WATER & ATMOSPHERE

February 2017

Shifting sands

The end of a Kiwi dream?

Life's a beach

NIWA scientists' favourite spots

Wave action

Sculpting New Zealand's coasts

Knowledge waves

Young scientists leading the way

Water & Atmosphere

February 2017

Cover: Warrington Beach, Otago. (*Dave Allen*)

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NIWA
Taihoro Nukurangi

enhancing the benefits of
New Zealand's natural resources

In brief

A helikite is deployed from CSIRO's research vessel the *Investigator* to measure temperature, humidity, wind speed, wind direction and atmospheric pressure. (*Tony Bromley*)

Aerosol assessment experiments

New capability has been developed to measure vertical profiles of aerosol and atmospheric properties that will be used for a Deep South National Science Challenge project to understand the relationship between aerosol and clouds in the Southern Ocean. Initial trials took place at Birdlings Flat in Canterbury, followed by the first deployment on a voyage around the Great Barrier Reef on the *Investigator* in November. The work, in conjunction with the University of Canterbury, uses a light-weight aerosol instrument tethered on a helikite (kite/balloon combination).

Carlos Mendonca, Catherine Pot and Isobel Bremner from Onslow College. (*Kent Hogan*)

NIWA Wellington Science Fair

Onslow College Year 13 student Catherine Pot was named the winner of the NIWA Wellington Science and Technology Fair 2016 with her simulation correction technique for the Van der Pauw method in measuring the conductivity of semiconductors. Catherine impressed physicists on the judging panel with her work, winning $1500 and a $4000 scholarship for study at Victoria University. The event, hosted by the Victoria University science faculty, drew 388 entries from 505 students from 40 Wellington region schools.

New Zealand's hottest year

NIWA's Annual Climate Summary, published in early January, confirmed New Zealand recorded its hottest year on record last year, with temperatures being 0.51°C to 1.20°C above the annual average throughout the country. Temperature anomalies were especially high in Northland, Auckland, Bay of Plenty, Hawke's Bay, Whanganui, Manawatu, Kapiti Coast, Wellington, West Coast, Otago and Southland.

No locations had below average temperatures. The first seven months of the year, from January to July, were remarkably warm. The nationwide average temperature for 2016 was 13.4°C (0.8°C above the 1981–2010 annual average). 2016 was the warmest year since 1909, and surpassed New Zealand's previous warmest year on record, 1998.

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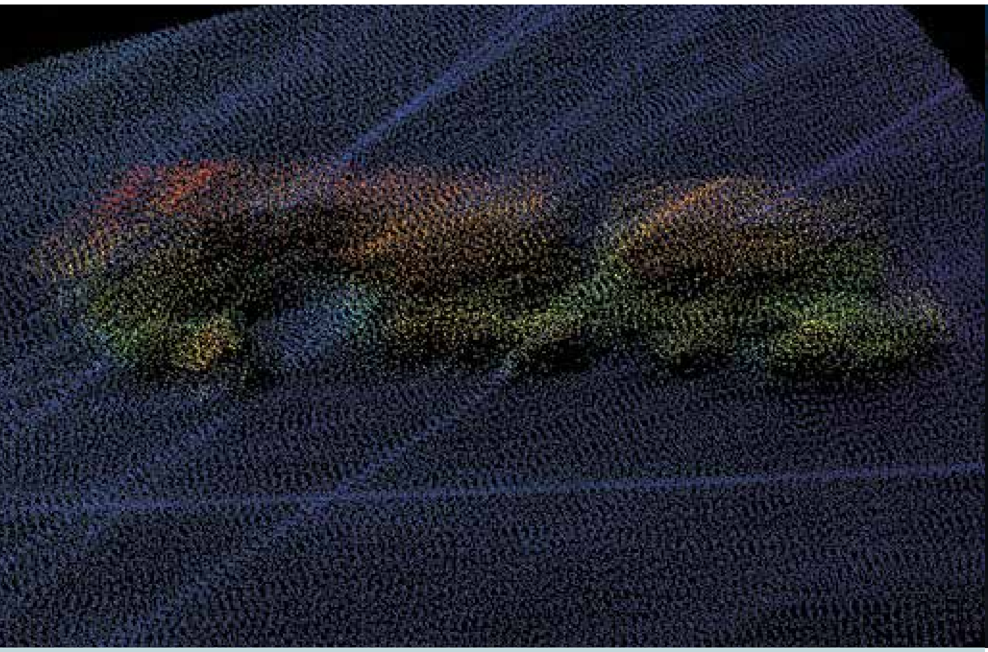


A 3D image showing the truck, lying on its side on the sea floor. (*NIWA*)

NIWA finds overboard truck

NIWA technology and expertise helped Maritime New Zealand find a truck and trailer unit that tumbled overboard from the deck of the BlueBridge ferry *Straitsman* in high winds off the south coast of Wellington last year. Researchers on NIWA's inshore research vessel *Ikatere* used the EM2040 multibeam echosounder to search an area based on the last reported position of the incident. High-density surveying revealed the condition and placement of the unit on the seafloor.

Mitigating coastal acidification

NIWA has been tasked by the Sustainable Seas Innovation Fund to undertake a two-year feasibility study to determine the effectiveness of potential methods for mitigating coastal water acidification around mussel farms. The research will include lab measurements and modelling, and will focus on the potential of controlling pH by returning processed mussel shells to the local environment. The research is aligned with the Ministry of Business, Innovation & Employment CARIM (Coastal Acidification: Rate, Impacts and Management) project, and is also supported by Environment Waikato and Marlborough District Council.

Marlborough Sounds mussel farm. (*Aquaculture NZ*)

Bryozoans. (*Crispin Middleton*)

Bountiful Bryozoans

Identifying bryozoans – also known as moss animals or sea mats – is now easier thanks to a new, fully illustrated electronic identification guide launched by NIWA. *Bountiful Bryozoans* helps people identify this group of marine creatures, which are abundant around New Zealand, but not widely recognised. Divers encounter them on underwater rock faces and they are common under rocks on the lower seashore or on wharf piles. Importantly, vessel owners who do not clean their boat hulls very often may discover they are fouled by bryozoans. In fact, bryozoans are in the top five groups of hull-fouling marine invertebrates. *Bountiful Bryozoans* joins the growing series of e-guides on New Zealand marine invertebrates and seaweeds developed by NIWA – alongside *Awesome Ascidians*, *Extraordinary Echinoderms*, *Splendid Sponges*, *Coastal Crabs*, *Beautiful Browns* (seaweeds) and *Amazing Antarctic Asteroids*.

The changing climate of New Zealand waters

At least 38 fish species in New Zealand waters may face a decline in their food supply as the climate changes, according to a new report by NIWA researchers.

Marine biogeochemist Dr Cliff Law led a team of researchers looking at how climate change will affect the oceans around New Zealand by 2100. The study is part of the Climate Change Impacts and Implications project, funded by the Ministry of Business, Innovation & Employment.

"The study confirmed that for our region the impacts of climate change are just as serious as those predicted for the rest of the ocean," Dr Law said.

"The interesting thing is that New Zealand is in this middle ground between the warmer subtropical waters where marine organisms are moving from, and the Sub-Antarctic waters where everything is a bit cooler and a potential new home for many species."

One part of the study looked at how the supply of particles from the surface ocean to deeper waters would change. These particles support food supply for fish, but the researchers found the flux would decline by up to 24 per cent by 2100. The largest predicted decline was in areas occupied by spiny dogfish, gemfish, frostfish and terakihi, while barracouta, southern blue whiting and blue warehou will be affected to a lesser degree.

"This is the first time we have directly linked the vertical food supply to fish in New Zealand waters, and it's important to show the knock-on effects of climate change in surface water on the fish stocks below," Dr Law said.

The project also looked at which ocean areas around New Zealand were most vulnerable to climate change, and identified the eastern Chatham Rise, the warmer subtropical waters north of New Zealand and the sub-Antarctic waters to the south.

"One issue is the eastern Chatham Rise; it is a very productive area with high biodiversity, including protected species such as cold water corals, and is also where there are extractive industry interests, such as fishing and mining.

"It is important that the effects of climate change on these areas are assessed with the cumulative effects of other pressures such as fishing and mineral extraction," Dr Law said.

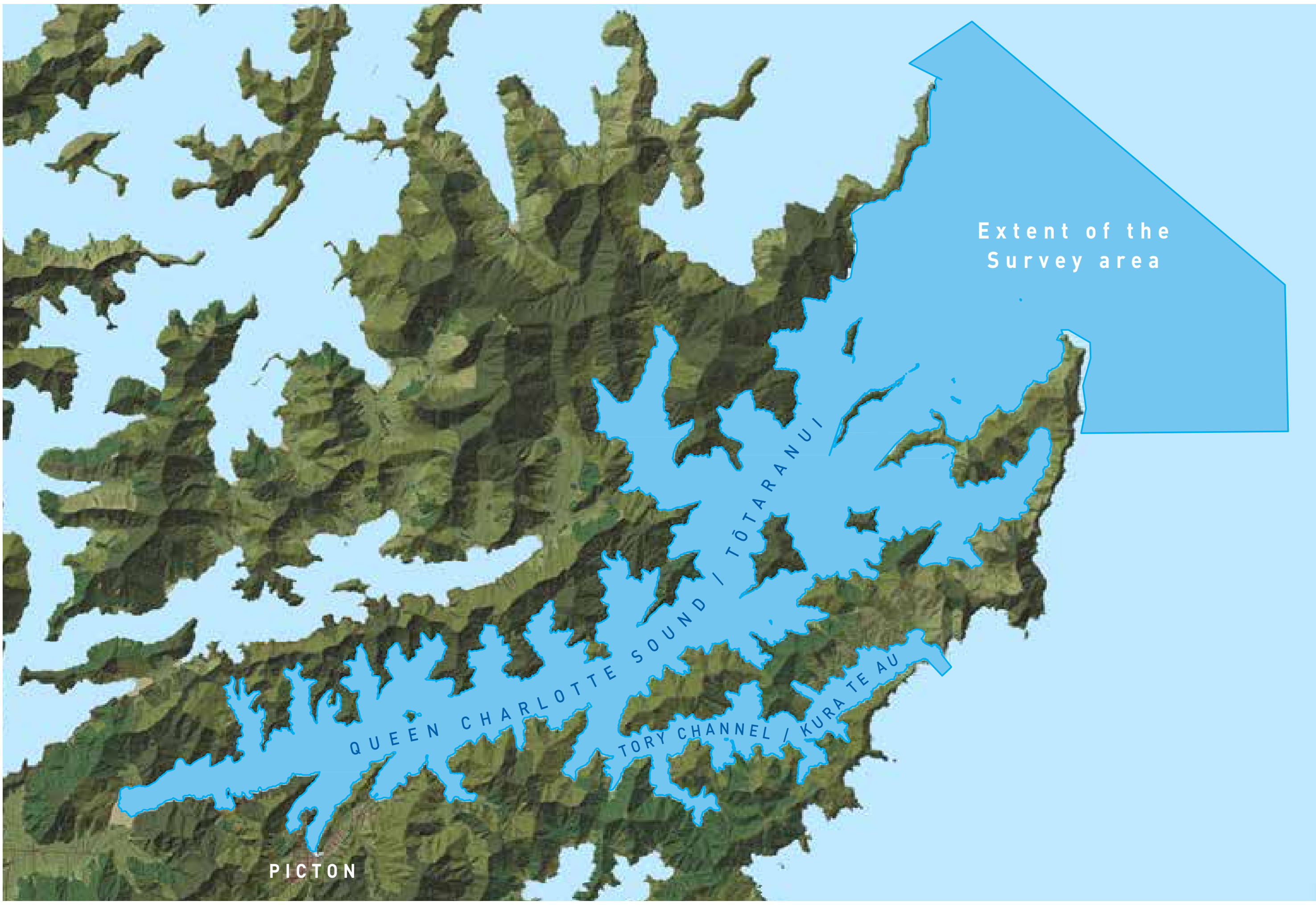
Other projections stemming from the research include:

- An increase in mean sea surface temperature of 2.5°C, and exceeding 3°C in the Tasman Sea.
- A decline in primary production in surface waters by an average of six per cent, with subtropical waters experiencing the largest decline.
- A decline in surface water nutrient concentrations, particularly in the eastern Chatham Rise.
- An increase in acidity, with pH decreasing by 0.33

Dr Law said the project highlighted the need to develop a high resolution model for New Zealand waters to more accurately determine the effects of climate change.

"The open ocean is a large area around New Zealand and at present we don't have models validated for this region. A model for New Zealand waters would enable us to get far more refined estimates on how things might change in the future."

"The study confirmed that for our region the impacts of climate change are just as serious as those predicted for the rest of the ocean," Dr Cliff Law. (*Dave Allen*)



What's underneath the water?

An underwater sonar survey to discover what lies beneath the surface of one of New Zealand's busiest shipping lanes is under way in the Marlborough Sounds.

It's been 70 years since the last survey of the Sounds and new information is needed to update nautical charts to make it safer for the increasing number and variety of vessels using these waterways.

The survey will cover 43,000 hectares or about 20 per cent of New Zealand's coastline – about the same length of the east coast of Continental USA.

NIWA and Discovery Marine Ltd are carrying out the work on behalf of Land Information New Zealand and the Marlborough District Council.

NIWA National Projects Director Dr Helen Neil says relatively little is known about the seabed in this area and its habitats.

"We expect to reveal new features that will provide valuable information on the undersea environment and marine ecosystem. It may also provide new avenues for research, eco-tourism opportunities, and will provide a base for assessing the effects of economic activity," she said.

The survey is being carried out by NIWA's research vessels *Ikatere* and *Rukuwai* using multibeam echosounder technology to detect the shape and depth of the seafloor.

Multibeam echosounders produce a fan of acoustic beams or "sound waves" directly down from the boat. These beams reflect off the seafloor, enabling the surveyors to calculate its depth and scan and map the habitat in detail. Scientists describe the process as "mowing a lawn" – where they proceed up and down scanning strips of the ocean floor, as you would mow a lawn.

Other data collected can determine the roughness of the seafloor and indicate the type of sediment. Data recorded in the water column can be used to determine habitats, identify seeps and plumes, and detect fish schools, kelp beds, cables, geological faultlines and other features. Scientists are also collecting bottom photographs and sediment samples.

The survey began in October and is on track and due to be completed in June.

Following the fieldwork, NIWA and DML will analyse the data which LINZ will then use to update its nautical charts. The data will also be freely available.

The survey data will also give Marlborough District Council a rich snapshot of the extent and distribution of different habitats on the seafloor – including those important for biodiversity.

Panorama: John Morgan

When natural disaster strikes, scientists have a crucial role to play

In the immediate aftermath of the magnitude 7.8 earthquake on 14 November, New Zealand's science community pulled together to provide help, expertise and advice. As well as giving the public some assurance that the scientific authorities were responding to the disaster, understanding what happened will ultimately help the country become stronger and more resilient in the face of these types of challenges.

NIWA scientists had much to offer. When the earthquake struck, our research vessel *Tangaroa* was on a collaborative voyage with GNS Science, looking at the Hikurangi Subduction Margin off the east coast of the North Island – where the Pacific Plate moves under the Australian Plate.

We diverted the ship south to Marlborough and Kaikoura, where our specialised equipment could be of most use in finding out what had happened to the sea floor. The team conducted sediment coring and seabed mapping, and voyage leader, NIWA marine geologist Dr Phil Barnes, and his colleagues, was able to identify which fault had ruptured and the length of the rupture.

The cores that the team collected also showed that the earthquake generated a huge turbidity current – a 300km rapidly moving underwater roll of mud, sand, gravel and water – in the Hikurangi Trough. Further analysis will help us understand the entire fault network activated during the earthquake.

In January NIWA's near-shore research vessel *Ikatere* surveyed the Kaikoura Canyon rim to look for landslides in the canyon and to get a clearer picture of how the offshore faults ruptured. One of the big questions the team will be seeking to answer is whether the canyon, which is capable of generating tsunamis, had been destabilised by the shaking.

NIWA's diverse range of expertise also meant our fisheries researchers were able to help determine the potential impacts on the valuable rock lobster fishery of the coastal uplifts the earthquake caused. And two of our scientists with expertise in tsunami threats were part of a panel advising the Ministry of Civil Defence and Emergency Management, while a third worked with GNS Science offering his expertise on offshore tectonic information in the hectic days after the quake.

As New Zealand's primary marine science experts, it is one of our roles to provide our knowledge and assistance in critical times like this, but it is important to remember that there is a great deal of ongoing research into ensuring New Zealand and New Zealanders are as prepared as possible to cope with significant natural disasters.

The Natural Hazards Research Platform, for instance, was established in 2009 by the Government to ensure a long-term commitment to natural hazard research. It is a collaborative group consisting of NIWA, GNS Science, the universities of Canterbury, Massey and Auckland, and Opus Research, with the aim of directly contributing to improved economic, infrastructural and social resilience to natural hazards in New Zealand.

Resilience to Nature's Challenges – one of the National Science Challenges – has also been set up to develop new scientific solutions to transform our response to and recovery from natural hazards.

And in early 2017 an updated Coastal Hazards Guidance report – largely written by NIWA experts – will be released by the Ministry for the Environment. It is essentially a manual for local government agencies to aid their decision-making when preparing for climate change. It updates a 2008 report with the latest science and legislation and considers the recommendations of the Parliamentary Commissioner for the Environment's 2015 report on sea-level rise – again recommendations that were based largely on NIWA expertise.

Knowledge and preparation are crucial components in building resilience, and there is a comprehensive programme of work being undertaken with this in mind.

As the communities most affected by November's earthquake begin to adjust and re-establish their lives, and we learn more about what our natural environment is capable of, I am proud that NIWA scientists have been able to make such an important contribution.

John Morgan is Chief Executive of NIWA

Marine Ecologist Mark Fenwick walks on 'land' north of Ward that fishing vessels had previously steamed over at high tide. (*Ken McLeod*)

Ikatare surveying near the Papatea fault, post earthquake. (*Dave Allen*)

Scientists set up offices in the great outdoors

Summer is a peak time for NIWA fieldwork. NIWA researchers are heading into the field, some with fancy technology and special clothing to withstand Antarctica's climate, while others head off with coffee cups and party balloons.

Phil Jellyman is jetboating up the Waimakariri River in Canterbury – in search of salmon. The NIWA freshwater fish ecologist is planning to implant acoustic tags on the fish to find out whether irrigation schemes are affecting their migration to spawning grounds up river.

Along the river he will install about 25 receivers that will gather information transmitted from the tags on the salmons' whereabouts.

The Waimakariri is one of New Zealand's top salmon fishing rivers, and at 151km long is one of the largest in North Canterbury. Farmers extract water from the river for most of spring and summer, but recent irrigation schemes are targeting floodwaters for harvesting. However, little is known about how that could affect the movement of salmon.

"We want to know what sized flood is prompting their movements up the river and how their upstream migration to spawning grounds is affected when water is taken from the river."

Salmon typically migrate when the water is dirty after the peak of a flood, probably because the dirtier floodwater gives them more cover, is slightly cooler and taps into some innate instinct they have. So the aim is to find out how much the flow harvesting by irrigation schemes could potentially delay the upstream movements of these fish.

"The upstream movement of salmon is happening at the same time that irrigation intake is at its peak," Dr Jellyman said.

The aim is to tag about 10 fish a month from January on.

NIWA will be partnering with North Canterbury Fish & Game and aims to ensure salmon anglers understand the project is important for the fishery's sustainability.

Dave Allen


Gerry le Roux

When Tony Bromley heads to the hills in January he's taking party balloons and cardboard coffee cups to help with some complex measurements involving power lines along the National Grid.

The NIWA atmospheric technician is aiming "to define the sag".

"Power lines expand with heat, and the more power that goes down the line the hotter they get. When that happens the lines sag in the middle of the span between power pylons. It's essential to know how low the sag could go to ensure the lines aren't going to touch anything."

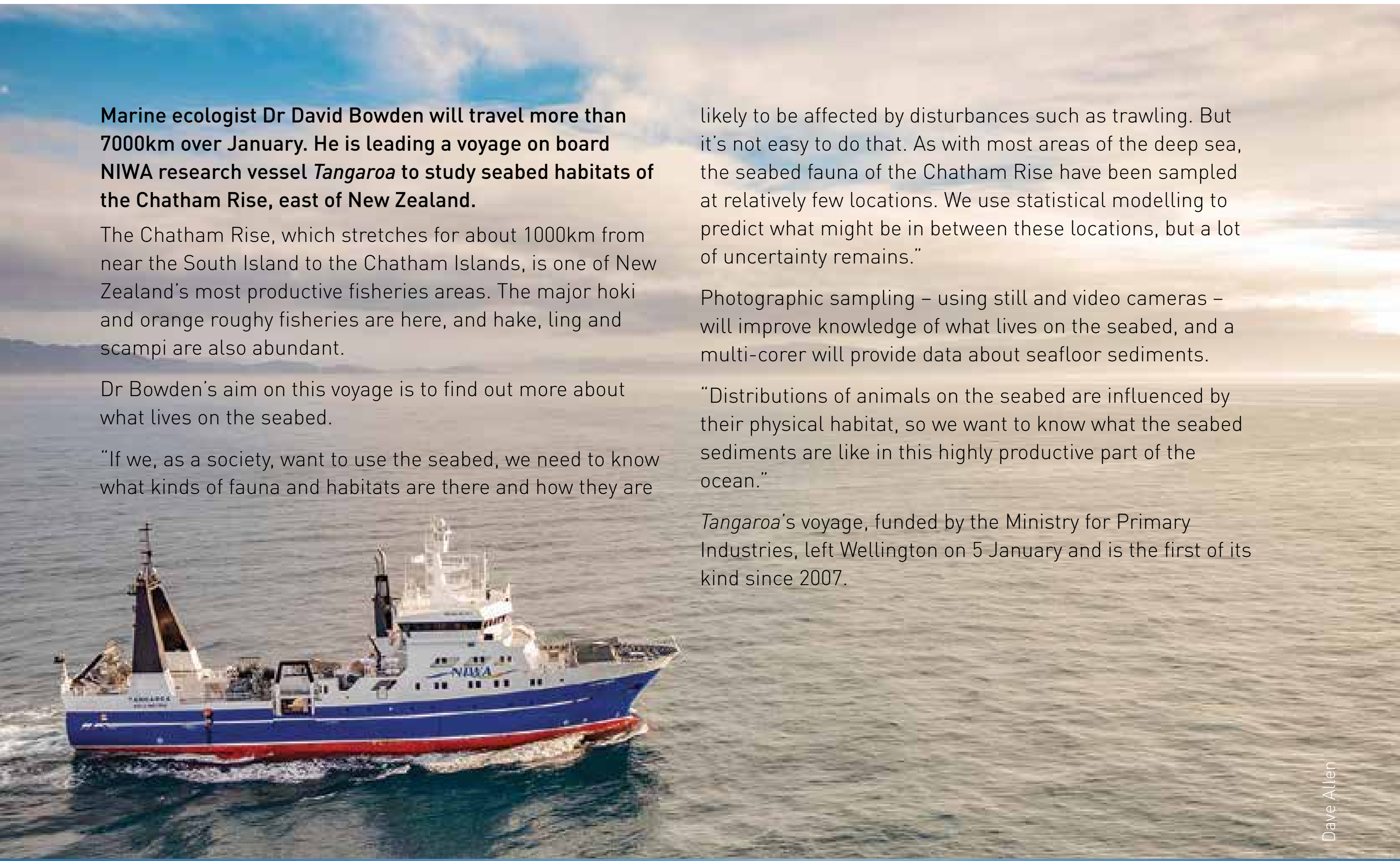
Measuring the potential depth of a sag involves complex calculations involving temperature, wind speed and direction, pressure, humidity and solar radiation measurements many metres off the ground. For instance, the wind has a cooling effect, but the amount of cooling depends on whether it is travelling across or along the lines.

All these measurements are used to work out the minimum distance between the lines and other objects, such as trees. Too close means the risk of outages and other issues. A helicopter will operate at the same time, taking precise distance measurements via laser.

Mr Bromley and his team will cover 1600km of lines over four weeks from Southland to Auckland. They will set up temporary meteorological stations at ground level along the length of the lines and then fill party balloons with helium.

The balloons will be attached to the coffee cups which contain transmitting sensors sending weather information back to the ground. Once a pre-set height has been reached, some clever programming triggers an electric current that burns through the string, releasing the balloon. The coffee cup falls to the ground and the sensors are retrieved and used again.

"The transmitters will only need to ascend to a height of about 100m at most, so we can see where they land. They also transmit a signal giving their actual location on the ground and a small handheld GPS unit can be used to find them – very useful if the transmitter is hidden in long grass. It is a very efficient use of our technology, especially being able to re-use the instruments many times."



Dave Allen

Marine ecologist Dr David Bowden will travel more than 7000km over January. He is leading a voyage on board NIWA research vessel *Tangaroa* to study seabed habitats of the Chatham Rise, east of New Zealand.

The Chatham Rise, which stretches for about 1000km from near the South Island to the Chatham Islands, is one of New Zealand's most productive fisheries areas. The major hoki and orange roughy fisheries are here, and hake, ling and scampi are also abundant.

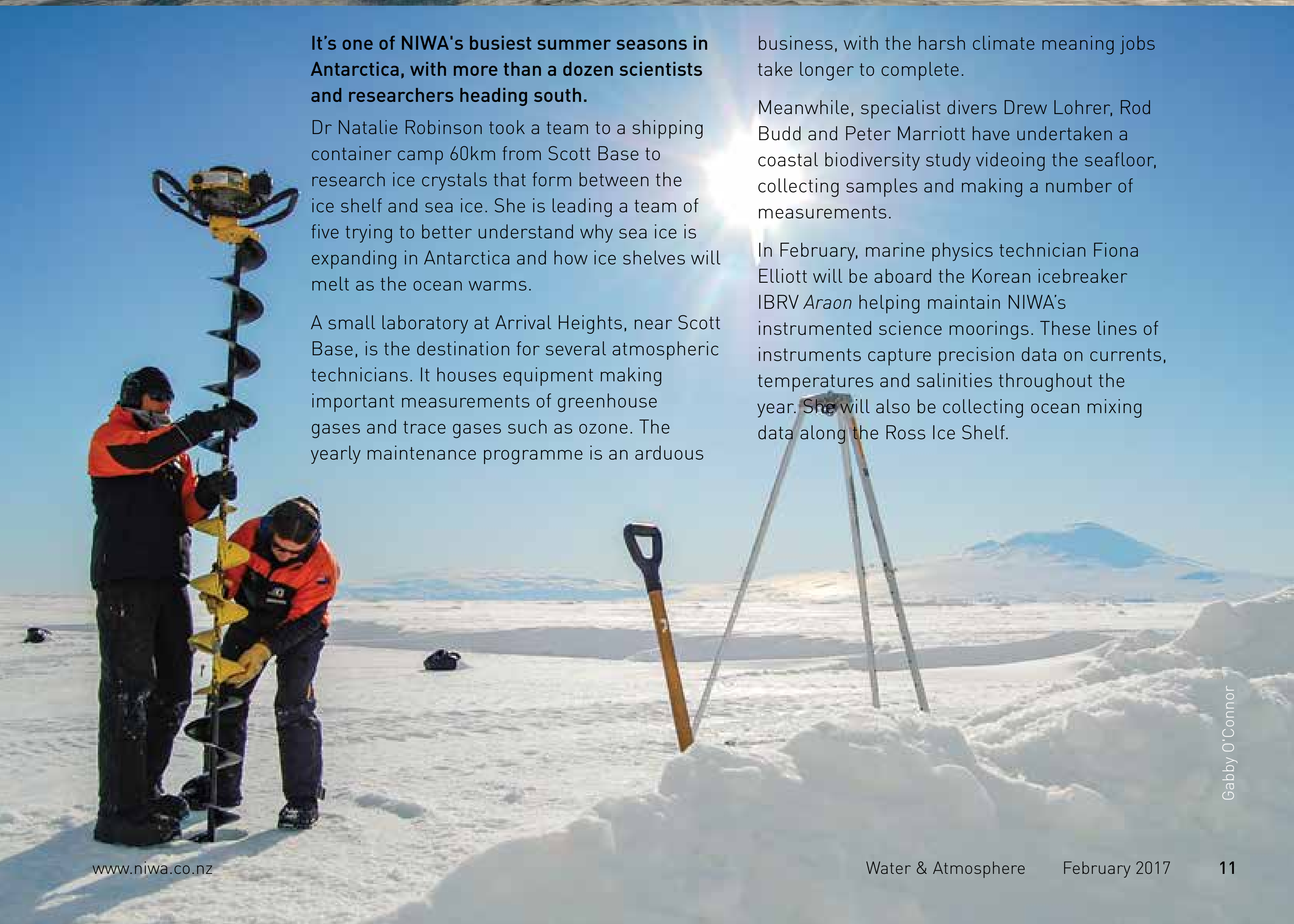
Dr Bowden's aim on this voyage is to find out more about what lives on the seabed.

"If we, as a society, want to use the seabed, we need to know what kinds of fauna and habitats are there and how they are likely to be affected by disturbances such as trawling. But it's not easy to do that. As with most areas of the deep sea, the seabed fauna of the Chatham Rise have been sampled at relatively few locations. We use statistical modelling to predict what might be in between these locations, but a lot of uncertainty remains."

Photographic sampling – using still and video cameras – will improve knowledge of what lives on the seabed, and a multi-corer will provide data about seafloor sediments.

"Distributions of animals on the seabed are influenced by their physical habitat, so we want to know what the seabed sediments are like in this highly productive part of the ocean."

Tangaroa's voyage, funded by the Ministry for Primary Industries, left Wellington on 5 January and is the first of its kind since 2007.


Gabby O'Connor

It's one of NIWA's busiest summer seasons in Antarctica, with more than a dozen scientists and researchers heading south.

Dr Natalie Robinson took a team to a shipping container camp 60km from Scott Base to research ice crystals that form between the ice shelf and sea ice. She is leading a team of five trying to better understand why sea ice is expanding in Antarctica and how ice shelves will melt as the ocean warms.

A small laboratory at Arrival Heights, near Scott Base, is the destination for several atmospheric technicians. It houses equipment making important measurements of greenhouse gases and trace gases such as ozone. The yearly maintenance programme is an arduous business, with the harsh climate meaning jobs take longer to complete.

Meanwhile, specialist divers Drew Lohrer, Rod Budd and Peter Marriott have undertaken a coastal biodiversity study videoing the seafloor, collecting samples and making a number of measurements.

In February, marine physics technician Fiona Elliott will be aboard the Korean icebreaker IBRV *Araon* helping maintain NIWA's instrumented science moorings. These lines of instruments capture precision data on currents, temperatures and salinities throughout the year. She will also be collecting ocean mixing data along the Ross Ice Shelf.

Shifting Sands – the end of a Kiwi dream?

The Kiwi dream of owning a beachfront property with panoramic views of the ocean is under threat – and not just for financial reasons.

iStock

The inflated property market has put the kibosh on many beachside fantasies, but there is another challenge to the realisation of this dream – one that cannot be easily overcome.

Just ask the residents of Granity, Punakaiki, or Carter's Beach on the South Island's West Coast; or Oamaru, Ocean Beach, or Clifton on the East Coast. In fact, from Cape Reinga to Bluff, thousands of properties are affected by this threat and it's only getting worse.

We're talking about coastal erosion – an ever-present threat to our coastlines – and NIWA scientists are working against the clock to help residents and councils alike to manage the risk and save their beachside property.

A community united

NIWA's Dr Murray Hicks, Principal Scientist – River and Coast Geomorphology, and Dr Michael Allis, Coastal Engineer, have been working extensively with communities on the South Island's West Coast affected by coastal erosion.

For more than 20 years the ocean has been bearing down on the Coast's isolated communities, claiming houses, garages, roads, and even a school pool. The issue came to a head in 2016 after several garages in Granity were damaged by large waves washing into people's backyards.

Drs Hicks and Allis attended an emotional public meeting in Ngakawau in late 2016 lasting more than two hours in which ideas were thrashed around and an agreement reached between the residents of the Granity, Ngakawau, and Hector communities to work with the West Coast Regional Council on the best sea erosion protection for their individual circumstances.

"Coastal erosion is a really sensitive issue. When it involves people's homes there is an extra emotional factor. After the Ngakawau meeting a woman came up and showed me photos of her property. The ocean is eating into her property, which is her home and livelihood. She has very limited options. As a researcher and scientist, [finding a solution] certainly keeps you up at night. In this case, I am confident that we have provided the best package of options for this community to combat the risk," says Dr Allis.

"There is a grieving process that communities go through. First it's denial – 'there's no erosion, our property will be fine', then sometimes anger and depression, but eventually there's acceptance – 'okay, let's find a solution that works'. Our role is to partner with councils and communities through this process, providing advice where appropriate. Ultimately, the landowners have to pay for any protection works, so they make the decision; we are just informing them to make the wise decision. These Buller district communities are just some of the places around New Zealand that have large numbers of properties at risk from coastal erosion. We are trying to establish a best practice protocol for community engagement to work alongside them through this process."

Blame the early settlers

Coastal erosion is not new, and it's often cyclical. On a monthly to seasonal basis, sand and gravel is deposited on the coast during relatively benign wave conditions, then is eroded and cast offshore during stormy conditions. Over longer time periods, often spanning centuries, accretion/erosion cycles can occur in response to waxing and waning supplies of sand and gravel brought to the coast by rivers – associated with episodic earthquakes and large floods. Over thousands of years, glacial cycles and associated swings in sea level also force the coastline in and out.

In the case of the West Coast – and many other coastal areas around New Zealand and overseas – a major part of the problem lies in where communities have been established.

"The issue of coastal erosion on the West Coast has become critical recently as there has been a relative deficit of earthquakes and landslides since the development has occurred. Earthquakes and landslides from past centuries had stocked the beaches with sediment, and when the early settlers arrived the coastline appeared stable and they decided to build close to the beach. I completely understand. It was a nice place, I'd love to live there – great views, beach access – but they weren't aware of the long-term cycles and built too close to the coast," says Dr Allis.

Indeed, these early settlers were focused on getting the communities established and business booming, not the environmental risks associated with the area.

The Oamaru District Council has long had to factor in coastal erosion to its plans after the town was settled on a low coastal terrace. Research on the issue dates back decades, with geologist Jeremy Gibb describing the coast as in a "long-term state of retreat" back in 1978. Fast forward 30 years and Waitaki Boys High School lost 60m of its sports ground to erosion in 2008. Planting along the ridge has held back the risk (at least in the short-term), along with the school's prudent decision to move its sports ground further inland.

"People like to live on the edge of water, which is a problem when the coastline is in a recessional phase, which is what we have found ourselves in over the past hundred years or so. Things are not looking as flash [now] in terms of coastal stability as they were when these communities were settled," says Dr Murray Hicks.

"The sensible thing is for communities to retreat from the coast, but most property owners want protection over the next 10–20 years and to buy some time before they are forced to retreat, without having to spend a huge amount of money of course.

In June 2007, the coastal cliffs at Oamaru lost a lot of ground, including a conservation area for blue penguins and the factory seen here. (*Murray Hicks*)

"One solution is sloping seawalls built from rock, but this is cost-prohibitive for most private owners, and regional councils can only undertake works if ratepayer funds are available. The general emphasis is on short-term measures with an integrated approach across the community, rather than have one person building a large seawall 20 metres long, which can have a disastrous effect on neighbours up and down the coast – with the seawall effectively becoming a breakwater and pushing the water around the wall onto neighbouring properties."

In Punakaiki the community is banding together to fund an extension of an existing seawall by 160 m with the assistance of the West Coast Regional Council.

Hydro dams exacerbating erosion

While there is a natural component to coastal erosion, humankind has not helped matters in some locations with advances in technology and our insatiable need for power exacerbating the problem.

"Globally there is a shortage of sand on beaches. In part this is due to rising sea levels, but the effect of dams on rivers on coastal erosion has been significant around the world, and New Zealand has followed a similar pattern," says Dr Hicks.

Over the past four decades Dr Hicks has established a sizable research cache on erosion in New Zealand and has provided expert guidance and assessments to councils and corporations on the impact of hydro dam developments on coasts.

"Rivers bring sand and gravel out to the coast and waves then move this material along the coastline. Dams can reduce coastal sand and gravel delivery in two ways: the first is simply by trapping this sediment behind the dam; the second is by reducing the size of floods downstream from the dams, which reduces the capacity of the river to transport sediment to the coast.

For scientists and researchers the decades-long time lag between dam construction and the arrival of the deficit in sediment load at the coast makes it difficult to provide a definitive cause-effect link with erosion of the adjacent coast. Researchers also have to ascertain how much sediment is stored in rivermouth bars, some of which may be large enough to buffer sediment supplies to the adjacent coast for many years. The initially controversial Clyde Dam on the Clutha River, together with the earlier-built Roxburgh Dam, provided researchers with a valuable case study.

"Back in the 1950s, about 570,000 cubic metres of sand and fine gravel was delivered to the coast by the Clutha River each year. The Roxburgh and Clyde Dams have in tandem reduced this by 95 per cent for the past 60 years. The issue of how this sediment deficit may be responsible for coastal erosion between the Clutha mouth and Otago Peninsula was significant in the re-consenting of the Clutha Hydro Scheme, but there were conflicting arguments as to how much of the Clutha sand naturally nourished the coastline and how much of it was dispersed offshore by waves and currents," says Dr Hicks.

The effects of hydro dams are also being felt further north. Dr Hicks' research in 2002 revealed that rates of coastal erosion north of the Waitaki River mouth increased over the first 40 years after the construction of the Waitaki Dam. This aligned with his estimates that damming the Waitaki River had reduced its delivery of gravel to the coast by 50%. However, more recent surveys show no consistent signal of a dam effect on the Waitaki coast.

"The eastern coastline by Oamaru was eroding quite severely even in a natural state. Naturally there is a strong northward longshore transport of beach gravel along this coast, with the bulk of the wave energy that drives this coming from the south; so Oamaru, to the south of the Waitaki mouth, never received much nourishment from Waitaki gravel," says Dr Hicks.

Eroding our rivers

The long-term effect of commercial gravel extraction from rivers is another area of concern for Dr Hicks and his colleagues.

Across New Zealand there are numerous companies involved in riverbed gravel extraction, with the gravel used for concrete and roading aggregate. As well as providing economic benefits (i.e., with provision of raw materials for infrastructure, employment and business opportunities), gravel extraction often also has the added benefit of enhancing flood protection by removing excess sediment. While this may be seen as a "win-win", as Dr Hicks found, the level of extraction is sometimes excessive.

Back in 2005, Dr Hicks, Dr David Kelly and Dr Alistair McKerchar researched the downstream effects of over-extraction of river gravels using biological and sedimentological data. The trio focused its research on the Kakanui River near Oamaru in Otago and the Waimea River and its tributary the Wairoa River near Nelson in the Tasman District.

"We found gravel harvesting can trigger severe physical and biological changes. Gravel tends to move downstream in pulses during freshes and floods. Gravel harvesting in the Kakanui appeared to have starved downstream reaches of gravel supply, thereby degrading the channel, fining the substrate, and exposing bedrock. Some of these same trends were apparent in the Wairoa River, but to a much lesser degree," says Dr Hicks.

"Over the past 20 years there has been considerable over-extraction in some regions. Rivers around Nelson and in Southland have limited gravel-supply rates and past extraction rates have far exceeded the supply rates. In Southland, lowering of the Oreti River bed has caused concern about bridge pier stability. In Mid to South Canterbury the over-extraction of river gravel has likely contributed to accelerated coastal erosion."

Rivers naturally transport sand and gravel out to the coast, helping replenish beaches; however, dammed rivers reduce this process by trapping sediment and reducing the size of floods. (*Dave Allen*)

Seawall construction on the Kapiti Coast. (*Dave Allen*)

Mining the science of sand extraction

Sand extraction is big business in New Zealand – iron-rich mineral sand (ironsand) is mined for domestic and steel manufacture, and Statistics New Zealand says iron and steel exports contributed more than $471 million to the New Zealand economy in 2015.

Coastal sand is also extracted for construction purposes and to renourish beaches where sand is naturally no longer present (such as Auckland's Mission Bay, which is renourished with sand from Pakiri, and Wellington's Oriental Bay, which is routinely replenished with sand from Golden Bay).

In a 2011 edition of *Water & Atmosphere*, Dr Alan Orpin detailed the approaches made to NIWA by mining companies wanting to know about ironsand reserves along the west coast of the North Island between Whanganui and Kaipara. In the article Dr Orpin stated: "There are some sedimentary bodies that are very rich in ironsands. But, to be economic, it's all about volume. The scale of marine extraction we are talking about is unprecedented."

Among the approaches was one from Trans-Tasman Resources, who commissioned NIWA to provide scientific data for their 2014 application to the Environmental Protection Agency (EPA) for a marine consent to undertake iron ore extraction and processing operations offshore in the South Taranaki Bight. The controversial proposal met with strong community opposition and the EPA ultimately rejected the application on the grounds "(Trans-Tasman Resources) did not consider the wider effect on the environment from digging up 50 million tonnes of sand per year."

"There are certainly considerable public concerns around this project that are understandable. Several NIWA scientists were involved in the 2014 application assessing coastal circulation patterns, drift on the coastlines, and sediment plume movement. In this case there wasn't a clear-cut link between the extraction project and coastal erosion. Trans-Tasman Resources are now trying again for consent and have another Environmental Protection Agency hearing in a few months' time. NIWA staff have again been involved in this process," says Dr Orpin.

RMA: Safeguarding our coasts

Solutions to New Zealand's erosion woes are not straightforward, but steps have been put in place to ensure the issue doesn't worsen through poor planning or building.

Dr Hicks says the Resource Management Act (RMA) 1991 (and subsequent amendments) highlighted the effects of activities on the environment in the medium- and long-term, along with central and local government and iwi policies.

NIWA is integral in the approvals process, with scientists providing technical reports and evidence at hearings and Environment Court fixtures. In the past year alone NIWA scientists have provided myriad assessments and technical reports across all areas of inquiry, including aquaculture, atmosphere, climate, coasts, fisheries, freshwater and estuaries, and natural hazards. In some cases the findings have forced developers and policy makers to pause to reflect the impact of the respective projects' initiatives on the environment and communities.

NIWA's impartiality is crucial to the process says Dr Orpin.

"NIWA scientists are regularly called upon to provide expert information for political and corporate decision makers. As scientists we are not for or against an issue; we are approached to speak to the science of an initiative," he says.

Looking to the future

Our coastlines will continue to evolve and erode over the coming decades. In the face of rising sea levels, New Zealand's coast will remain in a 'recessional stage' for some time, and pressures will persist on our rivers, with both sand and gravel extraction activities and dams permanent fixtures on the landscape.

There will be localised changes – as seen in the recent Kaikoura earthquakes, which dumped a considerable amount of sediment onto the eastern coast – but with rising sea levels and increasing storm ferocity, we cannot count on all our coasts being replenished anytime soon.

It's time for a shift in focus – to look further inland to realise our "Kiwi dream". It may still be possible to have a property with panoramic views of the ocean – just perhaps from up high on a hill.

Life's a beach

Ah, summer – time to hit the beach and soak up the sun, surf and suntan lotion.

Chris Williams

Of course, NIWA scientists are no different – they love heading to the coast for a break. But for many of them, work and play are both a personal and professional occupation.

Water & Atmosphere spoke with eight NIWA scientists to find out where they spend their summer holidays and what it is about those places they find fascinating.

Dr Ken Grange

Regional Manager (Nelson)

Rarawa Beach, Far North

For the past four decades Ken and his family have spent their summers at Rarawa Beach, on the east coast of the Far North. Their family bach is at nearby Houhora Harbour.

What makes Rarawa Beach special to you and your family?

Rarawa Beach has many attractions for a scientist and family person like me. It has pure white quartz sand so clean that it squeaks when you walk on it. The water is very clear and blue and there are always sufficient waves for surfing, bodysurfing, and swimming. At low tide the swimming can be combined with digging up a feed of tuatua. At the northern end of the beach there are outcrops of pillar larva and clear rockpools for kids to explore. If you know where to look behind the sand dunes there are large areas of rocks that used to form an offshore reef that was tossed ashore in a big tsunami, perhaps 5000 years ago.

And from a scientific perspective?

Scientifically, the beach is really interesting. It is very close to North Cape, so regularly receives warm water currents from further north. In storms, subtropical species wash ashore. These can include coconuts and nautilus shells, making the beach a beachcomber's paradise. It is one of the first beaches to receive flotsam from the tropics, its geological history includes both volcanic activity and tsunami inundation, and large numbers and varieties of rare shells wash ashore after storms.

How has the beach changed over the past 40 years?

The beach constantly changes with wave and swell action. The dunes have recently been cordoned off, so the erosion caused by visitors has decreased, allowing the dunes to stabilise. The major difference over the years is the increased number of four-wheel-drive vehicles on the beach.

Northland's Rarawa Beach – pure white quartz sand that is so clean it squeaks when you walk on it. (*Stuart Grange*)

Nava Fedaeff

Climate scientist (Auckland)

Matarangi Beach, Coromandel

Nava has been spending her holidays at Matarangi Beach for 18 years, enjoying the fine, white sand beach and emerald-green water. When the sun's out it's picture-perfect, but Nava thinks it's even more beautiful when shrouded by storm.

What makes Matarangi Beach interesting scientifically?

As Matarangi is a sandspit it's fascinating thinking about how it formed over time due to longshore drift. The channel end of the beach/spit is very mobile, and it is interesting to watch how it changes and shifts from visit to visit. Coming from a coastal and climate background, I particularly love visiting the beach after a big storm event to observe what kind of impact the weather has had. When walking down the beach it is very obvious the point at which there is a sudden disappearance of beach front houses. This is due to coastal setback zones which were imposed on new developments. Seeing policy like this in action is a good reminder of how far our understanding of coastal systems has come and that we now recognise how prone they are to change.

What changes have you noticed in the 18 years you've been going there?

You only need to visit Google Earth and look at historical photographs of the sand spit to see how frequently the sand at the tip of the spit shifts around. It's a great example of coastal processes at play. In more recent years, there has been quite a bit of erosion at the end of the beach extending to the dunes. As a result, many pine trees around the edge of the golf course have been lost. Once again, though, this is a natural process and no doubt the beach will build out again in the near future.

Matarangi Beach, Coromandel. (*Nic Andrew*)

Rakiura, Stewart Island. (*Graham Fenwick*)

Dr Graham Fenwick

Assistant Regional Manager (Christchurch)

Rakiura/Stewart Island

Most people wouldn't think of Stewart Island as a summer getaway destination, but Graham and his family have been holidaying at Rakiura for the past decade.

What draws you to Rakiura?

We continue to find new places to explore and enjoy revisiting favourite places. Maori Beach is one of those special places; so quiet, usually calm, always something new to find on the beach. Mason Bay is another, especially down on the ocean beach itself or in the white dunes among the golden pingao at sunset. Magical. The natural history (beach, coastline, bush, birds), local community, landscape, wilderness experience close-at-hand, the maritime history – it all combines to make it special.

As a scientist, what makes Rakiura unique?

The island gives a sense of living in the Roaring Forties – truly oceanic, exposed to some severe weather, yet tranquil much of the time. The weather can change abruptly and frequently. The huge diversity of coastal situations means that there are always different marine habitats, animals and algae to see and learn about.

The island may still be isolated, but have you noticed changes to the area?

We've seen the usual changes associated with a township: bush cleared here and there, new sections and houses, tidying of road margins, beautifying the township. Most changes are modest and sympathetic to the island's National Park status. Some do stand out, however, such as the introduction of willows to stabilise a couple of steep banks. Some coastal cliffs have retreated, threatening a few properties and roads, but these seemed predictable. Marine farming is expanding beyond Big Glory Bay and I expect that'll change people's perceptions.

Dr Emily Lane

Hydrodynamics scientist (Christchurch)

Charleston, West Coast

For Emily, a trip to the beach involves spending as much time below ground as it does on the beach. The keen caver has found the perfect combination on the West Coast, at Charleston with its two beaches, Constant Bay and the open ocean beach at the mouth of the Nile (Waitakere) River.

How long have you been holidaying there?

Eight years. The Canterbury caving club has a caving meet there every Queen's Birthday, and we started going along after returning to New Zealand from the United States. We are now part of a group who have established a caving base just outside Charleston, up toward Paparoa National Park. An integral part of any trip to Charleston is a bonfire on the beach at the mouth of the Nile River.

What draws you there?

The West Coast beaches are so dynamic, and a bit intimidating – definitely not for swimming. There is this amazing huge gneiss boulder that is perfect for climbing up on and has been sculpted by the waves with little pockets for children to sit in. The Nile River flows calmly out past it – deep, rich, tannin-filled, brown. It's slightly mysterious, but so inviting. At the northern end of the beach is a tiny island with a little bridge across to it. In the spring you need to watch out for the oystercatchers' eggs nestled among the rocks – the adult oystercatchers are usually squawking loudly and pretending to have a broken wing to attract you away from the nest. There are also some incredible limestone caves in the Paparoa National Park behind Charleston that are filled with fossils of shells, crabs and even the occasional whale.

How has the power of nature changed the beach?

After a big storm in 2015 the Nile River changed its course across the beach to sweep closer to the boulder. It washed away a lot of the sand under the boulder and revealed a natural arch. Over the past year the sand has slowly filled it up again – with a bit of digging the smaller kids were still able to make it under, but not the adults.

Charleston, West Coast. (*Emily Lane*)

Whale Bay, nestled between Woolleys Bay and Matapouri Bay on the Tutukaka coast, Northland. (*Sarah Fraser*)

Bruce Hartill

Fisheries scientist (Auckland)

Woolleys Bay and Matapouri, Whangarei District

As a keen recreational fisherman and a fisheries scientist, it's the lure of the line that has drawn Bruce and his family to Woolleys Bay and Matapouri, north of Tutukaka, for the past 15 summers.

What do you enjoy about Woolleys and Matapouri?

They are great all-round beaches with good surf to play in and nice coarse sand. The fishing off the rocks can be pretty worthwhile too. Because I work on recreational fisheries, I always take an interest in the local fishing, regardless of whether it is off the rocks or from a boat. When you look out from any vantage point you will usually see a small number of people fishing, and it might not seem like much is going on. When we do aerial surveys along this stretch of coast and in other areas, you quickly realise that those individual fishers soon add up, so we need to know about their catch, as well as that taken by the fishing industry.

How's the fishing been over the years?

The fishing is fairly seasonal and the foreshore at Woolleys can vary substantially from visit to visit, depending on when the most recent storm was.

Ruakaka Beach, Northland. (*Sarah Fraser*)

Serena Wilkens

Marine biologist (Wellington)

Ruakaka Beach, Northland

Serena grew up in Northland, so she's spent many holidays playing on the beautiful white sand beaches and in the surf.

Nothing beats childhood memories of the beach. What makes Ruakaka Beach special for you?

My early childhood love of the ocean (and later career as a marine biologist) probably originated here. This beach was always a great place to visit. The warm surf was great fun to play in and the white sand always yielded washed-up treasures which we collected as children, like shells and driftwood. Occasionally we would see dolphins and orca and have to dodge the odd paddle crab in the shallows.

Standing on the shore you look out to the Hen and Chickens Islands and Sail Rock Island and to the north, the majestic Mount Manaia and Bream Head.

How has it changed since you first holidayed there?

The once sleepy seaside Ruakaka village has more recently become quite an exclusive coastal subdivision. Many residents live there permanently, but many others now own very exclusive beach houses tucked behind the white sand dunes. This area has now become one of the fastest growing areas in Northland.

Dr Rob Bell

Principal Scientist (Hamilton)

Ohiwa Beach, Bay of Plenty

Landlocked Hamilton might seem a strange place for a coastal scientist to call home, but holidays are another matter – Ohiwa Beach is where Rob and his wife enjoy getting away to. "Initially with our family we camped on the other side of the harbour at Ohope for 10 years, but we switched sides to Ohiwa Beach 7 years ago."

Why the change?

Ohiwa provides an uncrowded, sandy beach to swim or bodysurf, to watch the moods of Whakaari (White Island) from our tent site, or kayak on Ohiwa Harbour, where godwits, terns, pied oystercatchers and dotterel nest. Also, there's a decent climb up to the adjoining 103m bluff to the pa site, offering sweeping views of eastern Bay of Plenty.

What do you enjoy about it professionally?

Ohiwa settlement has had a chequered history, having originally set up on the sand spit as a thriving coastal port and hotel in the late 1800s. But it has experienced a few cycles of dramatic erosion, including houses falling into the sea in the mid-1970s, followed by incredible accretion episodes. For example, the present beach is some 200m seaward of where the eroded shoreline was. Observing king tides and storm damage to the coastal dunes is part of the holiday experience – not work – for me.

What changes have you seen over the years?

The beach has been rather stable for some time, with established pingao and spinifex plants. However, there are increasing signs of beach erosion since the king tides of early February 2015, and more so following ex-tropical Cyclone Victor in January last year. Maybe the next erosional phase is just around the corner. Over the same period there has been substantial change to the inner sandspit in the harbour, with a new harbour channel cutting through the spit. This is good, in some ways, as the roosting seabirds now have an "island" largely to themselves.

Ohiwa Beach, Bay of Plenty. (*Rob Bell*)

Allans Beach, Otago Peninsula. (*Sadie Mills*)

Sadie Mills

Marine biology technician (Wellington)

Allans Beach, Otago Peninsula

Wild and beautiful, Allans Beach has been a favourite getaway for Sadie and her family for 20 years.

What do you love about Allans Beach?

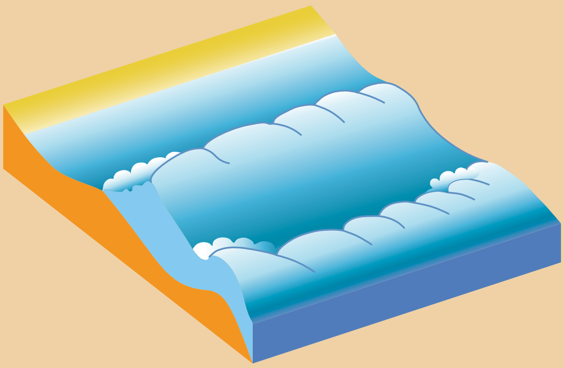
Although it's just 25 minutes from Dunedin, some days you're the only person on it. The beach is home to yellow-eyed penguins and sea lions, as are many of the beaches around the Otago Peninsula. The beach also has the entrance to Hoopers Inlet at one end of it, which has a whole lot of other estuary-associated flora and fauna, making it a pretty diverse area.

What changes have you noticed in the time you've been going there?

At the very end of the beach is a channel leading into Hoopers Inlet. Changes over time to the channel occasionally cause the entrance to become blocked up, creating a whole lot of different conditions in the inlet as it becomes isolated from the sea. There are also changes to the sand dunes behind the beach, which can be very steep some years as they are eroded away.

New Zealand has 13 different beach types, classified under three different categories: wave-dominated, tide-dominated and tide-modified.

For more information and to classify a beach you are interested in, see **niwa.co.nz/beach-types**



Wave action

New Zealand's coast is sculpted by ocean waves. Some wave conditions bring joy to surfers and beachgoers, but, at other times, waves can cause major hazards at sea or along the shore. Veronika Meduna explores some of NIWA's research into wave action and forecasting.

Dave Allen

New Zealand lies amid formidable ocean forces. The furious winds of the Southern Ocean can whip up some of the world's biggest waves, while storms travelling across from the tropics churn the sea. Waves carry energy across long distances and can cause many hazards, including dangers to shipping, land erosion and coastal flooding. To help coastal communities and local authorities to deal with such risks, NIWA has developed wave forecasting models that predict the size and direction of waves several days ahead.

The waves we see arriving at the coast were produced by the wind, often a long distance away, says Dr Richard Gorman, a keen sailor and wave modeller at NIWA in Hamilton.

Wave generation is essentially physics at work, he says. "As the wind blows across the sea, it transfers some of the energy to the water surface. The longer it blows and the stronger it is, the larger the waves."

Stormy conditions generate a mess of steep waves of different sizes, all happening at the same time and resulting in what oceanographers call wind sea. Bigger waves travel faster than smaller ones, and the biggest will move ahead of the weather system that has generated them and eventually outrun it. As they propagate further away from their wind-driven source, sometimes across hundreds of kilometres, they settle into a particular height and period and arrive at the beach as a regularly-spaced, energetic swell – the best waves for surfing. However, when storm systems track closer to the coast, wave action can become a serious hazard.

Unlike weather forecasters, who have data from meteorological stations that have been in place for a century or more, wave forecasters have to work with much shorter records of observations collected from buoys and satellites. Mathematics helps to fill the gaps and models have been developed to hindcast – or simulate conditions back in time – in order to better forecast the waves.

Dr Gorman says the NIWA wave forecasting tool combines global weather models with wave models to make large-scale predictions about waves that can start their journey on the other side of the Pacific and travel across the ocean to reach New Zealand's coastline.

The global models are divided into grid cells 17km apart, but are then scaled down to a smaller grid of 2km spacing to make regional predictions that look at what is happening closer to the coast. At an even smaller scale, other models simulate how particular wave patterns affect specific stretches of the coast, from sandy beaches to mudflats and estuaries.

Real-time wave observations

Like any other computer models, wave forecast models are verified and constantly refined through the input of real observations. These come from altimetry data from satellites and wave measurements from several buoys around New Zealand's coastline. The buoys collect wave height data constantly and beam it back via radio signals or cell phones to a central network at NIWA.

Data from three buoys – off Banks Peninsula, at Baring Head near Wellington and at the eastern end of Tory Channel – are also made directly available to regional councils and port companies.

The wave forecast models are based on the physics that describe the energy transfer from wind to water and how that energy travels across the ocean, says Dr Scott Stephens, a coastal scientist at NIWA.

"They are driven by weather models because you need to be forecasting the weather systems that create the waves in the first place. But once you've got weather and wave models set up, you then need to check that the forecasts are actually giving the correct results. The things you can adjust include the amount of wave dissipation, the wave energy that's lost as they travel, and wave buoys are used to verify that."

The model simulations have identified different "wave climates" along the coast, he says.

The south and west coasts of both islands get the highest energy waves, driven by the predominant westerly flows. The energy grading is highest in the southern South Island and lessens further north.

On the northeast coast of New Zealand, from North Cape to East Cape, the landmass provides shelter from the Southern Ocean, and waves are driven by weather systems in the Tasman Sea and ex-tropical cyclones. "Generally waves are smaller there, but occasionally you can get big waves in cyclone conditions."

And on the coast from Gisborne to Otago, waves usually arrive from the south and east. Although Cook Strait can experience wave conditions that are choppy enough to cancel ferry crossings, it is sheltered from large ocean swells and is more affected by local winds.

Predicting rip hazards

The energy of a wave is controlled by its height and its length. Its speed is governed by its wavelength in the open ocean, but in shallow water it is determined by the depth of the water column. The shallower the water the slower the wave can travel – which is why waves break on the beach.

"When a wave gets close to the coast, the front of the wave slows down and the back catches up to it," says Dr Stephens. "The wave steepens, peaks up, eventually the back catches up with the front and the wave breaks."

When waves hit the beach or shoreline, the interaction is complex. As waves begin to release their energy, they stir up sand in the water column. Once they break, their momentum drives a current, pushing water up on the beach or against the coastline.

As the water flows back, it can create rip channels. "All that water that's been pushed up on the beach has to go somewhere and it tends to find the path of least resistance to flow back offshore."

The returning flows scour out the seabed, creating deeper channels of fast-flowing currents that can carry swimmers far offshore. The two most important factors in predicting rip currents are the size of the waves and any pre-existing channels.

"Although wave energy is the number one control over the possibility of rips, if you are trying to forecast whether there will be rips today, it's more likely if there were rips yesterday. When you've had large waves for some time, and when there's already a channel at the beach, it is more likely that rips will occur," Dr Stephens says.

With the help of wave height forecasts, NIWA has created a rip current index, which provides a six-day forecast for rip hazards.

Keeping an eye on the beach

A stretch of beach constantly adjusts to wave conditions. Small waves tend to push sand onshore and build up the beach, while big waves strip sand away from the beach face and move it offshore. Without sand dunes or a wide buffer of sand, large waves can run over coastal defences and erode or flood the land.

Beach width is one measure of beach health, says Dr Michael Allis, a coastal engineer at NIWA in Hamilton.

"When the beach is healthy and wide, it means there's a reservoir of sand which can move offshore when the large storm waves arrive. The sand doesn't disappear, it moves slowly offshore and forms another bar. This means that the waves aren't going to reach quite as far inland and there'll be less damage. After the storm passes, the smaller waves help to push sand back onto the beach again."

To monitor what goes on, NIWA has set up Cam-Era, a network of computer-controlled cameras that collect a series of images every 30 minutes from some of the country's most pristine and energetic beaches, including Ngarunui Beach at Raglan and Tairua Beach on the Coromandel Peninsula.

Data from wave buoys located near Banks Peninsula, Wellington and Tory Channel are made available to regional councils and port companies. (*Mike Brewer*)

"By taking a lot of images of the coastline we can build an understanding of the natural beach conditions, and the changes to the beach in response to waves and tidal conditions. We measure beach width – defined as the distance between the dune crest and the high tide line – from a 10-minute series of 600 images that are averaged," Dr Allis says.

Every pixel is averaged across all images and "you no longer see the individual waves arriving at the beach, but what you do see is where the shoreline was, on average through that 10-minute window. Using the offshore tidal and wave conditions to give the water elevation, you can then work out how wide the beach was for that time period".

The Cam-Era system has been in place for almost two decades and it contributes to many research projects, including the prediction of rip currents and observations of how beach formations change over time.

This vast amount of data is an invaluable tool for building or advancing models to predict future beach hazards and what the shoreline might do under different wave conditions in the future.

"We calibrate shoreline models based on the past record of beach measurements and wave conditions, and use these to improve our predictions of the future beach conditions," Dr Allis says.

"We can better understand how the beach responds if we get a larger storm, a swing in wave direction, or with a rising sea level, and identify that we would expect a change to the amount of storm-cut beach erosion."

Managing mud in estuaries

Wave action also contributes to the reshaping and degradation of many estuaries around New Zealand's coast.

NIWA coastal scientist Andrew Swales has studied estuaries from Northland to Southland, with a focus on tracking how changes in land use and subsequent increases in soil erosion are affecting estuarine environments.

Using sediment cores to investigate rates of sedimentation in the past, "we've seen an order of magnitude increase in sediment accumulation rates during the European era", he says.

"Typically, in New Zealand estuaries prior to human arrival, you'd have rates of less than 1mm per annum. Now, in northern estuaries, we see a range of 3mm to 5mm per annum, and in lots of places it can be tens of millimetres per annum".

Increased sedimentation has led to a degradation of estuarine ecology. "It's a double whammy. Increased soil erosion means we're losing the productivity of the land, so it's an economic loss, and we're filling estuaries and smothering benthic fauna and reducing light. There are large-scale impacts on estuaries, changing from subtidal to intertidal, from sand to mud, to high turbidity and high sedimentation rates and losses of sensitive keystone species, such as seagrass."

In northern estuaries, soil erosion and wave action have also helped the spread of mangrove forests. Mr Swales' research has shown that mangroves are opportunists, moving into areas where increased sedimentation, coming in from catchments as plumes of silt, has been redistributed by tidal currents and wave resuspension onto intertidal flats. "That's what mangroves need to colonise. They grow above the mean sea level, halfway between the low and high tide."

Whether or not mangroves succeed in colonising a new area depends partly on the work of waves, he says. "Wave-driven erosion of the seabed controls the success of seedling recruitment in bigger estuaries. Waves exert an import control – for example, in the southern Firth of Thames, 700 hectares of mangrove forests have developed since the 1960s through probably four or five successful recruitment events, which have depended on climate and wind conditions that drive wave propagation."

Predicting tidal currents

Of all the different ocean movements, tides are the most predictable. NIWA has developed a tidal model that covers New Zealand's Exclusive Economic Zone and is being refined continually to include changes in sea level and climate.

The model is used to predict red alert tide days – days that coastal hazard managers should put in their diaries and make sure they keep an eye on the weather and the sea. Red alert days mark king tides, which peak one or two days after a new or full moon when the moon is closest to the Earth. But dates for the highest tides vary around New Zealand, and their potential to cause coastal hazards depends on local weather and wave conditions. If such king tides collide with low-pressure weather systems, high waves and now also rising sea levels, they are likely to play havoc.

"It doesn't take much to tip low-lying parts of the coast over", says Dr Rob Bell, a coastal oceanographer also known as the "Duke of Hazard".

"It only takes 30 to 40 centimetres of sea-level rise for a one-in-100-year event to become an annual affair. It's an unfolding story of increasing frequency of such events."

Field data from tidal and sea-level gauges and ocean-height satellite measurements are used to calibrate the tide model which is now also incorporating observations of climate variation. "The tide is the first base. With rising sea levels, everything else rides on the back of that, exacerbating all coastal hazards," Dr Bell says.

A king tide reaches Auckland's Northwestern Motorway. (*Justin Watene*)

Knowledge waves

The Joint Graduate School in Coastal and Marine Science, co-managed by NIWA and the University of Auckland, is equipping and energising young scientists from New Zealand and around the world for outstanding careers in oceanic research. Our vast and varied marine estate is the ultimate beneficiary.

It's dirty work, but someone's gotta do it – fellow student Richard Bulmer helps Jenny Hillman collect sediment cores at Mahurangi Harbour. (*Carolyn Lundquist*)

Jenny Hillman fell in love with the ocean at the tender age of three. Although British-born, she spent much of her childhood in the developing nations of northern and eastern Africa, where her father worked as an ecologist.

"I was the original 'water baby'," she laughs. "I remember a feeling of absolute freedom whenever I ventured into the water. By the time I was about seven I'd go out diving or snorkelling with my dad. I'd be captivated for hours. It made me very happy."

It proved an unparalleled learning experience too.

"I saw, first hand, how critically important the ocean is to the survival of people in those fragile nations," she says. "I was introduced at an early age to the challenge of sustainability ... to problems like overfishing, and I saw how science can make a genuine difference.

"I think, from that time, my future course was set."

Fast-forward to 2013. Armed with a degree in zoology, a master's degree in marine biology and several years' experience working in the developing world, Jenny was looking to broaden her horizons still further.

"I'd wanted to get into research for a long time, so I looked at the internet for options ... and I found Carolyn [Lundquist].

"Our interests aligned perfectly, and the Joint Graduate School offered very compelling possibilities for pursuing my PhD."

Instilling excellence

Since 2011, the Joint Graduate School in Coastal and Marine Science has offered postgraduate degrees in a range of coastal and marine topics (see sidebar). It aims to instil excellence in the research practices of high-achieving young scientists from New Zealand and around the world.

Dr Carolyn Lundquist is one of six NIWA staff filling adjunct positions at the school. She works alongside more than 40 staff from the university to identify research opportunities, teach and mentor students and draw out their natural leadership potential. A further 11 NIWA staff give their time to supervise and assess the work of students.

"The school provides a world-class postgraduate experience for highly committed and capable students like Jenny," Dr Lindquist says. "It gives them vitally important early career contact with leading scientists in their fields of study."

NIWA and the University of Auckland have collaborated on marine research projects over many years, and the organisations' capabilities and resources are complementary, "so joining forces to create the school made perfect sense", she says. "Together we offer an experience that's greater than the sum of our parts."

Future focus

The school plays a key role in improving the understanding, management and protection of New Zealand's precious marine environments.

Dr Rochelle Constantine, the school's director, recognises that New Zealand's national identity is intricately linked to its coasts and oceans. She says increased competition and pressure on resources have placed a premium on improving scientific understanding of coastal and ocean systems.

The school contributes by ensuring the continuity of a workforce that is skilled and experienced in fields of research directly relevant to those systems.

Consistently valuable

Jenny Hillman is now just a few months shy of completing her PhD. Her chosen field of research is complex by her own admission.

She's investigating the intricate connections between different habitats in the Mahurangi Harbour, north of Auckland, to understand how they affect the ecosystem's overall ability to provide what scientists and environmental managers call "services" – benefits to the human population that may range from food supplies and recreational opportunities, to the regulation of natural hazards.

"I'm exploring the many natural processes, such as sediment and nutrient movement, which connect the different habitats in the harbour – for example, a sand flat and a mangrove forest," she explains.

"It's important that we understand these processes clearly, so the ecosystem can be effectively protected and its services sustainably managed."

Jenny says working under the supervision of Dr Lindquist (with co-supervision by Auckland University Professor Simon Thrush) and alongside other subject experts from NIWA and the university has been outstanding. "I've learnt so much since I've been here," she says. "It's been inspiring to work with New Zealand's amazing scientists, in what is a wonderfully complete and integrated system."

Jenny's achievements at the school were recognised in 2015, when she was awarded the inaugural – and prestigious – George Mason Charitable Trust travel scholarship. The scholarship financed an exchange to the University of California, Davis, to aid her New Zealand research.

"The exchange provided me with new field techniques that I've since applied in my experiments here," she says. "It also led to a collaboration and consultations that have proven vital to progressing my work."

All-in-all, Jenny says the experiences afforded by the school have been consistently valuable; experiences she hopes to carry into extended research in New Zealand and, ultimately, back to where her "heart really belongs" – the developing world.

Brenton Twist in his office at NIWA's Greta Point campus in Wellington. (*Dave Allen*)

Brenton Twist

By the time Brenton Twist had started secondary school, he'd set his sights firmly on a career in marine science. Now, thanks to a Ministry of Primary Industry-funded Joint Graduate School scholarship, the Greymouth native is carrying out world-first research alongside internationally renowned marine biologists in some of New Zealand's most spectacular coastal locations.

Brenton is investigating the diversity, distribution and ecology of coralline algae in the southern South Island. These red-hued calcifying marine algae play a critical role in the ecology of temperate reefs, and may influence the distribution of some shellfish species.

Coralline algae are vulnerable to ocean acidification – a by-product of warming seas associated with climate change – so Brenton's work is providing valuable insight into anthropogenic influences on marine ecosystems.

Using a range of genetic species identification techniques, Brenton is gathering data that will eventually be published in a definitive guide to coralline algae in the southern region. His work follows similar research undertaken in northern and central New Zealand.

He will also undertake several ecological studies to determine the relationship between coralline algae taxa and benthic organisms in southern New Zealand's shallow subtidal reefs.

Researching for his PhD under the auspices of the Joint Graduate School has led Brenton to share knowledge and ideas with New Zealand's most respected marine scientists, including NIWA's Prof. Wendy Nelson, Auckland University's Dr Nick Shears, Otago University's Dr Chris Hepburn, members of Te Rūnanga o Ngāi Tahu State of the Takiwā monitoring team, and collaborators in the CARIM (Coastal Acidification: Rate, Impacts and Management) project.

To date, fieldwork and sample-gathering have taken Brenton to the spectacular and vulnerable coastlines of North Otago, the Catlins, Southland and Fiordland.

"This is definitely where I want to be," he says. "The scholarship has given me a jump start on what I hope will be a long research career in New Zealand."

Craig Norrie

In their first vulnerable days of life, mussel larvae are often transported en masse by ocean currents, settling far from where they were spawned.

A challenge for scientists studying mature mussel populations, particularly those that are struggling, is to know where the mussels came from and what happened in the spawning environment that led to reductions in the number of larvae successfully colonising the seafloor habitats.

Joint Graduate School PhD student Craig Norrie is applying a technique called trace elemental fingerprinting to the challenge. He's working under the supervision of NIWA marine ecologist Dr Carolyn Lundquist and Auckland University's Dr Brendon Dunphy to identify the spawning locations of mature mussel beds in Auckland's Hauraki Gulf.

"During their first 24 to 48 hours of life, mussel larvae begin to form shells," Craig explains. "The developing shells absorb chemical traces from the water around them.

"Since every water mass has a slightly different chemical 'fingerprint', we can look at the traces in the shell to determine where larvae were during those early hours of their life."

The technique involves firing a small laser beam at the mussel shell to create a reaction that enables individual chemical ingredients to be extracted and identified.

Although Craig is in just the first year of his PhD, he anticipates his research will provide information for restoration and management of mussel beds in the Hauraki Gulf, including understanding the sources of mussel larvae, and whether larvae from mussel aquaculture are contributing to the seeding of relict and restored populations in the gulf.

"Carrying out this research through the Joint Graduate School and within the supportive NIWA research environment has been really helpful," Craig says. "It's opened up opportunities for research I hope I can continue long after I've completed my PhD."

Mussel beds in the Hauraki Gulf are the focus of Craig Norrie's research.

Rebecca McPherson on board RV *Tangaroa* near the east coast of the South Island.

Rebecca McPherson

New Zealand's extraordinary natural beauty, reputation for research excellence and proximity to Antarctica prompted Scotland-born PhD student Rebecca McPherson to investigate study opportunities offered by the Joint Graduate School – and she's very glad she did.

While hoped-for research openings in Antarctica weren't available at the time, an enquiry to NIWA's Associate Prof. Craig Stevens, an adjunct staff member of the school, revealed a unique opportunity to study the mixing behaviour of freshwater plumes entering the salty water of Doubtful Sound in Fiordland.

"It sounded like the ideal opportunity to apply my background in mathematics and fluid dynamics to a 'real-world' situation," Rebecca says. "I didn't hesitate."

Doubtful Sound receives freshwater inputs from often very intense rainfall, and on a scheduled basis from the tailrace of the nearby Manapouri Power Station. The location represents what Rebecca calls "an ideal natural laboratory" in which controlled freshwater inputs can be studied closely.

"I'm looking at the way the freshwater stratifies, mixes, dilutes and dissipates when it enters the sound. We've installed moorings with equipment that can measure turbulence and changes in water properties at the millimetre scale."

Rebecca says the resulting data and analysis could be used to inform computer models that predict what happens to pollutants carried by streams and rivers when they meet the sea – an issue of "extreme importance" to New Zealanders.

By about mid-2017, Rebecca will have completed her PhD and will be looking for new openings – perhaps in post-doctoral study or further applied research.

What's certain, she says, is that the opportunities provided by the Joint Graduate School for collaborating and brainstorming with world-class scientists, across multiple disciplines, have given her research career an extremely valuable and enjoyable foundation.

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Awash with opportunity

The Joint Graduate School in Coastal and Marine Science offers master's and PhD research opportunities in:

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Sustaining the sea

We examine how the Sustainable Seas National Science Challenge plans to enhance the use of marine resources within biological constraints.

New Zealand derives significant value from the marine environment, and yet our use of it is threatening its future.

A report from the Ministry for the Environment in October 2016 found that most of New Zealand's native marine birds and many mammals were threatened with, or at risk of, extinction.

A report by Statistics New Zealand in the same month showed the marine economy contributed 1.9 per cent, or $4 billion, to the nation's GDP.

Vicky Robertson, Secretary for the Environment, points to human activity as a primary reason that marine habitats are in a fragile state.

"Fishing bycatch, introduced predators, and habitat change are among a raft of reasons for the poor state of much marine wildlife."

In this context, the mission of the Sustainable Seas Challenge is not only apposite, but urgent. The Challenge contract was set by the Government over a year ago, and secured by a consortium of science organisations led by NIWA.

Challenge Director Dr Julie Hall is charged with bringing science and society together to develop better tools for managing our marine resources, to allow for many uses without losing ecosystem functions and benefits.

She says the initial work of the Challenge identified that the best way to meet the objective is to pursue what is known as ecosystem-based management (EBM).

"Ecosystem-based management tries to account for and balance all the factors operating in an ecosystem," Dr Hall says.

"Being armed with knowledge of how an ecosystem functions and responds to change, and what that system does for us, means that people can make better-informed decisions about what we do and the effect human activities will have on it."

Dr Hall says the focus on EBM reflects the international consensus of science and policy makers.

"There's a congruence of thought in policy and science circles that our use of environments must account for the multiple stressors affecting an ecosystem.

Sustainable Seas Director Dr Julie Hall. (*Dave Allen*)

"That's what policy wants, and it is exactly what science is looking at.

"Once we have an accurate model of what the ecosystem does, society can decide how to use that ecosystem with full knowledge of the effect of our actions – and how to maximise uses without jeopardising its future productivity."

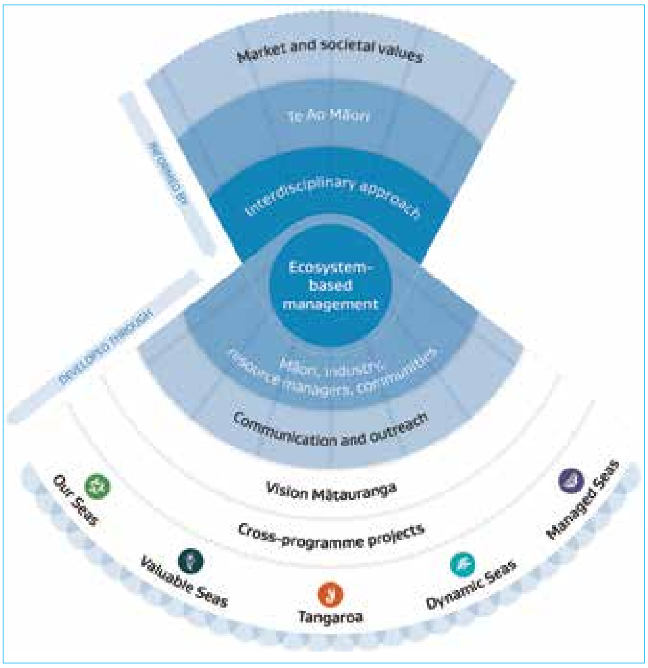
Dr Hall says that nailing the system will be an international first.

"There's plenty of people looking at this around the world, but no one has put a fully integrated system into practice yet. So if we crack EBM, there'll be a lot of international interest."

Five streams

The Challenge has five streams of work, which knit together to provide data and knowledge to develop EBM (see diagram).

Dynamic Seas includes all the projects investigating how marine ecosystems work, and **Managed Seas** is developing participation tools to make use of ecosystem models to manage the ecosystems themselves.



The diagram outlines the key components of the Challenge and how we will approach the research.

Ecosystem modeller Vidette McGregor. (*Dave Allen*)

The "people" side of the project is reflected in the other programmes. **Our Seas** and **Tangaroa** research examines how people are involved with, and value, the sea.

Valuable Seas is building a framework to manage the economic, cultural and social values of the sea to New Zealanders. This includes identifying the range of services the marine environment provides to people, and the economic and non-monetary values of these.

The result will be knowledge of the intricate operation of ecosystems, so people can understand the impact of their use; a framework for managing the different forms of value people place on the sea; and a framework for bringing people together to make decisions about using the ecosystem.

"The Challenge will provide New Zealanders with the tools, framework, information and data to enable EBM to happen," Dr Hall says.

Case in point

The Challenge has chosen an area across the middle of New Zealand to focus the first efforts at setting up ecosystem models.

Phase One will focus on the marine ecosystem in the Tasman-Golden Bay area by 2019. Phase Two will model two other areas, not yet chosen, by 2024.

Vidette McGregor, an ecosystem modeller at NIWA, is tasked with the job of running the "end to end" model for the Tasman-Golden Bay area.

Her Greta Point office has the hallmarks of statistics-heavy work. A whiteboard is cluttered with calculations. Multiple side-by-side computer screens display screeds of spreadsheet data.

Ms McGregor's computers use algorithms that represent the life cycles and predator-prey interactions of fish and shellfish species in Golden Bay, and contain data on factors such as ocean currents, nutrient levels, suspended sediments, and sunlight.

They are built into the internationally-proven Atlantis template originated by Beth Fulton at Australia's CSIRO.

Ms McGregor is testing the model, trying to perfect how accurately it represents what we already know the well-researched Bay looks like under the waves.

The simulation can represent half a million separate interactions of all the monitored factors. It takes a day to run a simulation that tracks 50 species, across 10 age cohorts, seeing how they evolve at 12-hour intervals over 100 years.

The model was used to show what had happened to cause the disappearance of scallops from the Tasman and Golden Bay area over the past decade. Simulations accurately predicted the population decline due to increasing levels of suspended sediments from land use run off.

"The principle works – we can model an ecosystem. We are then confident it can predict the outcome of certain changes in that ecosystem."

"When the model produces the same results we see in the wild, it can be used to explore scenarios. For example, what happens across the ecosystem if we increase the quota on a species? What happens to the ecosystem if sediment run off from land use is reduced?"

The model has had some early exposure to the public. It was introduced to a small local community to pilot the extent to which people could understand and use the initial model.

Ms McGregor says that even with advances in computing power, the sheer volume of interactions makes it impossible to generate quick simulations of various scenarios.

"For now, we'll simulate options in advance for communities to consider. We're quite some way from trying out ideas and seeing what happens while you wait."

Good services

The marine environment does a lot more for us than many people realise. These "services" include obvious ones like food, less obvious ones like oxygen and climate, and also less tangible things such as our cultural relationship with the coast.

Dr Judi Hewitt, a NIWA Principal Scientist in Marine Ecology, is leading Valuable Seas, which will quantify the services provided by marine ecosystems.

"Marine ecosystems underlie our values and the quality of our lives.

"A good EBM system will not only weigh the relative values of what we need from the ecosystem, it will take into account the relative cost to people of losing or gaining things that are important to them about the ecosystem.

"We'll start by counting the services and calculating their value to people, economically, socially and environmentally.

Dr Hewitt says the work is "thorny".

"People value our seas differently. We need to discuss these differences to understand the personal value systems people have. This analysis will help us to establish the core and common values."

She says one way the project is testing the values is to examine a handful of specific services and activities that people conduct with the sea. The research will look at whether, and how, ecosystem degradation has changed the perceived value of the services.

Dr Hewitt's colleague, Dr Drew Lohrer, is running workshops with New Zealanders to look at all the possible services, and evaluate their worth.

Jim Sinner, a senior scientist in Policy and Planning at the Cawthron Institute, is running the project merging scientific, social and economic values.

The Blue Economy workstream is just as thorny. Dr Hewitt says that while the economic outputs are well understood, the relative values between economic users of the sea is less clear.

"For example, quotas are obviously an economic limit on fishing, but they also affect others who provide services to fishing, or make money off side-effects of the practice. At the same time, quotas could provide economic opportunities for new innovative ways of making use of that species," she says.

Valuable Seas is tasked with finding those opportunities within sustainable limits. The Challenge has an innovation fund of $1.5 million per year for research projects that identify methods that increase diversification and add value to the marine economy. It is currently examining proposals.

Evolution of a species

Dr Hall says the project is the start of a long-term transition to using EBM to manage human interaction with the marine environment.

She points to cross-programme projects that will help disseminate and integrate knowledge into current practice.

"The Government is determined that none of the science output is left on a shelf – it must be made use of.

"We're looking at how EBM can be worked into policy, how legislation can be modified to reflect EBM principles and practice, and we'll be trialling EBM in the field."

She says there are many routes for the Challenge's findings to integrate with current practice.

"For example, the fisheries legislation is under review right now. It's at these sorts of times that policymakers will have opportunities to incorporate EBM principles."

Dr Hall says there is no single output from the Challenge, and no moment of truth when the EBM system kicks in.

"We won't switch suddenly from the current practices into EBM – it will be an evolution. Lessons learned from Sustainable Seas will be gradually built into existing systems.

"Over time, we will step closer and closer to management based on understanding of the marine ecosystem, and on full community discussion about what we need and value.

"In 10 to 15 years' time EBM could cover the whole of New Zealand."

Muddy sinks

New Zealand's mangrove swamps and coastal marshes may be particularly adept at absorbing and storing the carbon we emit.

One of the newest fields of climate change studies is into what is being called "Blue Carbon". This refers to the carbon captured in the marine environment, mainly by wetland vegetation (mangroves, salt marshes and seagrasses). Coastal wetland vegetation is found on every continent except Antarctica, covering the equivalent of 49 million hectares – an area about the size of Spain.

Their capacity for absorbing carbon is many times more than that of other ecosystems. Coastal vegetated habitats occupy just two per cent of the world's seabed area, but are estimated to account for approximately 50 per cent of the carbon transfer to ocean sediments. The rate of carbon sequestration is estimated at up to 100 times faster in coastal vegetation than in terrestrial forests. Carbon sequestered by coastal vegetation can be stored for millennia if undisturbed.

This is good news for New Zealand, which is among the top 10 nations for longest coastlines. And it highlights a potential positive role for our often derided mangrove swamps, as well as from coastal marsh habitats which have historically been lost or degraded due to coastal development.

The only mangrove species found in New Zealand is *Avicennia marina*. It covers over 26,000ha of our coastal land – equivalent in size to Wellington. It is also expanding its cover by four per cent a year. Mangroves are found only in northern New Zealand, from Northland to the Bay of Plenty.

One of the most intriguing aspects of coastal carbon sinks is that as much as two-thirds of the carbon is stored not in the plants but in the soil. For example, New Zealand's *Avicennia marina* mangrove swamps are estimated to store a total of about 120 tonnes of carbon per hectare in above- and below-ground biomass and soil to a depth of 100cm. Below-ground biomass and sediment contribute about 88 per cent of that total.

Very little is known about the particular carbon sequestration role of New Zealand mangroves compared to other New Zealand estuarine environments. That's why NIWA is undertaking a pilot study for a regional council comparing carbon sequestration across a number of estuarine habitats.

The study, headed by Dr Carolyn Lundquist, a Hamilton-based NIWA Principal Scientist in Marine Ecology, is

Mangroves. (*Alastair Jamieson*)

New mangrove plants establish themselves in the muddy fringe of Whangamata Harbour. Expanding their cover by 4 per cent a year, mangroves, *Avicennia marina*, now cover over 26,000 ha of New Zealand's coastal land. (*Dave Allen*)

monitoring the carbon (and nitrogen) stored in sediments in a suite of estuarine habitats. This is also complemented by NIWA strategic science funding research examining the "flux" (the release and absorption) of carbon from these zones using novel chambers on the seabed to capture and measure the carbon released from the sediment.

While the carbon-packing power of coastal environments could be a significant component in New Zealand's carbon sink, Dr Lundquist says it's too early to translate the results to a national scale.

"We have to know a lot more about variation between types of habitats.

"Initial results signal that saltmarsh and mangrove swamps store more carbon than other estuarine environments," Dr Lundquist says.

"Total carbon storage is 5–10 times higher in saltmarsh habitats, and 2–3 times higher in mangrove forests, compared to mudflat habitats.

"While a lot has been made of seagrass carbon storage in global Blue Carbon research, the trial study suggests it is surprisingly similar to mudflat and sandflat habitats in New Zealand."

So, is restoring coastal marshes a possible solution to help combat climate change?

NIWA Principal Scientist in Marine Ecology Dr Carolyn Lundquist. (*NIWA*)

Dr Lundquist says more information is needed about carbon sequestration rates and storage across multiple habitats within estuaries.

"Blue carbon has the potential to contribute to New Zealand's climate budget, but, as yet, our information is limited on the contribution of New Zealand coastal vegetation relative to global estimates."

Many other countries are now more intensively studying Blue Carbon, and some programmes are examining restoration and sustainable use of coastal ecosystems as part of a climate change response (see www.TheBlueCarbonInitiative.org).

NIWA plans further study to see if these patterns are consistent across multiple estuaries and for additional estuarine habitats and habitat quality. Dr Lundquist is particularly keen to discover whether there are differences between the age, size and density of mangrove forest, and between different species of coastal marsh plants, because introduced species such as *Spartina* and saltwater *Paspalum* have invaded native marshes in some regions.

Dr Lundquist has a proposal pending to study multiple estuarine habitats, looking at how different restoration/management strategies change the resulting carbon storage and other ecosystem services provided by coastal vegetation. One of Dr Lundquist's PhD students at the University of Auckland, Richard Bulmer, has examined carbon and nutrient cycling in New Zealand mangroves in his thesis research, primarily comparing intact and cleared mangrove sites.

"Coastal ecosystems contain a range of habitat types. Better understanding of the roles of all of these habitats, whether mangrove, coastal marsh, seagrass or mudflats, will help determine the role of these habitats in New Zealand's response to climate change," says Dr Lundquist.

Acid flux

Just as we're discovering the carbon sink power of coastal environments, we're also discovering their sensitivity to human impact and ocean acidification (see *Water & Atmosphere*, November 2015).

Globally, estuarine habitats have been harmed by direct and indirect consequences of aquaculture, agriculture, terrestrial and marine pollution and destruction by industrial and urban coastal development. There are some local examples, but no national data on habitat loss. For example, land development appears to have escalated silting in Whangamata Harbour over the past few decades, associated with an increase in mangroves and a decline in seagrasses.

Dr Lundquist says the impact of acidification on mangroves and seagrasses is also far from clear.

"Increasing carbon dioxide (CO_2) is expected to increase productivity through accelerated rates of photosynthesis, as for most plants.

"In overseas research, one species of mangrove, *Rhizophora mangle*, responded well to the doubling of CO_2 concentrations. It increased biomass, branching, leaf area, and maturation and reproduction, though these changes were also associated with decreases in plant nutritional quality.

"Environmental factors such as temperature, salinity and humidity are likely to have larger impacts than CO_2. So it is possible that there will be little or no change in mangrove production.

"In tropical regions with mangrove forests composed of many different species, community composition is likely to change due to species-specific responses to other factors associated with climate change."

There are also global concerns for mangroves about responses such as advances in the time of flowering due to rising atmospheric CO_2, which increases the potential for desynchronisation with key pollinators. While little is known about mangrove pollination, this potential effect of climate change is being explored in terrestrial forests in New Zealand.

The acidification story for seagrasses is similarly mixed.

"Seagrasses tend to be carbon limited, and no one has yet observed changes in seagrass distribution or productivity due to increased CO_2 concentrations or due to the reduction in seawater pH," Dr Lundquist says.

"Although seagrasses respond well to increased CO_2 enrichment, with increases in photosynthesis and growth, long-term exposure experiments are not conclusive.

"The reduction in pH projected this century is suggested to be unlikely to limit photosynthesis or counteract the effects of increasing CO_2 on seagrass growth."

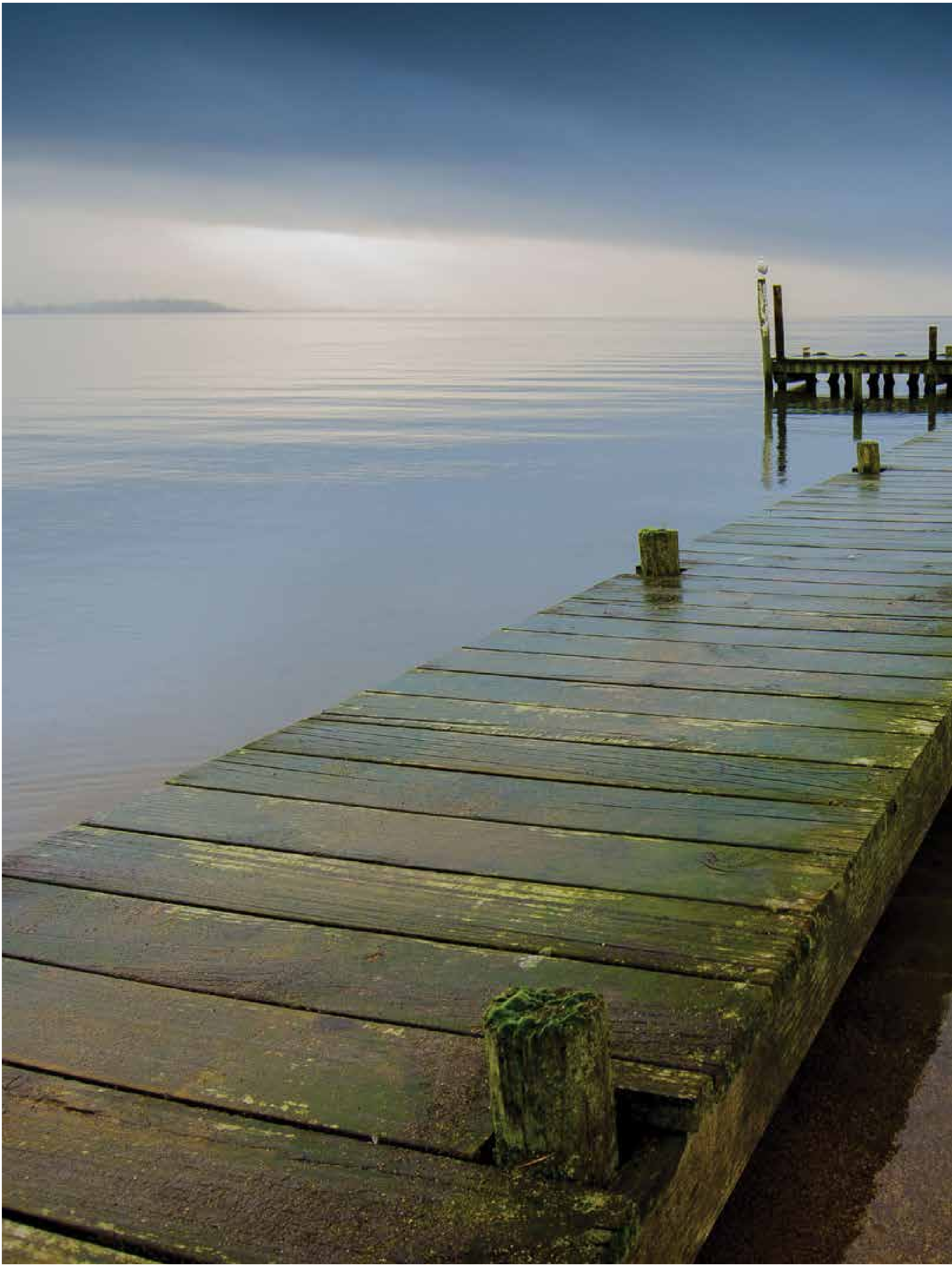
She points to field observations near volcanic seeps in Papua New Guinea, where pH varies from 8.1 to 7.8 – comparable to the reduction expected over this century.

"Seagrass communities in the areas with lower pH and higher CO_2 concentrations had three to four times the shoot densities and below ground biomass, but reduced species diversity compared to areas with higher pH.

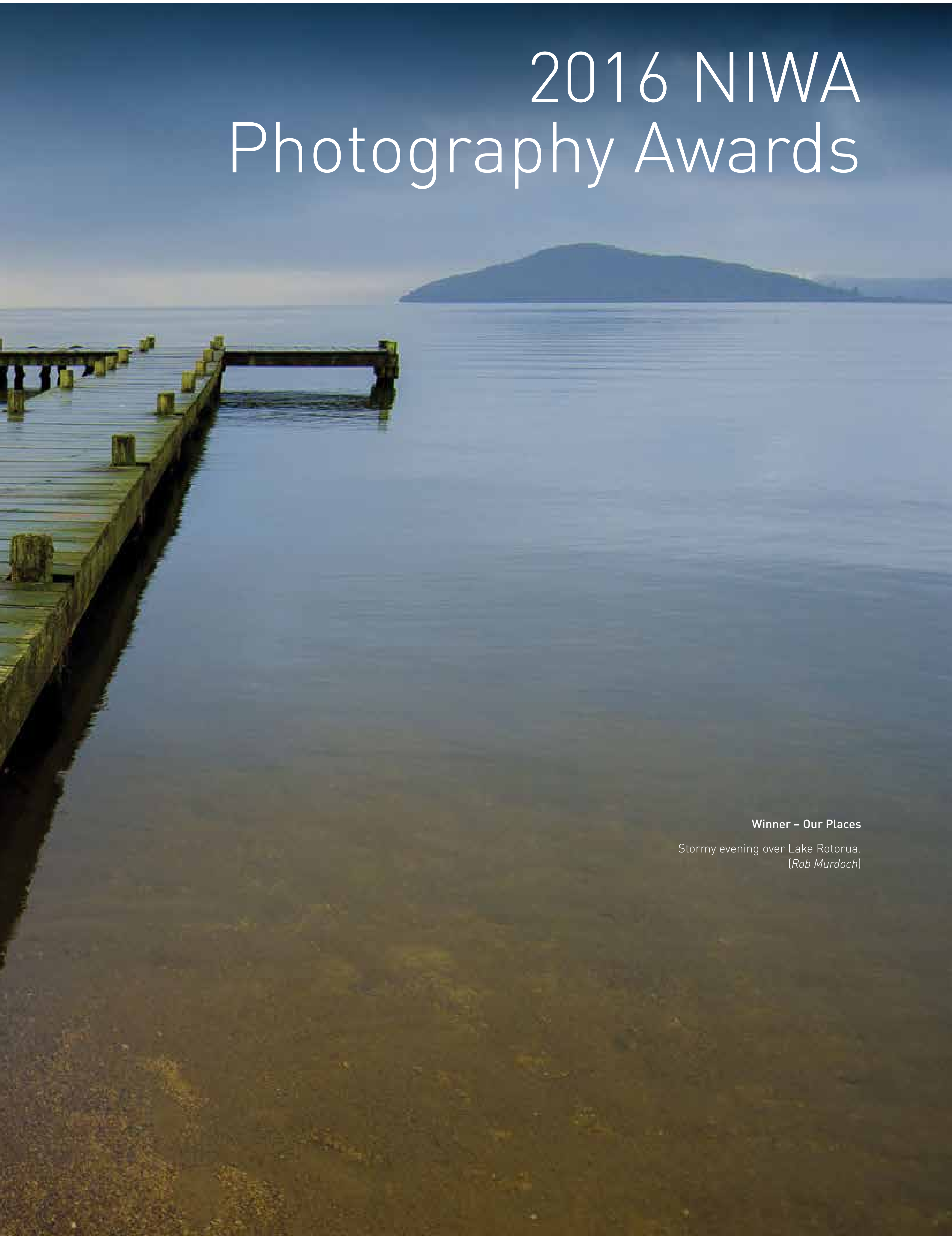
"It has been suggested that shallow water, dense and highly productive seagrass meadows could counter the effects of ocean acidification in localised areas and provide a buffer to calcifying organisms that occur within the seagrass beds or close by."

The importance of this pH-contributing role in coastal areas is underlined by a recently-funded NIWA project in the Sustainable Seas National Science Challenge. The innovative plan by NIWA scientist Dr Cliff Law is to examine the effect on water chemistry of remediation efforts such as returning shells used by the shellfish industry to the seabed, and determining if the shell material can counteract ocean acidification.

"Seagrass meadows could provide buffers to ocean acidification in localised areas." – Dr Carolyn Lundquist (*Crispin Middleton*)



2016 NIWA Photography Awards



Winner – Our Places

Stormy evening over Lake Rotorua. (*Rob Murdoch*)

Winner – People's Choice

Milky Way in The Remarkables.
(*Ayushi Kachhara*)

Winner – Freshwater

Blue glacial headwater, Rakaia River.
(*Shannan Crow*)

Winner – Special Award

Underwater angel.
(*Crispin Middleton*)

Winner – Our People

Arctic Sunset. (*Alison Kohout*)

Wellington Regional Winner – Our Work

Dusky dolphin playing alongside RV *Tangaroa*. (*Fiona Elliott*)


Winner – Our Work

Southern Buller's albatross giving the evil eye. (*Rob Murdoch*)

Q&A

Don't keep your head in the sand ...

Seemingly ubiquitous, sand is something we often take for granted. But sands' unique properties, movement and roles are fascinating, as NIWA Principal Scientist, River and Coastal, Dr Murray Hicks explains.

Let's get down to the nitty-gritty – what is sand made of?

Sand is made of mineral grains, ranging in size from 0.06mm to 2mm. These mineral grains are typically inorganic in origin and are weathered from rocks, but some sand is composed of shell fragments.

What makes different types of sand 'different'?

Sand types differ most obviously by colour, reflecting their composition from different minerals. For example, white sand is usually composed almost totally of the mineral quartz (and so is often termed "silica sand"). Black sand is composed of the heavy minerals magnetite or titano-magnetite. Yellow sand is a mixture of quartz and feldspar stained a rusty-yellow-brown by weathering of iron-rich minerals. Green sand is composed of the mineral glauconite, which forms on shallow sea floors distant from land, such as the Chatham Rise.

Where does sand come from and what factors influence its distribution?

Sand gets moved around by water and air currents, usually accumulating in deposits such as beaches, streambeds, the sea floor and sand dunes. Its resting time at a particular location may be temporary. A sand grain on a streambed may next end up being moved to a coastal river delta by a flood, then washed along the shore and up on to a beach berm by waves, or even blown inland to a dune field, then recycled alongshore after coastal storm waves erode the beach and sand dunes, then dumped in the heads of a submarine canyon from where it may be carried to the deep sea floor.

Dr Murray Hicks, NIWA Principal Scientist, River and Coastal.

There seems to be an awful lot of it in New Zealand, but are we taking sand for granted?

New Zealand's coastal sand is mined from beaches, harbours and inlets, and the nearshore shelf for the glass and aggregate industry. Sand is also mined from rivers, for example the Waikato River, and the river sand supply to the coast is intercepted by dams. Mining and trapping of sand certainly has the potential to affect coastal erosion, where these activities are large enough to make a significant impact on the sand "budget" of beaches.

What areas in New Zealand have unique sands, and why?

Unique, or at least notably distinctive, sands occur in several places around New Zealand. Starting at the top of the country, we have the dazzlingly-white silica sands at Parengarenga Harbour in Northland. Highly sought after for glass-making because of their purity, these are believed to have been washed onshore by waves and currents from seabed outcrops of old, highly-leached, quartz-rich soils formed during past glacial cycles and low sea-level stands. The central North Island's west coast is famed for its black sands, formed from the iron and titanium-rich titano-magnetite mineral sourced from the volcanic rocks of Taranaki. By virtue of its high density (weight per unit volume), this sand collects as a "lag" on the foreshore of the wave-exposed west coast. Popularly known as "iron sand", this black sand provides ore for the Glenbrook Steel Mill. Inland at Lake Taupo, light-grey pumice sand from volcanic eruptions collects in offshore bars and along the upper foreshore. The golden sandy beaches of Abel Tasman National Park, near Nelson, are formed from the weathering of the Separation Point granites that form the hinterland.

How does sand 'move' around New Zealand?

Sand is moved around New Zealand by water and wind. From hillslope erosion sites, sand-sized mineral grains are loosened from the source rock by weathering and sluiced downslope into streams, then carried seaward along river

channels by floods. At river mouths in estuaries, or at the open coast, the sand is reworked by tidal currents and waves to stock beaches. Waves breaking obliquely to the coast drive the sand along the shore in a longshore "river of sand", which is most intense within the surf zone. Cyclic offshore/onshore sand exchanges occur between the higher, visible parts of beaches and offshore bars, with steep storm waves washing sand offshore, and flatter swells returning it to the beach face. Onshore winds, strongest on our western coasts, blow sand inland off beaches to form dune fields. Some of the more spectacular examples are in Mason Bay on Stewart Island, Farewell Spit at the northwest tip of the South Island, Hokianga Harbour and Ninety Mile Beach in Northland.

What about sand beyond our beaches? We know there are vast, desert expanses on land, but what about underwater?

Offshore, sand covers vast areas of the New Zealand continental shelf and is moved around by the combined action of waves and ocean currents. Sometimes there is a net onshore migration of sand – many of the beaches along the North Island's northeast coast are built from sand washed onshore from the continental shelf, which used to be a river plain stocked substantially by sand from the ancient Waikato River during the last glacial period when sea level was about 120m lower than where it is now.

ASTRONOMICAL NUMBERS

According to NASA, our sun is one of at least 100 billion stars, just in the Milky Way. NASA calculates there are at least 100 billion galaxies in the observable universe, each one full of stars. All said, NASA reckons, that means there are more stars in the universe than grains of sand on Earth. Naturally this begs the question: just how many grains of sand are there on Earth?

Assuming a grain of sand has an average size, multiply it by all the beaches and deserts in the world, the Earth has (very) roughly 7.5×10^{18} grains of sand, or seven quintillion, 500 quadrillion grains.

Profile

A nod to Ngāmotu

Barb Hayden is never far from the sea. In fact, it's been a constant in her life – a personal and professional passion.

Nature versus nurture – for Barb Hayden life is the culmination of both.

As NIWA's Chief Scientist – Coasts and Oceans, Barb's oversees all the important work NIWA's scientists conduct to enhance understanding and stewardship of perhaps our most important natural resource.

Hers is a deep connection with the sea and one that started at a young age, encouraged by her father.

"My dad should probably be given credit for planting the seed. He had the presence of mind and good taste to buy some land and build a house overlooking the harbour in New Plymouth, where I lived with a daily view of the sea and the comings and goings of the port until I left home to go to university at 17.

"Ngāmotu Beach, next to the port, was walking distance from home and my primary school. Dad was a keen beach-goer, so that's where I learned to swim and spent my summers.

"Those lazy days at Ngāmotu Beach next to the busy port and with a 'Nodding Neddy' on the grass just above the sand quietly pumping oil from New Zealand's first discovered oil field probably, unwittingly, instilled in me an understanding of the multiple benefits we derive from the sea, and how these activities can and do operate alongside each other. Taranaki is a classic example."

While the sea was Barb's childhood constant, it wasn't until her final year of high school that it dawned on her that she might make it the subject of a career.

"I had an inspiring biology teacher, Mr Hutchinson, who ran fantastic field trips along New Plymouth's intertidal reefs. Unaware that such fun could translate into a career, I did a technology degree at Massey University, but the call of the sea was answered a couple of years later when I was working at the National Health Institute (now the Institute of Environmental Science and Research, ESR)."

Barb's role was to help facilitate exports of cultured shellfish, assessing the public health safety of commercial growing areas.

"We set up temporary laboratories in motels, court houses and tents, and assessed microbial water quality in some of New Zealand's most beautiful and remote coastal spots in Northland, Coromandel and on Waiheke Island. It was like being on holiday every day."

That experience led to an offer to do marine research fulltime at the Fisheries Research Division of MAF (later to become part of NIWA), as well as a PhD in marine science gained while researching recruitment of mussel spat in Marlborough Sounds. Barb has been with NIWA ever since, appointed Chief Scientist – Coasts and Oceans, based in Christchurch, in 2012.

It's a role she loves – not only because of the importance of the work NIWA does, but also because of the people she works with.

"New Zealand's marine estate is certainly special. It covers the ocean and seafloor from the coastal margin to the outer boundaries of the New Zealand's Exclusive Economic Zone and Extended Continental Shelf and includes the Ross Sea. Within that massive area are globally unique and diverse biota and vast natural resources.

"I like to refer to it as our estate because, just like the common law use of the word, it is New Zealand's legal marine property, containing natural resources that New Zealand is entitled to use and over which it has obligations of care on behalf of future generations. Therein lies the challenge that most occupies my mind; how best to get the balance right between resource use and effective stewardship.

"Marine biosecurity and environmentally sustainable resource use have been the two main research threads in my career; both are gnarly issues, but, with good collaboration between resource managers, industry and scientists, New Zealand is tracking well on both issues."

But it's the work of all NIWA's talented scientists that gives Barb most satisfaction.

"Scientists from multiple disciplines, all pitching in together to solve the issues of the day. I am constantly humbled by their smarts. I have the best job."

Barb Hayden at Whangamata Beach. (*Genny Shiel*)

And for a marine scientist she possibly has the best partner in life – Barb's husband is David Schiel, Distinguished Professor of Marine Science at the University of Canterbury. Their two children have left home and, while having not followed their parents into science careers, both have fascinating jobs – one as a conservator of historic architecture and monuments in New York, the other as a mechatronics engineer in San Francisco.

Personal time for Barb and David often involves kicking back and enjoying their bach in Whangamata.

"Whangamata is perfect for switching off. Our bach is simple, with no Internet, and is close enough to the beach that we can enjoy our early morning coffee, sitting on the sand and checking out the surf. In summer, I can be as active as I like or just sit and watch everyone else.

"I love chilling out in Whangamata, even in winter, when most of the holiday homes are empty, the town is quiet and the beach still beautiful – long winter beach walks can't be beaten for clearing the head."

Coastal Calculator turns possibilities into pictures

"We live in a world that is beyond our control, and life is in a constant flux of change. So we have a decision to make: keep trying to control a storm that is not going to go away or start learning how to live with the rain." Glenn Pemberton, "Hurting with God".

The appeal of living close to the sea for boating, for fishing, for views or ambience is one reason 65 per cent of New Zealanders live within 5km of the coast.

But it comes with an inherent risk of being caught out by its contrariness – battered by storm surges and high tides, or inundated by flooding.

As sea levels are projected to rise because of climate change, coastal communities around New Zealand, the Pacific and the rest of the world are going to have to adapt to the ocean's increasing ability to wreak havoc.

There isn't a uniform answer to knowing where (or where not) and how to adapt around New Zealand … it all depends.

The ability to assess a range of scenarios is one of the reasons why NIWA's Coastal Calculator tool is receiving a warm reception from regional, district and city councils around the country.

The Coastal Calculator was first developed in 2008 as a tool to identify coastal hazard exposure in the low-lying Kiribati Islands in the central Pacific Ocean. (*Dave Allen*)

The calculator contains a wide range of data and NIWA modelling, presented in a user-friendly way. It allows people to estimate the impacts of high tides, storm surges and large waves in their particular region, and to investigate the impact of sea-level rise. This in turn, helps to plan for the future and to make rules designed to avoid risk, such as what buildings and infrastructure should be placed where.

NIWA Coastal and Estuarine Physical Process Scientist Scott Stephens says there was one overarching goal in creating the Coastal Calculator.

"We wanted a science communications tool," Dr Stephens says. "We asked, how can we make the results of complex modelling and data more easily accessible to the person who needs to know about it?

"That's what we think the calculator provides – a way for people to look at their own particular place, change parameters such as the amount of sea-level rise, beach slope or shoreline characteristics and see a visual representation of what might happen." (See box).

Although the Coastal Calculator is user-friendly, its creation has been a complex operation employing multiple datasets and sophisticated computer models.

Actual sea-level measurements at any particular place is the first requirement. The longer those records have been kept, the more useful the information will be, as more extreme events are likely to have been recorded.

"In New Zealand we don't have long records in many places. To compensate we've had to use joint probability methods," Dr Stephens says.

Sea levels rise and fall for many reasons – from the twice-daily high and low tides to rare cyclonic events. Storms coincide with low pressure, which raises sea levels above predicted levels, while winds may push water up against the coast. Storms may coincide with high tides to create a very high "storm tide".

"By splitting the storm and tide components and using maths to model the likelihood of them occurring together you can estimate the frequency and magnitude of the total sea-level height – how big and how often in other words," he says.

Another component the calculator utilises are wave heights – which are sparsely recorded in New Zealand. To compensate for this lack of wave data NIWA has used a modelling product called WASP (Waves and Storm Surge Prediction). Using wind records, WASP was used to "hindcast" wave conditions around New Zealand for the years 1970 to 2000. This period of wave hindcasting is long enough to reasonably predict the frequency and magnitude of large waves.

The Coastal Calculator was first developed in 2008 as a tool to identify coastal hazard exposure in the low-lying Kiribati Islands in the central Pacific Ocean.

For councils around New Zealand, NIWA tailors the calculator to model coastal data at key locations such as beach sites, major port facilities or vulnerable areas such as low lying, high population density areas.

"Council staff can increase their understanding of potential coastal hazard exposure by selecting the scenarios they want to model. The beauty of the calculator is that they can do it themselves rather than relying too much on external consultants," Dr Stephens says.

"It informs communities of their hazard exposure – the magnitude, likelihood and approximate time frame of when coastal hazards could occur. When communities can visualise hazards before they happen, they can decide for themselves what they might want to do about it and get prepared."

The Coastal Calculator in use

Several councils around New Zealand (and Pacific Island nations) have used the Coastal Calculator to assess potential coast hazards and inform planning and consent decisionmaking.

The Bay of Plenty Regional Council is using its predictions to set minimum floor building levels along its coastline.

The Gisborne District Council used calculator maps to define areas prone to coastal storm inundation.

The Tasman District Council has not only used the calculator to develop building guidelines for minimum building platform and floor levels in coastal inundation-prone locations, but also to assist its argument in an Environment Court case.

NIWA
enhancing the value of New Zealand's natural resources

NIWA (the National Institute of Water & Atmospheric Research) was established as a Crown Research Institute in 1992. It operates as a stand-alone company with its own Board of Directors, and is wholly owned by the New Zealand Government.

NIWA's expertise is in:

- Aquaculture
- Atmosphere
- Biodiversity and biosecurity
- Climate
- Coasts
- Renewable energy
- Fisheries
- Freshwater and estuaries
- Māori development
- Natural hazards
- Environmental information
- Oceans
- Pacific rim

NIWA employs more than 600 scientists, technicians and support staff.

NIWA owns and operates nationally significant scientific infrastructure, including a fleet of research vessels, a high-performance computing facility and unique environmental monitoring networks, databases and collections.

Back cover:

Tunnel Beach, Otago. (*Dave Allen*)

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