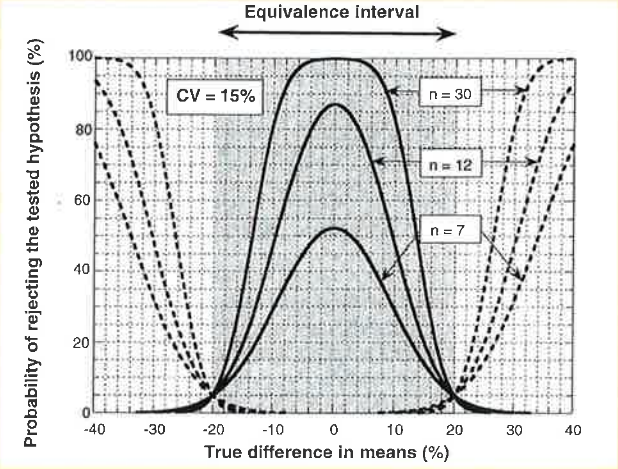
Power curves: strengthening or weakening support for an hypothesis

THE FIGURE BELOW (from McBride, in press) shows "power curves" for equivalence tests on data like the West Coast streams' taxonomic richness. (These data had a coefficient of variation (CV) of about 15%.)



Power curves show the probability of rejecting the tested hypothesis for a range of the true (but unknown) differences in mean taxonomic richness for various numbers (n) of replicates. The solid lines refer to tests of the inequivalence hypothesis (that the true difference is outside the equivalence interval) and the dashed lines refer to tests of the equivalence hypothesis (that the true difference is within the equivalence interval). The equivalence interval is ±20% of the upstream mean taxonomic richness. The significance level is $\alpha = 5\%$, so that each curve passes through the 5% rejection probability at the edges of the equivalence interval.

The figure shows that the further the true difference lies within the equivalence interval, the larger the probability of rejecting the inequivalence hypothesis, and the smaller the probability of rejecting the equivalence hypothesis. The converse applies if the true difference lies beyond the interval. Furthermore, the window of uncertainty surrounding the edges of the equivalence interval becomes smaller as the number of replicates increases. For example, with only seven replicates the power to reject the inequivalence hypothesis (and so infer equivalence) only exceeds 50% when the true difference is less than 3%. For 10 replicates this power is attained at a true difference of about 10%, and for 30 replicates it is attained at a true difference of about 14%. Once power exceeds 50% an hypothesis will be rejected.

Performing the equivalence tests

First we have to state the size of the equivalence interval. In general John reckons that a change of 20% from the upstream average taxonomic richness is environmentally significant. (He also looks at other information of course, such as loss of keystone species – species which are known to be critical to the structure of the stream community.)

Armed with this insight we can perform equivalence tests on his data. But first we must face a new, and important, question. That is, which of the two possible hypotheses should we test: (a) that the differences are equivalent, or (b) that they are not? Quite different answers can result, particularly if our measured difference is close to the edge of the equivalence interval. This is because of our demand for a "small" probability of making an error if the tested hypothesis is true. We are in effect saying: I will only reject my hypothesis if strong evidence is produced against it. That of course means that weak evidence won't count against it.

For example, the measured change in taxonomic richness in the Kaniere River – 19% of the upstream value – is very close to the critical value of 20%. If we test the hypothesis of inequivalence [case (b)], we might expect to have a hard time rejecting it for the Kaniere data, even though the measured difference was a little less than 20%. Rejection should be much easier for the Waimea where the measured difference was only 1%.

But let's first follow the standard practice in the environmental sciences of assuming no impact. Therefore we test the equivalence hypothesis [case (a)]. That is, we assume that any differences are small enough (i.e., less than 20% of the upstream value) for us to consider the upstream and downstream sites on the streams to be equivalent in their taxonomic richness.

The result is that we reject the hypothesis for two of the six streams (see Table) and conclude that only German Gully and Kapitea Creek have inequivalent taxonomic richness upstream and downstream of the mining operation. The other four are "equivalent", and it could be inferred that there is unlikely to have been an impact of any note on them.

But should we have made the equivalence assumption? If we want to emphasise environmental protection shouldn't we first assume that the sites are inequivalent, and only lose faith in that assumption if there is strong evidence against it (as in drugs testing)? If we do that, we find that only one of the streams, Waimea Creek, has equivalence of taxonomic richness between upstream and downstream sites (see Table).

So, if we take the latter (precautionary) approach we conclude that five of the streams are impacted by the mining operations. But if we take the opposite tack (testing the equivalence hypothesis, so minimising the chance of "crying wolf" – claiming an impact when it is not ecologically significant) we conclude that only two streams are impacted.

Which is right? Well, the statistician can't say! It's all a question of what burden of proof is adopted. For example, in criminal proceedings there would be many more convictions if juries were instructed to assume the defendant guilty, unless found innocent "beyond reasonable doubt". For our stream data one could be tempted to adopt the intermediary results given by the null hypothesis test (because they imply that four streams are affected). However, it is merely coincidental that these results are intermediary.

Yet another way

All of these techniques work by a procedure which first assumes an hypothesis (e.g., equivalence) to be true, and then asks the question: "what then is the probability of getting data at least as extreme as this, just by chance?" That probability is used as a weight of evidence against the hypothesis. But the more direct question, and some would say the more interesting and relevant question, inverts this to ask: "what is the probability that the taxonomic richness at the upstream and downstream sites are equivalent, given the actual data we have obtained?" To answer this question one has to use "Bayesian" statistical methods. These only work if the investigator (or regulator) is prepared to state the degree of belief held in the hypothesis before the data were collected. The procedure then updates this belief in the light of the actual data obtained.

The good news is that this prior belief can take the form: "I don't know". Doing that, we can use a Bayesian equivalence test procedure to calculate the probability that the true difference in taxonomic richness is less than 20% of the upstream value. The results are also shown on the Table. The probabilities shown can also be thought of as a weight of evidence for or against equivalence, and hence constitute a test.

Conclusion

The above discusses a number of ways of testing whether upstream and downstream sites are equivalent. How are we to interpret the results? Well, it's up to you! If you want my opinion, I'd go for the Bayesian results because they are giving a direct answer to the question asked. And I'd say that the effects of mining operations on the taxonomic richness of benthic invertebrates were negligible on one stream, marginal on another, likely on two and definite in the other two. ■

Graham McBride is based at NIWA in Hamilton.

Further information

For more information about equivalence tests and for copies of the one-page summary of the calculations mentioned in the article, please contact the author: Graham McBride, NIWA, PO Box 11-115, Hamilton (ph. 07 856 1726, fax. 07 856 0151, email: g.mcbride@niwa.cri.nz).

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STREAM ECOLOGY

The secret lives of adult aquatic insects

Kevin Collier
Brian Smith

Stream ecologists traditionally work with the immature larval stages of aquatic insects that live on and under stones in the streambed. It is easy to forget that insect larvae emerge from streams as flying adults, many of which live on vegetation in riparian areas. Recent work at NIWA has been delving into this poorly understood and secretive life stage of aquatic insects.

ALMOST ALL the insects found in streams are the young stages, called nymphs or larvae. The adults are generally terrestrial, or land-based, and, as you might expect, the number that survive can have an overwhelming influence on the population of larvae that occur in streams. This is because aquatic insects mate after emergence (see the diagram of the aquatic insect life cycle below) and some species need to feed to develop eggs.

Unsuitable habitat and high exposure to predation (e.g., by birds and spiders) can mean that, in some vulnerable species, few adults survive to lay their eggs back in the stream. Fewer stream larvae could mean lower biodiversity and less food for fish. Reduced numbers of larvae also may alter instream processes such as the breakdown of organic material and the growth of algae on which many larvae feed.

Adult aquatic insects very occasionally hit the limelight: for example, in the United States, synchronised mass emergences of mayflies from large rivers have been known to close bridges because of the traffic hazard they cause.

In New Zealand, most work on the adult stages of aquatic insects has been on taxonomy and very little is known about their ecology and habitat requirements. Yet this knowledge is important for stream restoration so that:

- appropriate plant species can be established in riparian areas to provide food and shelter;
- suitable environmental conditions (e.g., air temperatures) can be created to promote development and thereby enhance the size of the next generation;
- areas of restored stream can be recolonised by adult insects where there is no upstream source of larval colonists.

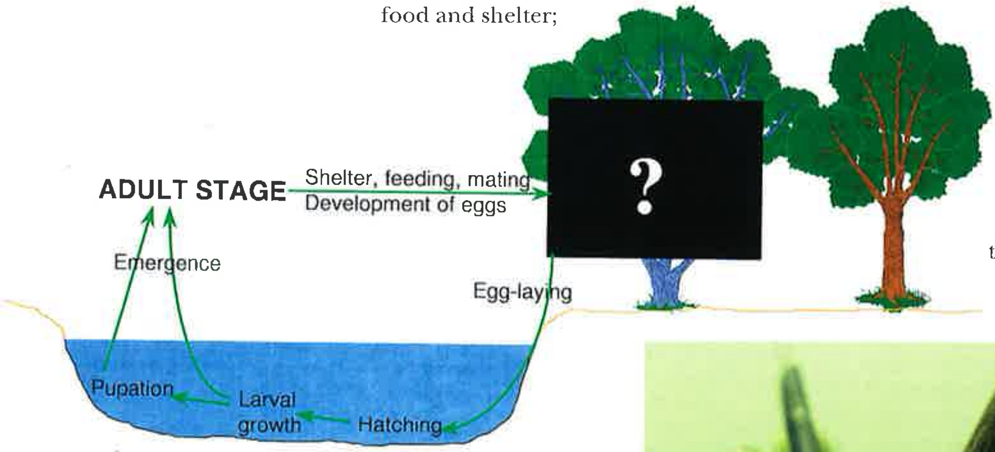
One reason that few people have studied the ecology of adults is that most are active during the night, and even then they are usually hard to find in large numbers. Most insects emerge from streams (see life-cycle diagram) in early summer, although adults of some can occur year-round. The work carried out at NIWA has focused on caddisflies and stoneflies which can live from several days to several weeks as adults. Mayflies are common stream insects but are not used for our studies because the adults do not feed and are short-lived. In addition, the eggs of many mayflies are already developed when they emerge.

The effects of land use

Using light traps (see panel), we caught adult caddisflies over summer in catchments of different land use at the Whatawhata Field Station, near Hamilton. Such collections could indicate the suitability of both instream habitat for larvae and terrestrial habitat for adults. This pattern is shown opposite (lower diagram).

The composition of these catches reflected the type of land use, in particular whether the catchment was in forest or in pasture.

The caddisflies caught in light traps were the adults of larvae from a wide range of stream habitat types (seeps, pools, runs, riffles, etc.). Sampling adults therefore provides useful information in addition to that from the usual benthic (stream bottom) invertebrate sampling which is often only carried out in a single type of stream habitat. Because of this, we believe that light trapping has potential as a monitoring tool to measure the effectiveness of catchment and riparian management actions aimed at improving conditions for aquatic life.



above: *Generalised life-cycle of aquatic insects. Very little is known about what happens between emergence and egg-laying.*

photo: *Adult stonefly feeding on a flower.*

opposite right: *Ordination analysis of adult caddisfly faunas collected over summer in catchments of three different land uses at Whatawhata, near Hamilton. Each axis summarises the composition of the fauna at a site as a single point on two ordination axes; the closer the sites are, the more similar they are.*

Catching adult insects

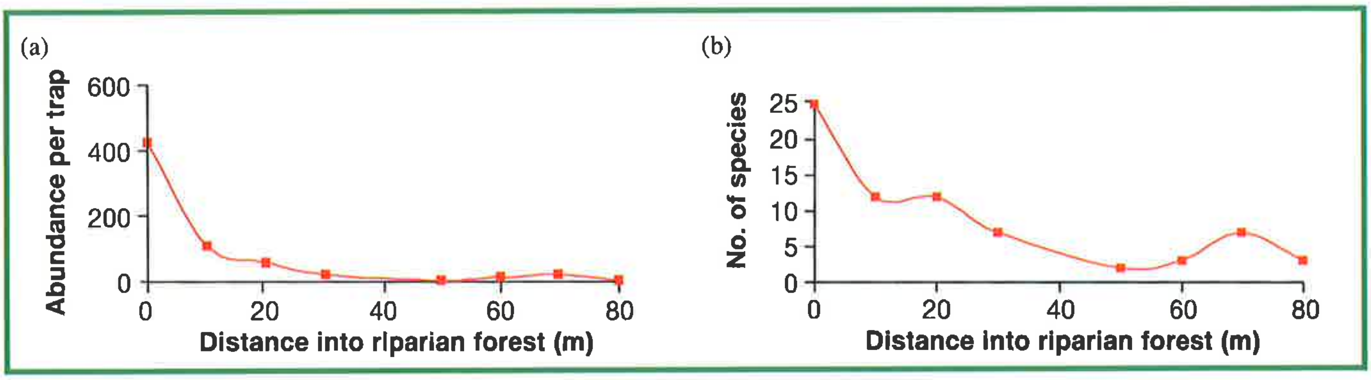
THE DIFFICULTIES of catching large numbers of adult insects at most times of the year have led to the development of a range of collection techniques. Conventional methods include Malaise traps which are like large tents made of netting, sweeping and "beating" vegetation into a net, and hand-picking from stones and plants using forceps. Two methods that have been widely used in recent NIWA studies are sticky trapping and light trapping.

Sticky traps consist of transparent plastic sheets coated with an extremely tacky compound appropriately called Tanglefoot (some researchers have also used grease). These traps can be placed across or next to streams to passively intercept insects unfortunate enough to fly into them (see insert).

Our light traps consist of ultraviolet (blacklight) tubes laid over a white tray containing water and a little detergent to reduce the water surface tension so that insects that fall into the water are unable to get out. The lights are attached to timers which turn them on and off automatically at predetermined intervals throughout the night.

The light traps catch flying insects that are attracted to ultraviolet light (mostly caddisflies and some mayflies) and are therefore selective, whereas sticky traps are not selective. An innovation developed at NIWA is the use of vertical barriers around the light traps; these direct the light upwards so that several traps can be placed close together without interfering with each other.

top: *Malaise trap set up alongside a stream.*
inset: *Sticky trap covered with insects.*

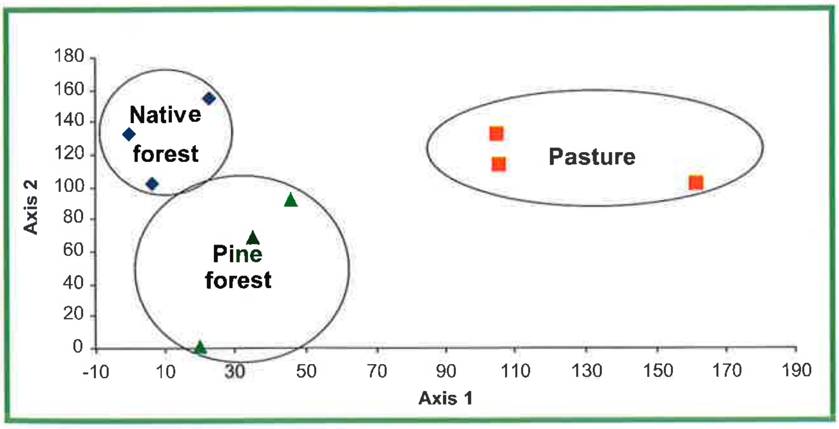


above: *The number of adult caddisflies (a) and number of caddisfly species (b) caught in light traps placed at varying distances into riparian forest alongside a North Island stream.*

Adult caddisfly movement

How far from the stream edge do adult caddisflies move, given suitable vegetation? To find out, we placed light traps and sticky traps at varying distances away from the edges of some North Island native forest streams. We collected caddisflies up to 200 m away (the maximum distance tested), but most were caught within 20–30 m of the streams (see (a) above).

This suggests that the main zone of interaction with the terrestrial environment is close to the stream edge. Individuals of several species ranged much more widely in riparian forests (see (b) above). These individuals may play an important role in exchanging genetic material between neighbouring populations, and in recolonising sites following restoration or large-scale disturbance.



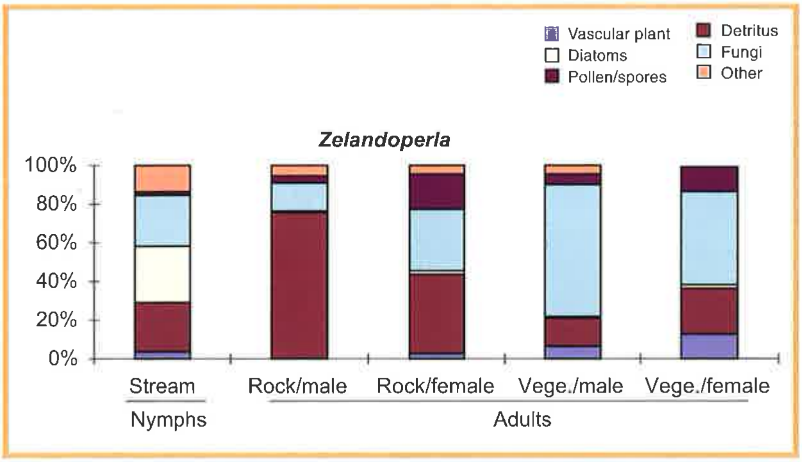
Diet and effects of microclimate

Two factors that can affect the survival and development of adult insects in riparian zones are diet and microclimate conditions such as air temperature and humidity. We have examined these factors in three species of adult stonefly. Stoneflies were used because:

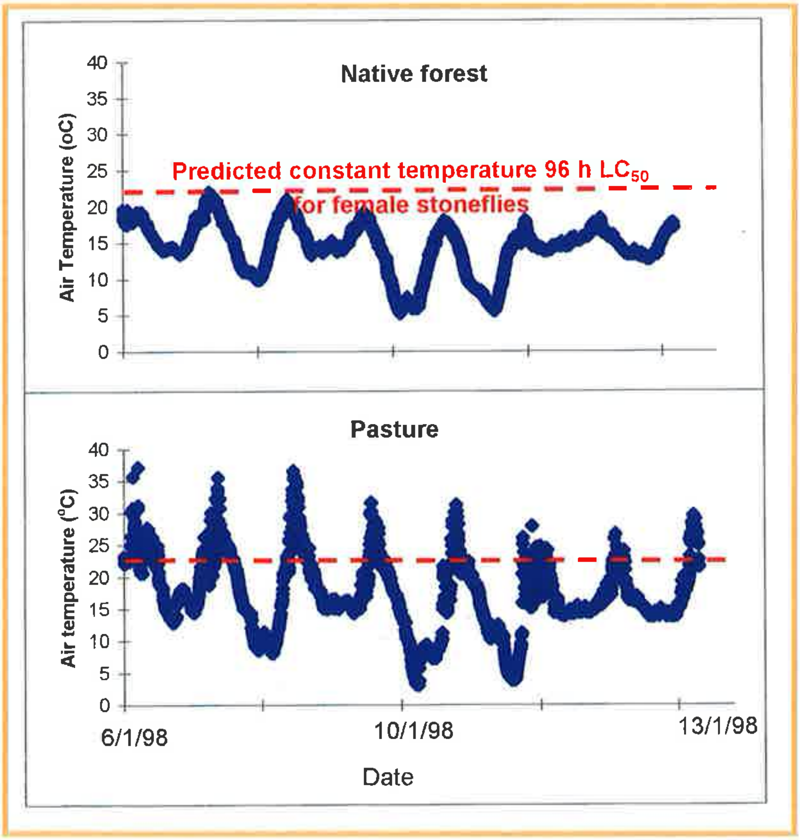
- their faunas are more diverse in forest streams than in pasture streams and this may be due in part to the suitability of adult habitat;
- immature stages have been shown to be sensitive to high water temperatures and so we might expect similar sensitivity to high air temperatures in adults;
- they are easy to rear and maintain in laboratory conditions for experimental purposes.

Diet

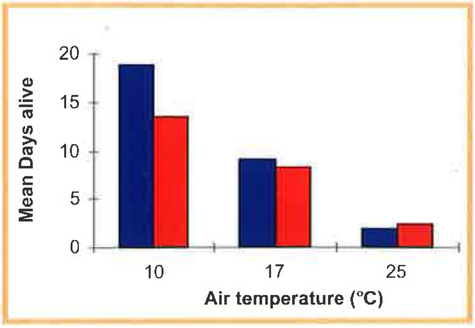
Analyses of the gut contents of stoneflies suggested that the diets of adults collected on rocks and from vegetation are different from those of late instar nymphs (the immature aquatic



above: *The percentage of various food items found in the guts of mature* Zelandoperla decorata *nymphs collected from the stream and adults collected from streamside rocks and vegetation.*



above: *Continuous air temperature records during summer from alongside a native forest stream and a pastoral stream showing typical daily fluctuations. The dashed horizontal line indicates the constant temperature at which 50% of female stoneflies were predicted to die within four days.*



left: *Mean days alive for* Zelandoperla decorata *adult males (blue bars) and females (red bars) kept in the laboratory at three constant temperatures and fed a dilute sucrose solution and water.*

stage). For example, male and female adults of the stonefly *Zelandoperla decorata* collected on rocks had more detritus in their guts; those collected from vegetation had mostly fungi (see figure left). Females collected from rocks and vegetation had more pollen in their guts than males.

However, gut contents tell only part of the story of stonefly diet because of different rates of digestion of the various food items.

We are currently testing these stoneflies to see if they also feed on nectar from flowering riparian plants. We are also carrying out stable isotope analyses to determine whether terrestrial food is assimilated into body tissues. The natural carbon isotope values are quite different for plants growing on the land and in the stream, and these value change little in animals that feed on these food sources (i.e., you are what you eat). (Refer to *Water & Atmosphere 4*(2): 11–12 for more information on carbon isotope ratios.)

Microclimate

The microclimate work was carried out on stoneflies reared in the laboratory until they emerged. They were maintained at different temperatures (10–25°C) or humidities (15–100%). We found that both air temperature and humidity had significant effects on adult longevity, as shown for temperature with *Zelandoperla decorata* (bottom). Our results predicted that half of the adult female stoneflies used would have died within four days at 22–23°C. This air temperature is frequently exceeded during summer in pastoral areas (see figures to the left) suggesting that it may be an important factor limiting the distribution of some stoneflies.

However, our experiments were conducted at constant temperatures. To get a better idea of what happens in natural situations, we need to make comparisons using realistically fluctuating air temperatures like those that occur naturally.

Future work

As well as influencing life-span, diet and microclimate have the potential to affect sexual maturation of stoneflies. We will investigate the role of these factors on ovary development and therefore on the number of eggs produced for the next generation of larvae over the next two years by carrying out laboratory feeding experiments on different types of food and under different temperature regimes.

In addition, we are investigating links between adult aquatic insects and terrestrial predators such as spiders, because emerged adults potentially represent an important food source for riparian food webs at certain times of year. It is hoped that this work will help to further unravel the ecological secrets of this poorly known stage of aquatic insects.
■

Kevin Collier and Brian Smith are based at NIWA in Hamilton.

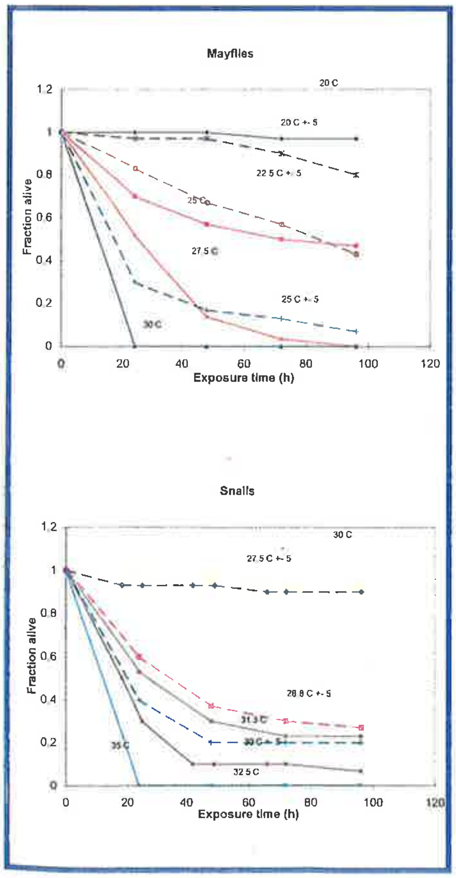
STREAM ECOLOGY

How do fluctuating temperatures in streams affect invertebrates?

Tim Cox

Kit Rutherford

How high does water temperature have to be, and for how long, before stream invertebrates start to suffer? The question can be highly relevant for the management of unshaded streams and a combination of laboratory experiments and a computer method is helping ecologists to predict the answers.



left: *Stream invertebrate survival at different temperatures and temperature regimes: experimental results.*

HIGH WATER TEMPERATURES are not good for stream health and it is known that some stream invertebrates, such as mayflies, are especially sensitive.

In the past, ecologists have measured just how sensitive by exposing test animals to a constant high temperature and observing the proportions that survive for a given time. The results provide a measure of the "thermal tolerance" of different invertebrates. For example Quinn *et al.* 1994 found that 50% of mayflies (*Deleatidium* spp) previously kept at 15°C survived for 96 hours when exposed to a constant temperature of 23°C.

Unfortunately it is difficult to apply laboratory findings such as this to natural streams where temperature fluctuates throughout the day. In order to ensure 50% survival does the daily maximum temperature have to be below 23°C or does this limit apply to the daily mean temperature? This is an important question for unshaded streams at summer low flow when temperatures may vary by 5–10°C throughout the day and commonly approach 25°C in the afternoon.

Laboratory tests

We conducted a series of laboratory experiments using two important invertebrate species: *Deleatidium* spp (mayfly) and *Potamopyrgus antipodarum* (snail). We exposed these species both to constant high temperature and to temperatures which varied by ±5°C diurnally (i.e., fluctuating between 5°C more and 5°C less than the mean temperature over a 24-hour period).

The figure (left) shows measured survival versus exposure time for the two species studied under constant and diurnally varying temperature. Our results corroborate other studies which indicate that snails tolerate higher temperatures than mayflies. This study also shows that daily mean temperature is a poor indicator of invertebrate survival. Whereas 50% of mayflies survived for 96 hours at a constant temperature of 25°C, only 10% survived when the mean temperature was 25°C but there was a diurnal variation of ±5°C. For snails, 25% of test animals survived for 96 hours when temperature was constant at 31.3°C and survival was similar (about 30%) when temperature varied diurnally in the range 28.8±5°C.

In the past, the results from constant temperature studies have been used to set temperature limits. For example, the constant temperature results (bottom left) suggest that a limit of 25°C will ensure 50% survival of mayflies for 96 hours. This limit may be appropriate when the temperature is constant. However, when the temperature varies diurnally by ±5°C this limit will only ensure about 10% survival (that is, less protection) if applied to the daily mean temperature, but will ensure about 80% survival (that is, more protection) if applied to the daily maximum.

Predicting mortality in real streams

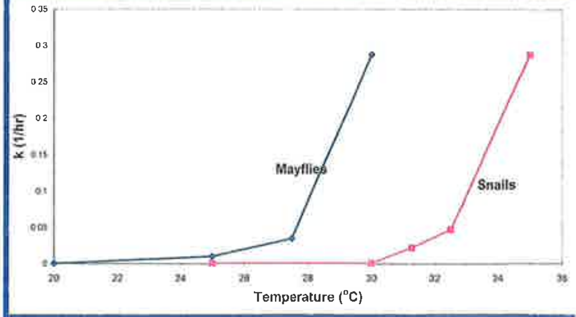
The survival rates found in our experiments were then used to develop a computer-based method which estimates the response of invertebrates to any specified diurnally varying temperature regime given the measured responses to constant temperature. Through this type of analysis we hope to improve our ability to predict the impacts of temperature regimes on stream invertebrates.

In developing our "model", the objective was to set a limit on the daily maximum temperature which will ensure that a certain proportion of the animals survive. The inputs into the model are:

- measurements of survival at a range of constant temperatures; and
- the diurnal temperature pattern to which the invertebrates are exposed.

Also, we assume that when the temperature is constant the number of live test organisms decreases exponentially with time.

Fitting exponential curves to the constant temperature results gave us a "mortality-rate coefficient" at each test temperature. The figure below shows how these coefficients varied with temperature.



above: *Mortality rate coefficients (derived from the survival curves) plotted against temperature.*

We then used our model to predict the numbers of invertebrates expected to survive when exposed to the diurnally varying temperature patterns which we had investigated. Observed and predicted survival are compared in the figure (right).

The model accurately predicted mayfly mortality at 22.5 ± 5°C and snail mortality at 28.8 ± 5°C but often tended to overestimate mortality. We are currently investigating ways to improve the predictions.

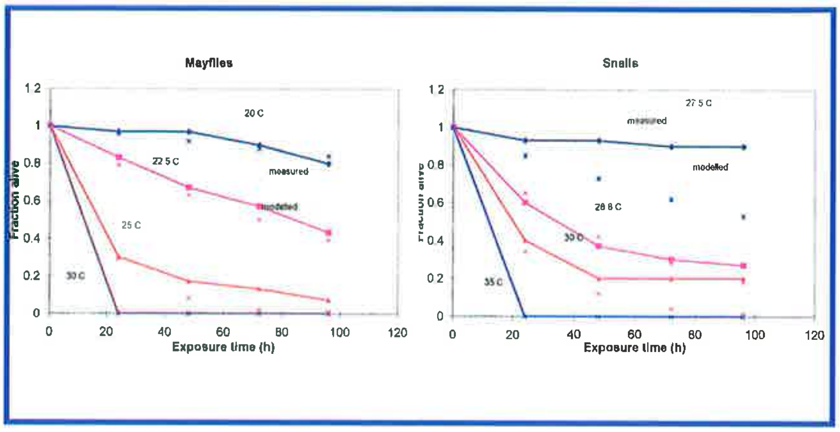
Incorporating "acclimation"

It is well known that some organisms respond to high temperature by altering their physiology thereby increasing their thermal tolerance. This response is termed "acclimation". It is not clear how quickly invertebrates alter their physiology and hence whether the are able to acclimate to diurnally varying temperatures. If acclimation occurs then the past history of temperature exposure will need to be considered when predicting response and our model will need to be more complex.

The current model does, however, provide a useful tool for extending constant temperature results to make more accurate assessments for diurnally varying temperatures. It is clear that temperature limits based on tests at constant temperature do not apply to either the daily mean (insufficient protection) or the daily maximum (unduly stringent) but to temperatures somewhere between these two extremes.

In conjunction with this research, work is currently underway with Hawkes Bay Regional Council to model stream temperatures in the Hawkes Bay. This will enable site-specific predictions to be made about temperature impacts on stream invertebrate populations. ■

Tim Cox is a visiting Fulbright scholar currently based at the University of Waikato and NIWA, Hamilton. Kit Rutherford is with NIWA, Hamilton.



Invertebrate mortality under diurnally-varying temperatures: observed vs. predicted.

Reference

Quinn, J.M., Steele, G.L., Hickey, C.W. and Vickers, M.L. 1994. Upper thermal tolerances of twelve New Zealand stream invertebrate species. *New Zealand Journal of Marine and Freshwater Research* 28: 391-397.

Having trouble with giants and other bullies?

R.M. McDowall

Bob McDowell, New Zealand's foremost expert on native fish, gives some advice on how tell one bully from another.

TO THOSE UNFAMILIAR with them, New Zealand's species of *Gobiomorphus*, commonly known as "bullies", pose real problems with identification. Even those familiar with them have trouble at times. Yet, with some attention to a few details, there is no reason why there should be such problems. Separating Cran's bully (*G. basalis*) from common bullies (*G. cotidianus*) has perhaps caused the most serious difficulties as these species have broadly overlapping distributions throughout the North Island. Difficulties are compounded in the southern North Island where there are also populations of the mostly South Island-distributed upland bully (*G. breviceps*). Giant bullies (*G. gobioides*) add to confusion at low elevations and near the tidal estuaries of rivers. Even redfin bullies (*G. huttoni*) cause problems at times.

One aspect of this problem is that in all species the sexes look different, which can cause confusion – I recall one biologist who could not identify redfin bully females, because they didn't have red fins. But that is the difference between males and females! Sexual differences are slight in giant and common bullies, though typically the male is stouter and has a much blunter snout than the female. The male common bully is darker, sometimes quite black, and may have a bright orange fringe in the first dorsal fin. Differences are more striking in the other species, reaching a maximum in the redfin bully, in which the male has bright orange to crimson banding and patches on the fins and body, which the female lacks.

When discussing these problems recently with a regional council biologist, I suggested that he should explore the detailed differences by looking at some fish with a binocular microscope. To this suggestion he protested "But we do all our identification in the field". I was already well aware of this, and the reason I suggested time with a microscope was that this would help to rapidly develop some familiarity with the distinguishing features of the different species. Such experience becomes enormously valuable in the field, even though there is no microscope available. If you can't distinguish the species properly in the field, then spending more time trying to do so in the field only adds to the confusion. But some time in the lab, where identifications are more certain provides the "launching pad" to develop confidence in the field.

Collect representatives of all species, preferably including both sexes and diverse sizes, and preserve them carefully (plenty of formalin in spacious jars so that they don't get bent or their fins crushed). Set aside time with a good field guide and really come to grips with the diagnostic characters. Spend time comparing and contrasting the species and the sexes, especially of the most similar species. Start with the biggest specimens as the characters on these are clearer. It won't take long. Attention to detail is essential. Note the distinguishing characters, and exploit these when in the field. With a little time, you will develop an almost intuitive sense of the differences – so that even seeing a bully roll over in the water when electric fishing may be enough to give a good idea of identity.

It's harder when specimens are small and/or poorly preserved (and there is nothing worse than working with defrosted frozen specimens). With the sort of growing familiarity I have been talking about, and with a bit of experience and attention to detail, there ought to be few problems. There is never any justification for adopting the procedure said to have been applied by a biologist (fortunately no longer in New Zealand) who just called fish from "downstream" common bullies and those from "upstream" Cran's bullies. No-one knows how he decided where downstream ended and upstream began – in other words his identifications were essentially worthless, and his research results therefore unreliable. Another known error is to call small bullies around estuaries and lowland reaches of rivers common bullies, but big ones giant bullies! The problem, of course, is that giant bullies are small before they grow big, and it is not rare to see large common bullies that are bigger than small giant bullies! In other words, unless a bully is substantially greater than about 150 mm long (really big for a common bully, but far from impossible), size is not a useful criterion. Some seem to think that giant bullies are really just overgrown common bullies, but they are quite distinct species.

So here are some general hints for identification. Recognise that:

- bully species change in shape, general appearance and colour with growth, life stage and sex;
- juveniles tend to lack diagnostic colour patterns, or may be less intensely coloured than adults;
- females are more slender and have more pointed snouts than males;
- males have blunter snouts and tend to have larger, more flamboyant fins;
- the genital papilla in the male is triangular in shape, and tapers to a quite fine point, whereas in the female it is more rhomboidal, tapering, if at all, to a broad tip;
- breeding males are often jet-black, especially when courting or nest guarding, and always tend to be more intensely coloured than females, often with the outer fringe of the first dorsal fin a bright colour – green, yellow, orange, or red.

Distinguishing the species

Given the above, the following characters are useful for distinguishing the species encountered in our waterways:

Bluegill bully
(Gobiomorphus hubbsi)

Identification of adults is straightforward. Look for:

- the bright metallic blue opercular (or gill) membrane immediately behind the head. (This soft, flexible tissue enables the fish to seal its mouth/pharyngeal cavity when breathing.) Once seen this is unmistakable and is true of both sexes. Sometime the colour is dulled to a smoky blue-grey, and may be indistinct, but this is rare, and usually only in small fish;
- distinct, dark olive-grey, angular, leopard-like spots all over head, especially on the cheeks and snout (below and in front of the eyes); belly sometimes a dull, rusty orange colour;
- elongate, slender form with lower jaw distinctly longer than upper, mouth quite small and narrow;
- it is small, seldom growing to more than 65–70 mm, but may be as much as 93 mm long.

Juvenile bluegills cause some identification problems. They enter river mouths from the sea during spring, as small, slender, transparent, almost whitebait-like fish about 20 mm long, sometimes in huge numbers. (Whitebaiters occasionally catch many kilograms of these little fish, and curse them as inedible and a problem to sort from their real whitebait catches.) They tend to have a series of < < < <-shaped bands across the sides, and the protruding lower jaw is fairly obvious. Soon after entering fresh water they become benthic, live amongst river gravels, and develop markings in which the < < < <-shaped bands become more pronounced.

Redfin bully
(Gobiomorphus huttoni)

This species should also cause no problems (but it does):

- don't look for red fins in females because they don't have any; only the males do;
- a complete "give-away" for redfins from a really small size (35 mm or less), is that they have several diagonal stripes that slope forward and downward across the sides of the head. In males these are alternating dark grey-olive and bright orange-red stripes, while in females a light grey-brown substitutes for the orange-red. Very small redfins are a bit more difficult, and probably require retention of some specimens and microscopic examination with access to a field guide. But that applies to virtually all bullies less than about 30–35 mm.

We now enter the territory of the more difficult bully identification problems: it's time to talk a bit about "pores and papillae" on the heads of bullies. In an earlier article (see *Water & Atmosphere* 5(2): 12–13) I talked about these in detail. To summarise, bullies have structures on the head that are an extension of the lateral line system. They consist primarily of rows or patches of small papilla-like structures (or nodules). Sometimes they are exposed on the surface of the skin, or they may be hidden within canals that course over the heads of bullies. The canals open through the surface of the skin as a series of small pores which are always in the same position in any species. All bullies have rows and patches of papillae, but not all species have canals and pores. Bluegill redfin, common and giant bullies, all of which spend their larval and juvenile life stages lives at sea, have canals and pores. But in Cran's upland and Tarndale bullies, and populations of common bullies that are confined to lakes, the canal walls break down (or never form during development). In these species the rows of papillae lie on the surface of the skin as additional rows and patches.

The positions of the pores is of crucial importance. Fish *with a single pore on top of the head* along the dorsal midline and about level with a line through the rear of the eyes, are either bluegills or redfins. But, *if there are two distinctly separate pores at about that position,* then the fish are either giant or common bullies. Be careful not to confuse papillae and pores (as some do) – the pores are distinct holes in the skin that connect with a canal beneath the skin. And don't mistake the particular pores mentioned above for other pores such as those just behind the eyes, or those on top of the head, at or a little forward of the eyes.

There is potential for confusing pores and the fishes' nostrils. Fish have two pairs of nostrils on the snout. One pair is usually obvious as small projecting tubules, usually just above the upper lip. The other pair are simple holes, usually much larger than the laterosensory pores, and typically just in front of the eyes. Again, some time with a magnifier or low power microscope to distinguish these structures pays dividends.

Upland, Cran's and Tarndale bullies have no pores, but they do have prolific rows and patches of papillae. And to really confuse things, populations of common bullies that are confined to lakes, and which therefore do not spend their larval life at sea, for some reason lose the canals and pores and only have rows and patches of papillae. Sometimes this loss of pores and canals in lake populations of common bullies is partial, and the number and distribution of pores can be erratic.

If fish under examination have pores (assuming that any bluegills and redfins have been recognised and removed from the "identification equation"), then the fish are either giant or common bullies. If there are no pores, then they are either uplands, Cran's, or Tarndale bullies – except that they could also be non-migratory lake stocks of common bullies! Giants and common bullies often occur together. If you ever catch a giant bully, you can expect to find a common bully at the same locality, but the reverse is far less often true. Distinguishing these two species isn't always easy – until you know what to look for, and then it is just a bit easier!

Giant bully
(Gobiomorphus gobioides)

- This species always has six spines in the first dorsal fin. These are not hard to count in the field if you have some fine forceps (carry some in the field for such eventualities) and can gently lift the collapsed fin forward and hold it against a good light source (including sunlight). If you think this is near impossible, try it when you have access to a microscope to check the result;
- in my experience giant bullies occur only in localities where they have free access to the sea (I think records from lakes are probably errors);
- the lower jaw of the giant bully is *distinctly longer* than the upper – I've heard them described as "freshwater groper";
- the giant bully has distinctive, "worm-shaped" olive-golden, sort-of-horizontal (as opposed to sort-of-vertical) markings on the cheeks, and *there are several, erratic rows of small, olive-golden spots along the sides* – the best way to describe these is that they are not unlike the rows of dots that you get if you try to push a loosely gripped piece of chalk forwards across a blackboard and it goes d-d-d-d-d-d-d. They are difficult to describe any better, but once you've seen them, they are unmistakable (or at least I think they are);
- female giant bullies have a distinctly concave dorsal head profile, more or less a "dent" in the head, at about the eyes;
- I have never seen a male giant bully with the outer fringe of the first dorsal fin orange, or other bright colour (if it's orange, it is probably a common bully – see below);

Common bully
(Gobiomorphus cotidianus)

- Common bullies often occur where there is no sea access; this is the commonest species in lakes;
- there are usually seven spines in the first dorsal fin, rarely six, and occasionally eight, especially in Lake Ellesmere;
- the lower jaw is only a little longer than the upper;
- often there are three narrow horizontal lines across the cheeks below the eyes, caused mostly by rows of papillae;
- the outer fringe of the dorsal fin in the male can be bright orange – about the colour of a real orange. This is not much help if are looking at a female, but the chances are about 1:1 that you have a male, and sorting out the males is some help. Note that these bright colours disappear rapidly in preservative.

The above are the easier species to identify. Upland, Cran's and Tarndale bullies, and lake populations of common bullies (that lack open head pores) are more troublesome, and it is here that time spent with fish in the laboratory bears fruit.

Tarndale bully
(Gobiomorphus alpinus)

- Distribution is as good a hint as any as this species is known only from several small sub-alpine tarns in high elevation Molesworth Station in Marlborough – that part of Molesworth Station formerly known as Tarndale Station for obvious reasons. These tarns include Bowscale Tarn, a small unnamed tarn upstream of Bowscale Tarn, and Island Lake in headwaters of the Clarence River, and Fish Lake, nearby but in headwaters of the Wairau River. No other bullies are known there, and so identification of any bullies taken from these small lakes can be assured. Nor does the Tarndale bully occur anywhere else. The only other species of bully living nearby is the upland bully;
- detail of morphological features can be obtained from the more technical literature, and it suffices, here, to note that the first dorsal fin of the Tarndale bully has three to seven, but usually only six, first dorsal fin spines;
- and it has scales forward on the head not reaching the level of the eyes on the back, nor forward as far as the gill openings below the head.

The key to identifying the remaining species, and in particular separating them from lake populations of common bullies depends partly on knowing the distribution of scales on the head:

- in common bullies, scales extend forwards on the back of the head to about the level of a line through the back of the eyes – and they project forward mid-dorsally to form a point not unlike a "widow's peak". There is usually an indistinct crease on the back of the head at the anterior margins of the scale coverage. And scale coverage is complete in that the scales are relatively large and overlap each other throughout. Similarly, scales on the ventral surface cover across the entire belly, and extend forwards around the pelvic fin bases to cover the triangle that lies ventrally between, and between the gill covers. Again, these scales are relatively large and overlap each other – there are no spaces between them.
- by contrast, scales in these areas of the body in upland and Cran's bullies are distinctly reduced. Coverage varies both within and between species, but in the mid-dorsal line (back of the head) scales typically reach nowhere near the level of a line through the rear of the eyes, may not even reach the back of the head, and sometimes there may be few scales in front of the first dorsal fin. Scales in this area are typically small, quite separate from each other, and not overlapping, increasingly so nearer the head. Much the same is true on the belly, with often no scales in front of the pelvic fins and sometimes even further back, and belly scales tending to be small, separate, and not overlapping.

These characters should enable separation of lake stocks of common bullies (the ones that lack open pores) from upland and Cran's bullies. At this point I will take refuge in the use of distribution to clarify a few things.

Upland bully
(Gobiomorphus breviceps)

MALE

FEMALE

The upland bully generally causes few identification problems (again except when small, when any bully can be troublesome):

- any bully (other than a lake common bully and Tarndale bully) in the South Island, or Stewart Island that lacks pores is an upland bully. However, knowing this is only "so much" help, as upland bullies also occur intermittently in the southern and western North Island – Wairarapa and as far north in the west as about the Mokau River;
- there is reduced scale coverage on the back of the head and belly;
- it has bold, angular yellow-orange (males) to brownish (females) spots all over the head;
- a really broad vertical creamish-yellow band across the base of the pectoral fins, spotted with yellow-orange (males) to brownish (females) spots;
- first dorsal fin of male has a distinct yellowish-orange stripe across the fringe;
- usually there are only 14–15 rays in the pectoral fins (sometimes 16);
- and usually there are only six spines in the first dorsal (sometimes five or seven).

Cran's bully
(Gobiomorphus basalis)

- This bully is found only – and throughout – the North Island. Note that it does not show overlap with distribution of upland bully from Hawkes Bay across the central North Island to the Waikato, and northwards from there;
- it has reduced scale coverage on the back of the head to dorsal fin and belly, scales often not overlapping (as discussed above);
- there are no angular orange to brownish spots on the head;
- first dorsal fin of male has an orange marginal stripe (a real orange colour, not yellowish), often bright reddish-pink markings in the second dorsal fin and along the lower quarter of the tail, and a "lemon-orange blush" spreading onto fin from the anal fin base;
- usually seven or eight first dorsal spines (rarely six);
- usually 17–18 pectoral fin rays (but may have as few as 15).

A few populations will continue to cause some problems, e.g. those in several Hawkes Bay–Gisborne lakes (Tutira, Tiniroto Lakes, Putere Lakes) the identity of which I am unsure. They could be either common or Cran's bullies, and so far I have not seen live or freshly preserved specimens big enough to work with. Otherwise, I cannot emphasise enough the value of developing some familiarity with well preserved or live fish by using a microscope and a good field guide, or spending time with someone who is thoroughly familiar with the species.

If all else fails, send me some specimens, and I will identify them and return them to you as "voucher specimens" that you can use as a standard for comparisons. It is not always easy, but it is never impossible, with well-preserved or freshly captured specimens.

The key is experience gained from practice. ■

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Recent publications by NIWA staff

The following list includes papers in refereed journals, books and book chapters reported between May and July 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 the interloan system if required.

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