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in honour of

Dr Dennis P. Gordon

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A forum for the exchange of views on science and science policy

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Instructions to Authors

New Zealand Science Review provides a forum for the discussion of science policy. It also covers science education, science planning, and freedom of information. It is aimed at scientists, decision makers, and the interested public. Readability and absence of jargon are essential.

Manuscripts on the above topics are welcome, and should be emailed to the editor (editor@scientists.org.nz).

As well as full papers, short contributions, reports on new developments and conferences, and reviews of books, all in the general areas of interest detailed above, are invited. The journal may also accept reviews of a general nature and research reports.

Full manuscripts (with author's name removed) will be sent for peer review, and authors will be sent copies of the reviewer's comments and a decision on publication. Manuscripts should not normally have appeared in print elsewhere, but already published results discussed in the different, special context of the journal will be considered.

Manuscripts should be accompanied by biographies of not more than 100 words on each author's personal history and current interests. Authors are also expected to supply a suitable high-definition passport-size photograph of themselves. This will be published with the article.

Articles may be submitted in MS Office Word, rich text format, or plain text. Diagrams and photographs should be on separate files (preferably eps, tif, jpg, at 300 dpi), not embedded in the text.

All tables and illustrations should be numbered separately – Tables 1, 2, 3, 4, etc., and Figures 1, 2, 3, 4, etc. – and be referred to in the text. Footnotes should be eliminated as far as possible. Diagrams and photographs will be printed in black and white, so symbols should be readily distinguishable without colour, and hatching should be used rather than block shading. However, colour may be used if the author or the author's institute is willing to pay for the added cost.

References should preferably be cited by the author–date (Harvard) system as described in the Lincoln University Press *Write Edit Print: Style Manual for Aotearoa New Zealand* (1997), which is also used as the standard for other editorial conventions. This system entails citing each author's surname and the year of publication in the text and an alphabetical listing of all authors cited at the end. Alternative systems may be acceptable provided that they are used accurately and consistently.

Editorial

Principal Scientist Dr Dennis Gordon retired in October 2015 from his position at the National Institute of Water and Atmospheric Research (NIWA). Over his career he has made very significant contributions to the understanding of biodiversity in New Zealand and globally, both through his work on fossil and modern bryozoan material and through his contributions to national and international efforts to document biodiversity. Among his many achievements, Dennis led an ambitious project to produce the comprehensive three-volume *New Zealand Inventory of Biodiversity*, published in 2009–2012, which summarises the state of knowledge for all of New Zealand's living and fossil organisms (see page 108).

In April 2016, a one-day symposium was held in Wellington to celebrate the contribution Dennis made to the field of systematics, discuss the role that taxonomy plays in biological science, and highlight the important work being carried out for the benefit of New Zealand in managing its natural heritage. The symposium brought together scientists from government departments, Crown research institutes, museums and universities, reflecting Dennis' rare ability to rally experts from a wide range of fields and backgrounds.

This issue includes articles from symposium speakers and researchers who have worked with Dennis. Topics include accounts of Dennis' contribution to the field of systematics (and bryozoology in particular), the state of taxonomic research in the national and international scene, applications of taxonomy to conservation and environmental management, and recent developments and future directions for systematics research in New Zealand.

The issue begins with Dennis, and Mark Costello, setting the record straight as to the status of bryozoans – definitely not a minor phylum! They show that perceptions have changed from the phylum being considered minor in the 1960s to it now being seen as abundant and diverse in form and function in a range of present and past habitats, proving ideal for investigating significant evolutionary questions.

Professor Abby Smith with Philip Bock and Peter Batson summarise the full range of Dennis' achievements in taxonomy generally and the bryozoans in particular. He has produced more than 170 publications, described nearly 700 new taxa, and, with his colleagues, named over 500 living and fossil species – a phenomenal record.

Ashley Rowden provides three examples of his work with Dennis showing how his understanding of taxonomy and systematics has enabled insights into the regeneration of biogenic reef habitat impacted by fishing, the factors that influence the distribution of bryozoan assemblages and thickets in New Zealand, and where they require protection.

The symposium followed a report released in late 2015 on the state of taxonomy in New Zealand which expressed serious concern for the future of the science. The Royal Society of New Zealand report was the work of an expert panel on National Taxonomic Collections chaired by NIWA principal scientist Wendy Nelson, and identified declining support for nationally important collections at a time when demand for their services is increasing within New Zealand and overseas, particularly as growing international trade increases biosecurity risks[1].

Panel's Chair, Wendy Nelson, outlines the Panel's conclusions and reproduces as an appendix the executive summary of their report. Wendy notes that the report recognises the reliance of many sectors on the expertise and data within the taxonomy and collections community, ranging from export assurance, human health, and biosecurity to environmental protection. The panel recommended collections be recognised as national heritage assets and essential components of the New Zealand science system. It also recommended the Government urgently address the immediate investment needs of national taxonomic collections and research staff so that critical expertise was restored and services and quality not put at further risk. New investment was also needed, the report said, to support training and to ensure New Zealand has a strong and expert taxonomic workforce. The recently released report from MBIE on the Science and Innovation System Performance referred to the Royal Society report and its findings, including that New Zealand's taxonomic knowledge is undeveloped compared with other advanced economies.

[1] Nelson, W.A.; Breitwieser, I.; Fordyce, E.; Bradford-Grieve, J.; Penman, D.; Roskruge, N.; Trnski, T.; Waugh, S.; Webb, C.J. 2015. *National Taxonomic Collections in New Zealand.* Royal Society of New Zealand. 63 pp. + Appendices (66 pp.) ISBN 978-1-877317-12-5 www.royalsociety.org.nz/national-taxonomic-collections-in-new-zealand

This paper is followed by Janet Bradford-Grieve posing the question: ‘Is there a taxonomic crisis?’ Janet compares the situation here with that in Australia and Canada. Our taxonomic workforce is ageing and male-dominated, with very few under 40 years of age. Most were funded to spend only a small proportion of their time on research, and there is a lack of strategic connection between science funders and priority setters.

Next, Mary Livingston describes the requirements in modern fisheries management for informed and definitive species identification based on sound taxonomic expertise and well-managed and accessible voucher specimens and records, thereby reminding us that taxonomy is not an esoteric pursuit but a key tool in ensuring the sustainable use of our biological resources.

Richard Leschen and colleagues cover the significance of insects in ecosystem functioning in freshwater habitats, and describe what they call ‘a grim picture emerging for the future of many aquatic organisms’. The research focus and ecological understanding of many New Zealand insects is poor or absent, with a large number considered to be ‘data-deficient’. There is inadequate funding for needed taxonomic work, and there are no researchers employed specifically to revise freshwater insect groups.

I discuss the ubiquitous nature of nematodes, and show the need for understanding the diversity of small organisms in order to understand how various ecosystems work, and, more importantly, how to protect them.

The final paper in this issue, by Heidi Meudt, moves on to the systematics of vascular plants, using examples of her own work on hebes and forget-me-nots to show how an integrative approach to analysing morphological, molecular, cytological and other data sets can aid species delimitation and discovery, while giving insights into diversification, conservation of threatened species, polyploidy, and biogeography.

I first met Dennis in 2008 as I was finishing my PhD at the Portobello Marine Laboratory in Dunedin. Although I only had a vague idea of who he was, I knew that he was highly regarded by the scientific community. I was therefore more than a little nervous as I was telling him about my yet-to-be-published research on marine nematode taxonomy, but I was quickly reassured by his response – not only did he know about nematodes and just how understudied they are in this part of the world (I usually get blank stares even from biologists), but he was also genuinely interested! This ten-minute corridor conversation was enough to help me persevere in my taxonomic efforts, and luckily (and unexpectedly) for me I ended up working a few doors down from him in Wellington just a few years later.

I would like to thank all who contributed to the success of the symposium, and in particular those who found time in the busy schedules to contribute to this special issue of *New Zealand Science Review*. It is heartening to see the energy and enthusiasm with which taxonomists and environmental researchers strive to provide the best possible science for the benefit of New Zealand despite the many challenges that still need to be overcome. Dennis is a perfect example of such scientific vigour and passion, and, fortunately for us, he is staying on as emeritus scientist at NIWA, and continues to conduct much-needed taxonomic research and to mentor the next generation of taxonomists.

Daniel Leduc
Guest editor

Bryozoa—not a minor phylum

Dennis P. Gordon[1] and Mark J. Costello[2]

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Introduction

At the one-day symposium to mark the first author's formal retirement, he gave a presentation titled 'A life in bryozoology', noting that he began publishing on Bryozoa in the late 1960s, with a taxonomic article in a student journal (Gordon 1967) followed by a paper in *Nature* (Gordon 1968). Of the 174 peer-reviewed papers published since then, 137 have focused on some aspect of bryozoology (e.g. ecology, conservation, growth, anatomy, ultrastructure, form and function, systematics, paleontology, phylogeny, marine fouling and invasive species, marine natural products). During the past 50 years of his research, perceptions of phylum Bryozoa in the scientific community have changed markedly from what was historically the case. The purpose of this short paper is to highlight what has changed.

A 1930s–1960s view of Bryozoa

A few years before his formal research on Bryozoa began at university, the first author became acquainted with Bryozoa at Mt Albert Grammar, Auckland, thanks to teacher-prescribed textbooks in the form of a two-volume paperback—*Animals Without Backbones* (Buchsbaum 1958). The text of the volumes was unchanged from the first (1938) edition, in which Bryozoa was included as a 'minor phylum' in a short chapter called 'Lesser lights', which also included Rotifera, Gastrotricha, Brachiopoda, Phoronida and Chaetognatha. Buchsbaum's criteria for assembling these disparate groups in the one chapter was that 'they have a small number of species or of individuals; the members are of small size; they constitute no important source of food or disease for man; and they illustrate no principle of theoretical interest that is not as well shown by other phyla' (Buchsbaum 1958, p. 188). This was still the prevailing view in the 1960s, although Bryozoa did actually rate an entire lecture in the mid-sixties invertebrate course in the then Zoology Department at Auckland University. For Bryozoa today, Buchsbaum's criteria no longer apply.

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A 21st century view of Bryozoa

First, consider the numbers. Bryozoa now constitutes a phylum of ~21,300 described species, of which >6000 are living (Figure 1) and ~15,000 are fossil—up from about 15,040 species (~12,000 fossil) in the 1920s (Marcus 1930). Data from

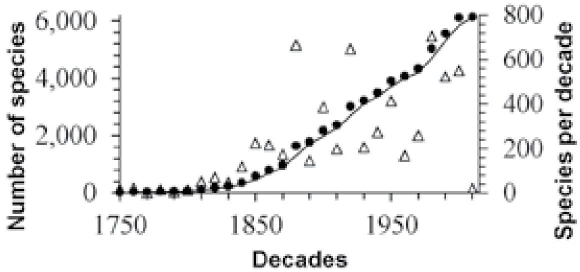
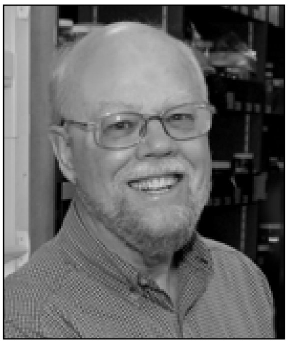
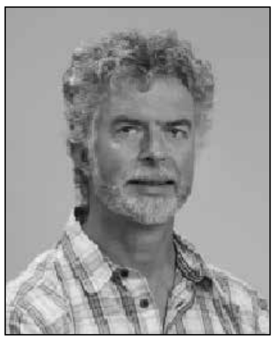


Figure 1. Number of Recent bryozoan species (i.e. species living today or within the last 12,000 years) described per decade (empty triangles), and cumulative number of species (black circles). The curve shows a near-linear rate of description since the early 19th century, with peak decades of discovery in the 1880s, 1920s and 1980s. The 1960s–1970s have relatively few species described, as well as the 1910s and 1930s–1940s owing to the impacts of world wars. From Bock, P. (2014). Bryozoa. Accessed 7 October 2016 through the World Register of Marine Species at http://www.marinespecies.org/aphia.php?p=taxdetails&id=146142



Dennis Gordon is an Emeritus Researcher at NIWA, where he worked for 36 years (13 of those years as a DSIR scientist) prior to official retirement in October 2015. During that period he was part of the biological oceanography group before leading a programme in marine taxonomy and later overseeing the marine biodiversity group as a Principal Scientist. Beyond his specialised research on the systematics, biology and phylogeny of living and fossil Bryozoa, Dr Gordon has a broad interest in all of life and served on the international teams that coordinate the production of the Catalogue of Life and the World Register of Marine Species. In 2005 he received the New Zealand Marine Sciences Society Award for his contribution to the advancement of marine science in New Zealand. He also coordinated, edited and part-authored the 2009–12 trilogy of volumes, *New Zealand Inventory of Biodiversity*, for which he received the 2012 NIWA Research Excellence award. Dr Gordon is a past council member of the New Zealand Association of Scientists.



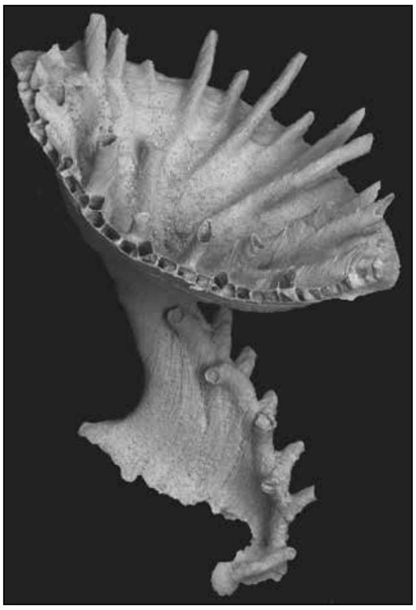
Mark Costello is an ecologist, particularly interested in global patterns of marine biodiversity and biogeography, and in marine conservation. He led the startup of the *World Register of Marine Species* and *Ocean Biogeographic Information System* (as part of the Census of Marine Life). Originally from Ireland, he has worked in Britain and Canada, and been teaching on marine ecology, biogeography, biodiversity informatics and marine reserves in the University of Auckland since 2004.

the World Register of Marine Species (WoRMS) (Figure 1) show the rate of description of Recent species from 1758 (the starting point of zoological names in the tenth edition of Carl Linnaeus's *Systema Naturae*) to the present day. There is no upper asymptote and it is likely that an additional 5000+ species could be added (Appeltans *et al*. 2012). In New Zealand seas alone there are more than 1000 living species, of which about 340 remain to be described. Bryozoans are abundant in some biotopes, where they form biogenic habitat for numerous other organisms (Wood *et al*. 2012). Their skeletal remains constitute the single most abundant component of carbonate sediments on New Zealand's continental shelves (Nelson *et al*. 1988), reflected in equivalent taxonomic and numerical abundances of bryozoans in New Zealand's Cenozoic limestone rocks (e.g. Gordon & Taylor 2015). Living taxa constitute the taxonomically most speciose macrofaunal invertebrate group in the Spirits Bay area, New Zealand's marine-biodiversity hotspot, where there are about 300 species of bryozoans, almost as many as in the combined Exclusive Economic Zones of Britain and Ireland (Cryer *et al*. 2000; Taylor & Gordon 2003). Studies of tropical coral reefs during the 2000–2010 Census of Marine Life revealed that bryozoan diversity is very high and significantly understudied and that there could be as many as 1000 species in the Great Barrier Reef alone (Gordon & Bock 2008). Recent studies on seamounts and in the deep sea also show that bryozoan diversity can be locally very high, as on New Zealand's Cavalli Seamounts (e.g. Rowden *et al*. 2004), with high levels of generic diversity (e.g. Gordon 2014).

What about size? All bryozoans are colonial (Figures 2, 3), even those few that technically comprise only a single feeding zooid (the bryozoan individual) with attached diminutive polymorphs or zooid buds, and, while it is true that most zooids are around half a millimeter in length (the largest achieve 10 mm), colonies in some parts of the world can be a metre across. Intermediate sizes, from robust fist-shaped clumps as hard as coral, to cabbage-like brittle growths of alien species on shaded wharf piles, are not uncommon. As mentioned above, the larger forms can form biogenic habitat for myriad other organisms, as was once the case off Abel Tasman National Park prior to bottom trawling (Bradstock & Gordon 1983) and is still the case around many parts of our coastline. Bryozoan micro-reefs attract juveniles of commercial fish such as snapper, terakihi and John Dory, which shelter and feed there.

It is true that bryozoans constitute no important source of food or disease for humankind, though they do provide a food source for a documented 399 predator species (Lidgard 2008). There are cases of fishers in Britain's North Sea getting contact dermatitis from handling bryozoan bycatch (Carle & Christopherson 1982) but this is in the nature of an allergic reaction rather than a malady. More significantly, bryozoans are turning out to have an interesting variety of secondary metabolites that continue to be investigated for marine natural products, which potentially include cytotoxic, antibiotic, antiviral, anticancer, neutriceutical, radioprotection and even antifouling (e.g. Blackman & Walls 1995; Rinehart *et al*. 1996; Kawamata *et al*. 2006; Andersen 2012; Pejin *et al*. 2013, 2014). The most promising are macrocytic lactone bryostatin-1, an antitumour metabolite with significant biological activities (Sima & Vetvicka 2011) including immunomodulation, down-regulation of multi drug-resistance gene expression, anticancer activity and enhancement of the activity of chemotherapeutics. Bryostatins

Figure 2. *Discantenna tumba* **Gordon & Taylor, 2010, an endemic genus and species of cyclostome bryozoan (class Stenolaemata) from the Graveyard Seamount complex on the Chatham Rise.**



are already in clinical use (Blackhall *et al*. 2001; El-Rayes *et al*. 2006; Peterson *et al*. 2006). Alkaloid pterocellins were isolated from a bryozoan found in New Zealand (Prinsep *et al*. 2004) and they possess cytotoxic activities against murine leukemia, human melanoma and breast cancer cell lines. Additionally, and remarkably, bryostatin-1 appears to have potential for treating memory disorders (e.g. Sun & Alkon 2005, 2006). Initially promising studies using rats are currently being followed up by a more-intensive clinical study on human Alzheimer's patients (Staken & Payne 2015; ClinicalTrials.gov 2015).

When it comes to matters of theoretical interest, bryozoans have proven to be ideal for investigating significant evolutionary questions at micro to macro scales (e.g. Jackson & Cheetham 1990, 1999; McKinney 1995a,b; McKinney *et al*. 1998; Barnes & Dick 2000; Taylor 2016). For example, how much of the variation within living and fossil bryozoan colonies and individual zooids is inherited? What is the significance of morphological stasis, i.e. the unchanged appearance of certain skeletal characters over long periods of millions of years? Is the hypothesis of punctuated equilibrium (the hypothesis that evolutionary development is marked by isolated episodes of rapid speciation between long periods of little or no change) real? [Bryozoans give some of the best evidence of the phenomenon.] When and how in the geological record did key morphological novelties

Figure 3. *Foveolaria* **n. sp., an undescribed species of cheilostome bryozoan (class Gymnolaemata) collected from the New Zealand deep sea from fishing bycatch through the Scientific Observer Programme.**

originate? How does varied competitive ability among different evolutionary branches of bryozoans work out over geological time, inasmuch as some clades were displaced? The reasons why bryozoans are so useful in addressing these and related questions include their fossilisable skeletons and their modular nature—individual bryozoan colonies are made up of parts and subparts, including zooids that feed, are non-feeding and modified for defence, attachment, or reproduction, and also parts of zooids, like spines and cuticular structures, that can be modified. Tracing adaptive changes in those modules and submodules that are preserved in the fossil record has proven to be very fruitful in elucidating evolutionary trajectories because life-history, phylogenetic, environmental and biotic-interaction data for both extant and fossil populations are easily collected for comparative study. Because so much information is preserved in the fossil remains, paleo-ecological studies can be made on such features as boundary interactions between spatially competing encrusting colonies, certain types of predation (evidenced by boreholes) and seasonal growth (reflected in varying zooid size). The rich fossil record of bryozoans is very fine-grained in some parts of the world and adaptive changes, if present, can be tracked through specific periods of time. A current example is an ongoing study of bryozoan competitive ability in the Plio-Pleistocene of the Wanganui Basin (Liow *et al*. 2016).

Modularity has been a significant factor in the evolutionary success and radiation of bryozoans, especially in the largest order, Cheilostomata, which originated in the late Jurassic about 150 million years ago. In the Cretaceous, especially starting around 110 million years ago, the evolution of novel complex structures from simpler pre-existing modules (zooids and spines, for example) is well-shown by the fossil record (e.g. Gordon & Voigt 1996; Jablonski *et al*. 1997; Ostrovsky & Taylor 2005). Some feeding zooids evolved into non-feeding defensive zooids (avicularia)—in these, the lid-like opercula that protect the retracted feeding apparatus became modified as jaw-like mandibles; in turn, some avicularian mandibles became narrow and bristle-like, as in the ambulatory zooids of free-living colonies that can 'walk' on the seafloor. Some spines evolved into reproductive incubatory chambers (ooecia); some small, interzooidally budded non-feeding zooids evolved into a variety of frontal body walls. Bryozoan modularity also has implications for theoretical studies of resource partitioning, since defensive and other zooidal morphs cannot feed and are therefore energetically expensive to produce (e.g. Harvell 1986). There are other surprising features about bryozoans, too, that have only recently merited attention but which are worthy of further study, such as the remarkably common occurrence of matrotrophy, i.e. maternal provisioning of developing embryos, including via placental structures (Ostrovsky *et al*. 2009), as well as the existence of the seemingly paradoxical prevalence of polyembryony (embryo cloning) in an entire class of Bryozoa—Stenolaemata (e.g. Hughes *et al*. 2005). Concerning the future of bryozoan studies, one can only say, 'Watch this space. The bryozoan star is in the ascendancy!'

Acknowledgment

The specimens illustrated in Figures 2 and 3 were respectively obtained from the following sources: NIWA cruise TAN0104: 'Seamounts: their importance to fisheries and marine ecosystems', undertaken by NIWA and funded by the former New Zealand Foundation for Research, Science and Technology (C01X0028 (SBB013)) with additional funding from the former Ministry of Fisheries (project no. ZBD2000/04); and TRIP2938/5: Specimens collected under the Scientific Observer Program funded by the New Zealand Ministry for Primary Industries.

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The contribution of Dennis P. Gordon to the understanding of New Zealand Bryozoa

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Introduction

Few biologists have had such an impact on the understanding of New Zealand biodiversity as Dr Dennis Preston Gordon (1944 –) (Figure 1). His canon of more than 170 scientific publications covers the full gamut of biodiversity studies, ranging from taxonomy and systematics, ecology, evolution and life history, to large-scale syntheses of regional and global patterns, and the higher order of classification of all living organisms.

In the 1990s, as project leader of the taxonomy programme at NIWA, Dennis became increasingly involved in tackling the overarching challenges facing biodiversity science[1]. His work in this area has informed research and environmental management decision-making in New Zealand and elsewhere. He became an advocate for the organisational infrastructure, networks and databases, required to understand and wisely manage the great menagerie of life on Earth. In this capacity he played many key roles at an international level. Dennis chaired the Species 2000 Asia-Oceania Working Group, and served on the Ocean Biogeographic Information System (OBIS) International Committee and on the Steering Committee of WoRMS, the World Register of Marine Species.

Dennis Gordon's *magnum opus* is the *New Zealand Inventory of Biodiversity* – a momentous, three-volume work[2]. Its brief was to inventory all species known to exist – or to have existed

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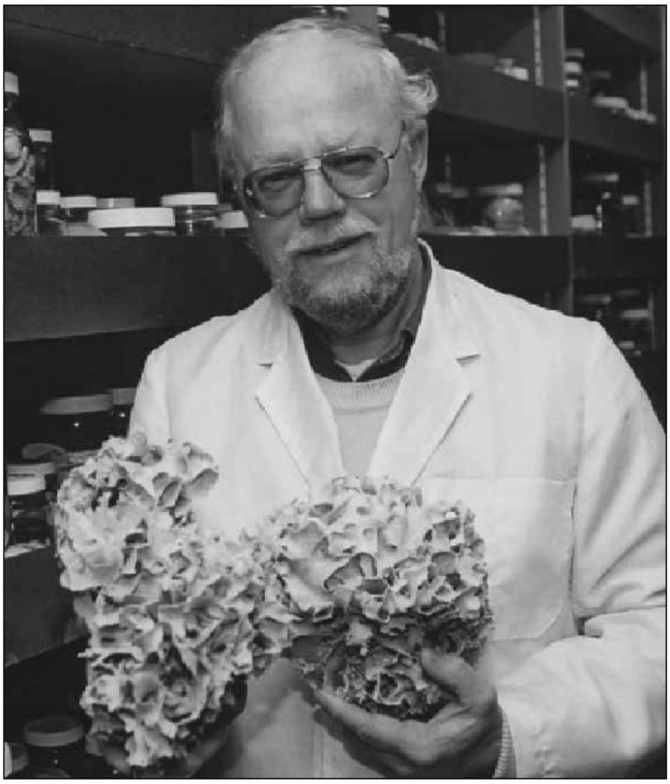
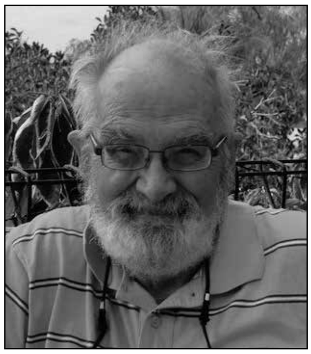


Figure 1. Dr Dennis Gordon holding two very large New Zealand bryozoans.

(Photo by Alan Blacklock.)

Abby Smith is a Professor of Marine Science at the University of Otago, Dunedin, New Zealand. She is a biogeochemist who specialises in skeletal carbonate mineralogy of temperate invertebrates, especially bryozoans.



Phil Bock is an Honorary Researcher at Museum Victoria, Melbourne, Australia. In his retirement, he travels, communicates on social media, and maintains the *Bryozoa Home Page*, www.bryozoa.net, a very useful resource for all bryozoologists.

Peter Batson is a postgraduate student at the University of Otago studying the taxonomy and anatomy of bryozoans.

– in all of New Zealand's terrestrial and aquatic environments over the last half billion years. After a decade of sustained scholarship and organisation (the *Inventory* has 237 authors from 19 countries), it is a resource that the entire nation can take pride in. No other country has produced a similar document.

To a different, smaller and more dispersed community, Dennis wears a different hat. He is one of the world's leading bryozoan biologists and taxonomists. His contribution to understanding of this phylum in New Zealand and beyond has been immense. This article describes the bryozoological legacy (so far) of Dr Dennis Preston Gordon.

Bryozoans: a fascinating phylum

It was as a zoology student at the University of Auckland in the mid-1960s that Gordon began his studies on bryozoans. This was during the John Morton era of 'form and function' biology, and was a formative time for the budding researcher. Gordon honed his skills in observation, taxonomy, natural history and scientific writing, and published an article on the bryozoans of Auckland shores in *Tane*, the journal of the Auckland University Field Club, later becoming its co-editor for a time[3]. In 1968, while still an MSc student, his international publishing career began promisingly with an article in *Nature* on sexual dimorphism in *Hippopodinella adpressa*[4]. A year later Gordon departed to Halifax, Canada, to commence his PhD at Dalhousie University, studying the biology of the intertidal species, *Cryptosula pallasiana*[5,6]. By the end of his studies he was well and truly hooked on bryozoans.

Bryozoa are beguiling and abundant aquatic animals, if not well known outside of marine biology. With >20,000 living and fossil species, they are not at all a minor phylum. They are often among the most speciose macrofaunal groups in samples taken from parts of New Zealand's continental shelf [7]. Some of the larger, coral-like species play a keystone role in benthic communities, locally providing habitat for a myriad of other organisms, and producing much of the seafloor sediment over large tracts of the New Zealand continental margin[8].

Like corals, bryozoans are colonial organisms consisting of interconnected individuals (zooids). Each zooid is typically smaller than a millimeter and most bear a crown of ciliated tentacles that capture phytoplankton. Viewed together, the zooids of a bryozoan colony look intricately tessellated, like a miniature M.C. Escher lithograph. The zooids collectively grow into a wide range of shapes, from flat crusts and amorphous lumps to branching and lattice-like forms. In texture, colonies range from soft and flexible to rigid and thickly calcified, and they come in all the colours of the rainbow (Figure 2). The phylum has a reputation of being taxonomically challenging, and the group's relative obscurity may stem in part from their micro-modular nature. Identification is based largely on features of the individual zooids, not the colony as a whole, so even a football-sized colony may require a microscope to accurately determine its species.

Following completion of his PhD in 1973, Dennis commenced a post-doctoral position at the University of Wales, Swansea, followed by a research fellowship at Leigh Marine Laboratory, University of Auckland. During this time he published on bryozoan biology and ecophysiology, including his discovery of a gizzard in cheilostomes[9], studies on the enigmatic 'brown bodies' produced by bryozoans[5], and a review on bryo-

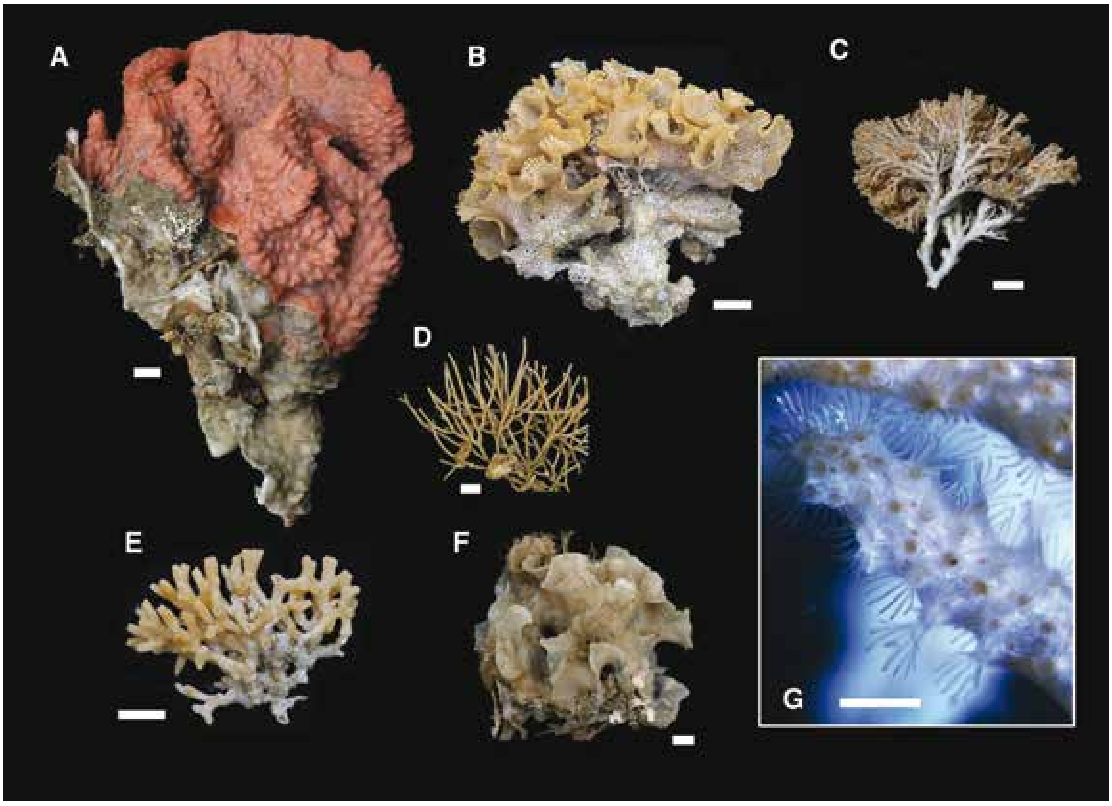


Figure 2: Diversity of colony form among large, conspicuous New Zealand bryozoans: A, ***Celleporaria agglutinans*****, a massive encrusting species; B,** ***Hornera foliacea*****, a reticulate (lace-like) form; C,** ***Hornera robusta*****, an erect branching species; D,** ***Cellaria immersa*****, rigid branches articulated at flexible nodes; E,** ***Heteropora*** **sp., with robust cylindrical branches; F,** ***Hippomenella vellicata*****, a foliose form; G (inset), a micrograph of a living bryozoan colony with the ciliated tentacle crowns of the individual zooids extended. Scale bar: A – F = ~1 cm; G = 0.5 mm. (Photos: Peter Batson)**

zoan aging processes[10]. He also co-wrote, with Leigh's Bill Ballantine, a paper reporting the establishment of New Zealand's first marine reserve to the scientific community[11].

At the end of the 1970s Dennis joined the New Zealand Oceanographic Institute, then part of DSIR and moved to its Wellington campus at Greta Point in Evans Bay, now part of NIWA. With this change came a re-focusing on taxonomic questions. New Zealand had recently declared a 200-nautical-mile Exclusive Economic Zone (EEZ) and there was elevated awareness of the need to document New Zealand's marine biological and geological resources. With access to large historic and rapidly expanding new collections of material from the New Zealand region, Dennis began a sustained period of describing and monographing bryozoan diversity from the region. His previous training and natural ability in pattern recognition would come to the fore in this vocation. Everywhere Dennis looked he saw a treasure trove of unrecognised forms – an alluring, if daunting, challenge for New Zealand's sole 1980s-era bryozoologist.

Bryozoan colonies have a curious tendency to look like other things – seaweeds, corals, hydroids – even dinosaur vertebrae[2] – and so are often misidentified as such. Dennis once described a distinctive deepwater genus, *Discantenna*: no prizes for guessing what it looks like[12]. Some bryozoans have departed far from the norm: New Zealand's seven otionellid species are roughly the size and shape of lentils and have a fringe of bristle-like 'legs'. Rather than gluing themselves to the seafloor like their kin, they clamber over the sandy bottoms on which they live. Others overgrow snails and continue the spiral of the shell beyond the reach of the original occupant.

In 1978 the New Zealand region's known bryozoan biodiversity was 378 species. By 2009, thanks largely to Dennis' efforts, this number had increased to 953 species[2]. These descriptions were published in three large and well-illustrated NZOI memoirs[13, 14, 15] and numerous taxonomic papers, and their impact extended far beyond these shores. Partly this was because of the sheer number of species involved, but also because Dennis had to establish much higher-level taxonomy (new genera and families) to accommodate the many disparate species he encountered. Thus his monograph on the cheilostome bryozoans of the Kermadec Ridge, a work one might assume to have a rather specialised audience, has been cited more than 300 times [13].

Bryozoan colonies often produce beautiful geometric structures, but it takes a microscopic view of their individual zooids to appreciate their true beauty and complexity (Figure 3). At that scale their carbonate skeletons look like spun glass, ornately sculpted, and rich with quantifiable characters. This trait, along with their excellent fossil record, has made them invaluable models for testing evolutionary hypotheses, such as punctuated equilibrium theory [16]. Yet the phylum scarcely rates a mention in most biology textbooks. In his 2003 *New Zealand Geographic* article dedicated to the Bryozoa[7], Dennis suggested that the common names long affixed to the phylum – 'moss animals' and 'sea mats' were not helpful – and he suggested 'lace corals' as a more appealing alternative, and indeed this recommendation has been mostly taken up among marine scientists.

During the 1980s and 90s, Dennis published widely on New Zealand Bryozoa, spanning intertidal to deep-sea environments, and began work on regional 'bryofaunas' elsewhere in the Pacific, such as Australia, New Caledonia, and Western Samoa[17, 18, 19]. He also co-authored an atlas on the alien bryozoan species invading New Zealand ports and harbours courtesy of international shipping[20]. Among them was his old friend *Cryptosula pallasiana*, the cheilostome he studied in Canada for his doctorate. Collectively these studies no doubt focused his awareness of the challenges facing taxonomy and biodiversity researchers, especially when integrating datasets across biogeographic regions and changing ecosystems. Concurrently Dennis continued to expand his body of work on cheilostome bryozoan systematics, often based on the comparative anatomy of skeletal wall structure[21]. He also authored or coauthored studies of fossil bryozoan assemblages[22], reviewed bryozoan energetics[23], and produced a much-cited paper with Mike Bradstock on the environmental protection of Tasman Bay bryozoans to protect a commercial fish stocks, a world first[24].

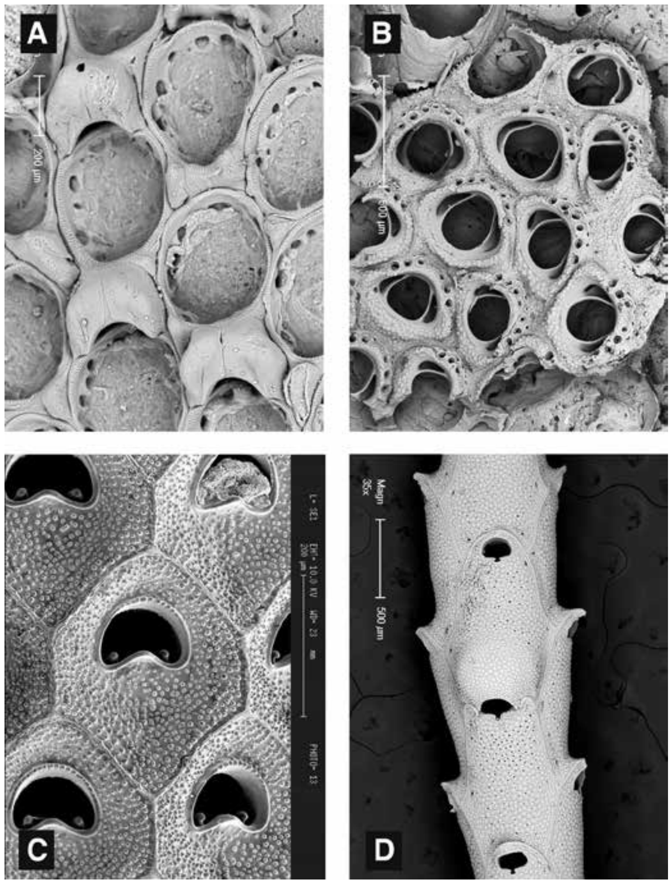


Figure 3: Scanning electron micrographs of some of the cheilostome bryozoans described by Dennis Gordon: A, *Aplousina anxiosa* **Gordon 1986; B,** *Chaperia multispinosa* **Gordon, 1984; C,** *Cellaria* **sp. (Gordon described ten species belonging to this genus, both living and fossil); D,** *Taylorius* **sp. (Gordon recently described three New Zealand species within this genus).**

Until the mid-1990s, Dennis's bryozoological research focused on the most diverse group: the cheilostomes, which had stormed onto the bryozoan scene in the Cretaceous. This modern clade had several key innovations: box-shaped zooids fitted with hinged jack-in-the-box lids that sealed away the vulnerable soft parts when the tentacles were retracted. However, Dennis did not focus on them entirely. Over the years he had carefully collected and catalogued bryozoans from other living clades, including the freshwater phylactolaemates, soft-bodied ctenostomes, and the archaic cyclostomes whose generally smaller, tubular zooids had changed little since the Paleozoic. Working in collaboration with Paul Taylor of the Natural History Museum, London, and Abby Smith at the University of Otago, Dennis started the process of describing New Zealand's cyclostomes more thoroughly[25, 26]. By 2010, it had become evident that New Zealand was the global diversity hotspot for these archaic bryozoans, with at least 124 species in our EEZ waters, many of them living on seamounts and offshore ridges[26].

A bryo-legacy

Alone or in collaboration with others, Dennis has described 692 new taxa to date, which include at least 1 superfamily, 22 families and 133 genera of Bryozoa. There are at least 434 Recent (living) species and 105 fossil species named by Dennis Gordon and his colleagues (Appendix 1, published only on the New Zealand Association of Scientists website, www.scientists.org.nz/files/journal/2016-73/).

In the last decade, Dennis has continued to publish widely on bryozoans, as well as broader synthetic works on biological classification and biodiversity[27, 28, 29]. His recent taxonomic papers have ranged far and wide – including species descriptions of living and fossil European, South American, Australian, Asian and Antarctic Bryozoa. Among the more intriguing contributions was a co-authored description of the first truly amphibious bryozoan in this otherwise strictly aquatic phylum. It inhabits the leaves of mangrove trees in Australia's Northern Territory[30].

One of the hallmarks of Dennis's career is his willingness and ability to collaborate, leading to a multidisciplinary and highly collaborative career. He first attended a meeting of the International Bryozoology Association (IBA) in 1971 and has missed only two meetings since. His commitment over the years reached its peak in 1995, when he hosted (almost single-handedly) their triennial meeting, including leading long pre- and post-conference field trips. The 10th International Bryozoology Conference in Wellington, New Zealand, included 73 delegates from 19 countries, and was the first time that the IBA met in the Southern Hemisphere.

The esteem in which Dennis is held by his peers could not be better demonstrated than by the many bryozoans named for him (Table 1). Among them are the genera *Dengordonia* Soule, Soule & Chaney, 1995, *Gordoniella* Zágorsek, 2001 and *Dennisia*, Hara 2001, as well species such as *Klugerella gordoni* Moyano, 1991, *Leptinatella gordoni* Cook & Bock, 2000, *Trochosodon gordoni*, Bock & Cook, 2004, *Caberoides gordoni* Di Martino & Taylor, 2015, and *Reniporella gordoni* Guha & Gopikrishna, 2004.

Over the years Dennis has supported and encouraged many students of the Bryozoa, some of whom have gone on to forge their own careers in this specialised field (in New Zealand, students whom he has supported and mentored include the authors of this paper, Abby Smith and Peter Batson, and also Seaborne Rust, Anna Wood, and Michelle Carter – see full list of publications). It is easy to see, both in person and through his published work, Dennis's unflagging sense of wonder at the natural world.

In addition to his busy working life, Dennis has been married since 1977 to Brenda Raewyn Gordon. The couple are well known in the world-wide bryozoan science community as exceptional and enthusiastic hosts and guides. They have three sons: Timothy, Caleb, and Adrian, and (at present) one grandson. Dennis is a member of the pastoral team in his church, and is a keen photographer, especially of rare and beautiful plants. He retired in 2016, although continuing to work as an Emeritus Researcher at NIWA, and often comments that now he can really give more time to his beloved bryozoans.

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Note: A comprehensive bibliography of the published bryozoological works of Dennis P. Gordon is available at the following link: http://bryozoa.net/gordon_refs.html

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Table 1. Bryozoans named after Dennis Gordon.

Genus	Authorship	Family	Type Species	Authorship
Dengordonia	Soule, Soule & Chaney 1995	SMITTINIDAE	*Dengordonia uniporosa*	Soule, Soule & Chaney 1995
Dennisia	Hara, 2001	LEPRALIELLIDAE	*Dennisia eocenica*	Hara, 2001
Gordoniella	Zágorsek, 2001	CRIBRILINIDAE	*Gordoniella diporica*	Zágorsek, 2001

Species	Authorship	Family
Caberoides gordoni	Di Martino & Taylor, 2015	CATENICELLIDAE
Gordoniella budai	Zágoršek, 2001	CRIBRILINIDAE
Gordoniella diporica	Zágoršek, 2001	CRIBRILINIDAE
Gordoniella longituda	Zágoršek, 2003	CRIBRILINIDAE
Klugerella gordoni	Moyano, 1991	CRIBRILINIDAE
Leptinatella gordoni	Cook & Bock, 2000	CALLOPORIDAE
Reniporella gordoni	Guha & Gopikrishna, 2004	STEGINOPORELLIDAE
Trochosodon gordoni	Bock & Cook, 2004	CONESCHARELLINIDAE
Disporella gordoni (now *D. pristis*)	Taylor, Schembri & Cook, 1989	LICHENOPORIDAE

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The study of taxonomy and systematics enhances ecological and conservation science

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The study of taxonomy and systematics can enhance ecological and conservation science. However, understanding how taxonomy and systematics can bring about such enhancement is not always readily appreciated. This situation can lead to some ecologists ignoring or dismissing the benefits of working with taxonomists and systematists to achieve their goals. Here I provide examples, from collaborative research with marine bryozoologist Dennis Gordon, on how his understanding of taxonomy and systematics has enabled insights into the regeneration of biogenic reef habitat impacted by fishing, the factors that influence the distribution of bryozoan assemblages and thickets in the New Zealand region, and where they require protection.

Introduction

Defining species and groups of species based on shared characteristics, and studying the relationships among them, can enhance ecological and conservation science. However, understanding how taxonomy and systematics can bring about such enhancement is not always readily appreciated. This situation can lead to some ecologists ignoring or dismissing the benefits of working with taxonomists and systematists to achieve their goals of elucidating the nature of the relationships between environment and faunal distributions, which they sometimes use to generate information that is useful for the protection of vulnerable communities and habitats. Here I take the opportunity to provide three examples, from collaborative research with marine bryozoologist Dennis Gordon, on how his understanding gained through taxonomy and systematics has enabled ecological insights, and led to the identification of conservation issues for bryozoan assemblages and habitats in the New Zealand region.

When I first started work at the National Institute of Water & Atmospheric Research (NIWA) I was in Dr Gordon's Biodiversity Group, and hired to help organise the large amount of historical data that NIWA had on benthic fauna, and analyse these data to describe the benthic communities and habitats of the New Zealand region. It soon became apparent to me that very little of the available data could be compiled across different sampling occasions and places to allow for a robust analysis of benthic communities at a regional scale – apart from just a few exceptions, the most notable of which were bryozoan data. These data were based largely on identifications made or checked by one person – Dr Gordon – and he knew these data very well, and through the study of bryozoan taxonomy and systematics he knew the species and their habits. This meant that by working with him on these data I could begin to do the job I was hired by NIWA to do.

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Bryozoan biodiversity

The first bit of research that we did together was to use the bryozoan data that Dr Gordon had compiled, to examine biodiversity patterns in the New Zealand region and consider the conservation implications of these patterns (Rowden *et al*. 2004). We worked with Richard Warwick, from Plymouth Marine Laboratory; with his colleague Bob Clarke, he had over the years been developing ways to quantify biodiversity, and in particular to devise metrics that could be used for practical purposes.

Two of these metrics relied upon the taxonomic relationships of the species in a sample. These metrics are called Average Taxonomic Distinctness (AvTD) and Variation in Taxonomic Distinctness (VarTD) (Warwick & Clarke 2001). AvTD is a measure of the degree to which the species in a sample are related taxonomically to each other, and is the average path length between every pair of species traced through a taxonomic tree. VarTD is the degree to which taxa are evenly or unevenly spread across the full taxonomic tree, and is reflected in variability of the full set of pairwise distinctness weights making up the average. These metrics can only be used to their full potential if you have a dataset, like the bryozoan data set, that has all taxa identified to species level. These metrics have the advantage that they can overcome many of the problems of traditional diversity metrics such as species richness measures (e.g. sampling size = effort bias) and can be based on simple

Ashley Rowden has an environmental science degree from the University of London, and after undertaking a PhD at Plymouth Marine Laboratory and the University of Plymouth, he took up a Royal Society fellowship at the University of Otago's Portobello Marine Laboratory. Then, after six years back in the UK lecturing at the University of Plymouth he returned to New Zealand to work at the National Institute of Water & Atmospheric Research in Wellington, where he has been involved in ecological research in a number of marine habitats from the intertidal to the deep sea. Some of his research has concerned applied aspects of marine science, such as determining the effects of fishing and aquaculture, and the production of environmental classifications for conservation and management purposes.

presence-absence data. Such indices are particularly relevant to assessments of biodiversity for colonial organisms such as bryozoans, where the estimation of abundance is problematic.

Figure 1 shows one of our results of the analysis of bryozoan biodiversity patterns in the New Zealand region, where measures of AvTD are related to water depth. The points on the graph are colour-coded by the three main community types that were first identified by multivariate analysis. Open symbols are for the intertidal/shelf/slope community and the filled symbols identify two deeper-water communities. What is interesting about this graph is: (1) the relatively sharp decline in diversity just beyond the shelf/slope break below about 200 m depth; and (2) the elevated levels of AvTD at depths of around 800–1200 m which parallel the underlying decline in diversity with depth.

After examining this plot, we hypothesised that the apparent depression in diversity on the slope could be the result of disturbance from historical and contemporary mass sediment flows and turbidity currents on the slope caused by seismic activity. We also observed that the elevated levels of diversity in the deep sea were associated with seamounts, areas of hard substrate with potentially suitable environmental conditions for bryozoans (higher current flow and food availability). Seamounts can sometimes act as island-like habitats that promote high levels of endemism, which could also be reflected in the

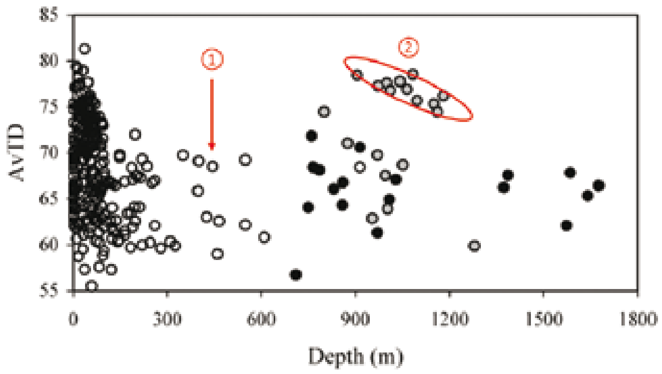

Figure 1: Plot showing the relationship between water depth and AvTD calculated for those stations with ≥10 species of Bryozoa in the New Zealand region. Station community membership is also indicated: Inter-tidal/Shelf/Slope (open circles), Deep sea 1 (solid grey circles), Deep sea 2 (solid black circles) (modified from Rowden *et al.* 2004).

measures of taxonomic distinctness. This latter hypothesis we and others have taken up elsewhere using the VarTD metric (e.g. Brewin *et al*. 2009), while the hypothesis about slope instability controlling regional patterns of biodiversity in the New Zealand region is still to be addressed (three unsuccessful Marsden proposals and counting).

We also used the measures of AvTD to examine whether certain sites have a diversity that is higher or lower than one might expect for a region. Such an analysis relies on calculating a theoretical mean value for the region (using many random permutations of samples of increasing species richness) and comparing this mean – the straight line and its confidence funnel in Figure 2 – with values for particular sites. Figure 2 shows the result of our analysis for each of the main bryozoan communities, and you will note here that there are some sites that are either significantly higher or lower than the theoretical regional mean (i.e. above or below the funnel).

If you plot these values – represented by expanding circles, and colour-coded by the amount the values are above (black) or below (white) the regional mean – on a map of the region, you can identify some areas of particular interest. This is what we did. Figure 3 shows that of one the areas of particular interest is the Three Kings Plateau, specifically Spirits Bay, and the other is Foveaux Strait. These areas have both relatively high and low levels of AvTD compared to the regional mean. They are areas that have been subjected to scallop fishing, and oyster dredging, respectively – which could account for the lower levels of AvTD. Yet there are some sites that have high AvTD, and this means that some sites may have not yet been disturbed and thus are good candidates for protection in these areas.

Which brings us neatly on to my second example of collaborative studies with Dr Gordon where having bryozoans identified to the lowest taxonomic level possible, and his knowledge of the different morphologies and life habits of these species gained through the study of taxonomy, allowed for ecological insight.

Biogenic reef habitat

Complex habitat formed by living and non-living organisms that occurs as discrete, and sometimes extensive, structures on the seafloor is known generically as 'biogenic reef'. In our study concerning biogenic reef habitat (Cranfield *et al.* 2004), we were attempting to examine the hypothesis that John Cranfield

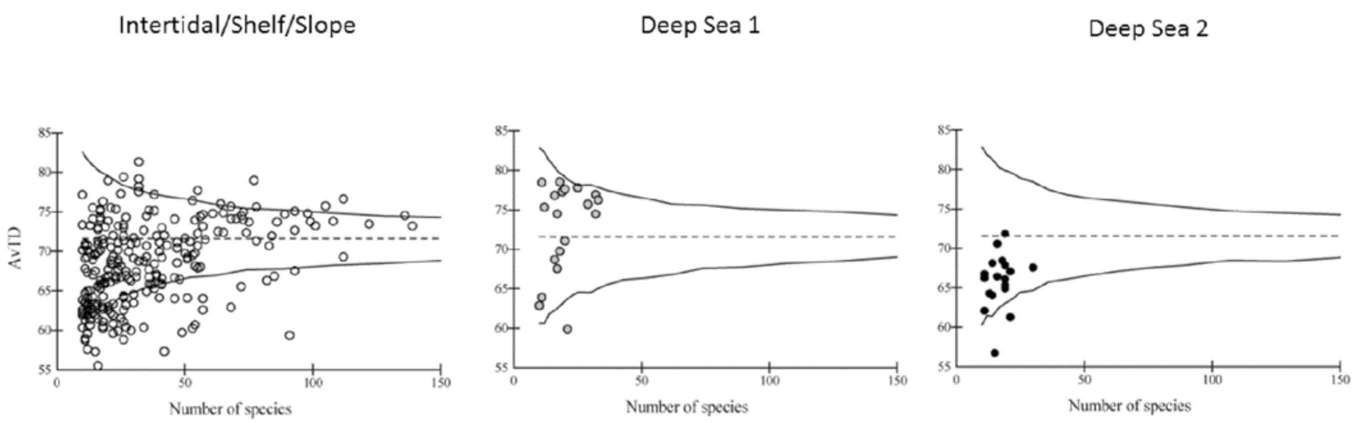

Figure 2: Plots showing the departure from the theoretical mean AvTD, and 95% confidence funnel, of stations in the New Zealand region with ≥10 species of Bryozoa for Inter-tidal/Shelf/Slope (open circles), Deep sea 1 (solid grey circles), Deep sea 2 (solid black circles) communities (modified from Rowden *et al.* 2004).

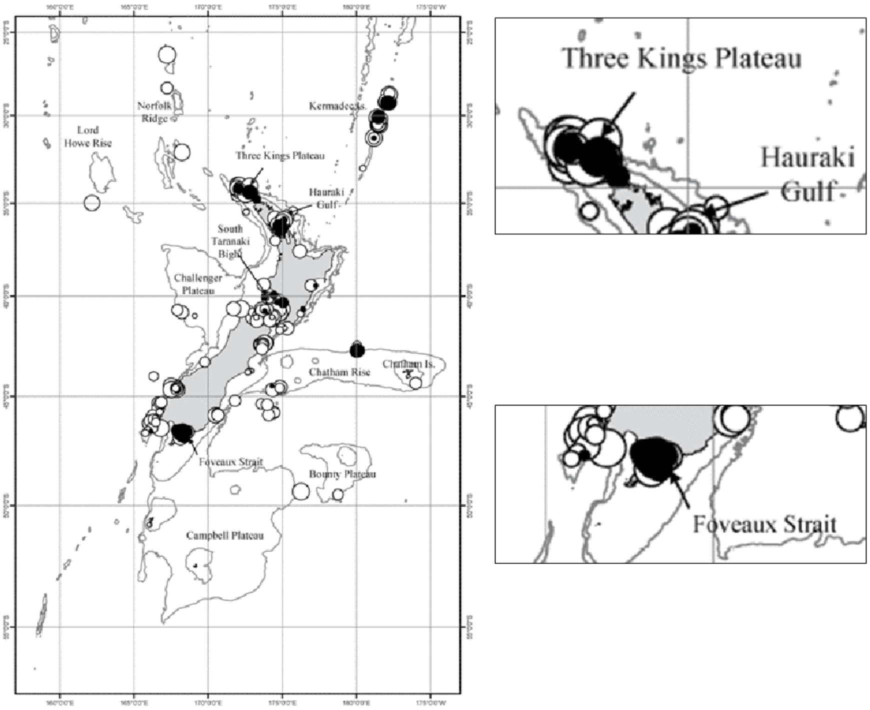

Figure 3: Map of the New Zealand region (and expanded detail for Three Kings Plateau and Foveaux Strait) showing the distribution of stations with values of AvTD above (solid black circles) and below (open circles) the theoretical regional mean, with increasing symbol size reflecting the magnitude of departure from the mean (modified from Rowden *et al.* 2004).

and colleagues from NIWA had postulated in an earlier paper – that over a hundred years of oyster dredging had reduced seafloor habitat complexity in Foveaux Strait, and this had had a profound impact on the structure of seafloor communities (Cranfield *et al*. 1999).

To examine this notion, five sites were chosen that represented a gradient of habitat complexity from 1 to 5 (Figure 4). These sites included previously dredged sites as well as the most un-impacted site that could be found (5): one that was as close as possible to representing the biogenic reef habitat that once dominated the seafloor of the Foveaux Strait.

Multivariate analysis confirmed the differences in the structure of seafloor communities among the sites. The ordination plot that we used to illustrate this result (Figure 5) shows samples from the five sites separated by their relative community dissimilarity. A test for seriation, i.e. sequential change in the community structure, was positive – which is illustrated in the

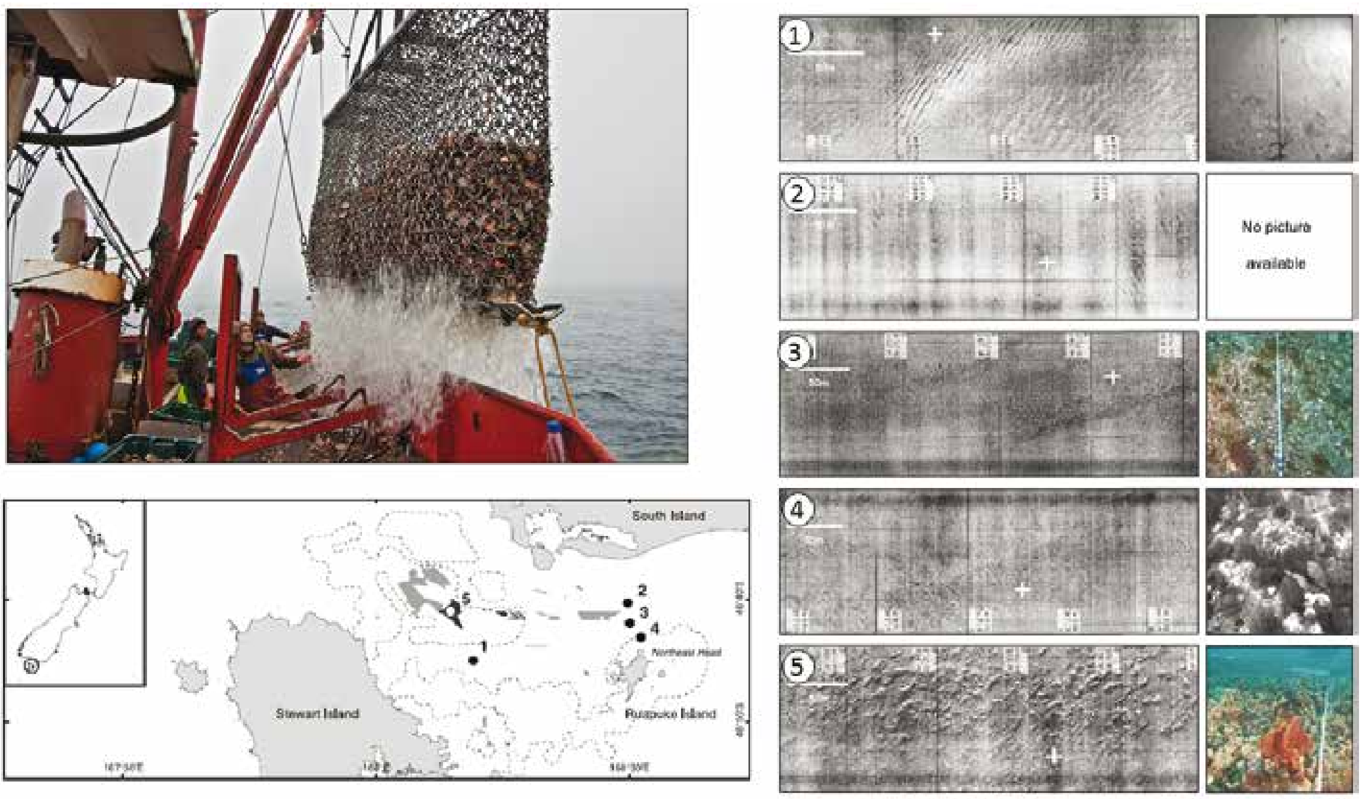

Figure 4: Figure showing (anti-clockwise from top left): Photograph of oyster dredge; Inset map showing location of Foveaux Strait in New Zealand, and main map showing the position of the five sampling sites in Foveaux Strait (numbered according to rank habitat complexity). Light grey shading demarcates areas of low relief biogenic reef, dark shading demarcates areas of high-relief biogenic reef as mapped from the 1998 side-scan sonar survey. Dotted lines delimit the probable extent of biogenic habitat on which commercial pot-fishing for the reef fish blue cod (*Parapercis colias*) occurred between 1994 and 1997; Sonograms (left panels) and underwater images (right panels) taken of areas of the seabed in Foveaux Strait. (1) Habitat 1, (2) Habitat 2, (3) Habitat 3, (4) Habitat 4, (5) Habitat 5. All sonograms are oriented with north at the top. White crosses mark the location of the five study sites of different habitat complexity, white scale bars show 50 m. Area of the seabed covered by video image varies (modified from Cranfield *et al.* 2004).

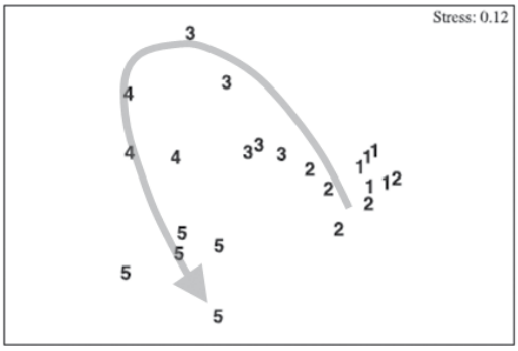

Table 3
Breakdown of average similarity, within sites of different habitat complexity (Habitat 1–5 = least to most complex habitat), into contributions from each taxon of the macrofauna assemblage sampled; species are ordered in decreasing contribution (cut-off applied at 25%)

	A	$\bar{S}_i$	$\bar{S}_i/SD(\bar{S}_i)$	$\bar{S}_i$ %	$\Sigma\bar{S}_i$ %
Habitat 1: Average similarity = 45.75%					
Micropora sp. (Bryozoa) ●	7.00	2.57	9.03	5.62	5.62
Penetrantia parva (Bryozoa) ●	4.80	2.33	9.14	5.09	10.71
Glycymeris modesta (Bivalvia)	4.00	2.18	7.90	4.76	15.47
'*Schizoporella*' *spectabilis* (Bryozoa) ●	4.80	2.13	3.37	4.65	20.12
Chaperia granulosa (Bryozoa) ●	4.60	2.12	3.41	4.64	24.76
Leptochiton sp. (Polyplacophora)	5.00	1.99	6.10	4.36	29.12
Habitat 2: Average similarity = 49.28%					
'*Schizoporella*' *spectabilis* (Bryozoa) ●	10.00	3.43	11.07	6.95	6.95
Micropora sp. (Bryozoa) ●	7.00	3.13	11.07	6.36	13.31
Buffonellaria turbula (Bryozoa) ●	7.00	3.13	11.07	6.36	19.68
Cribellopora napi (Bryozoa) ●	5.00	2.88	11.07	5.85	25.52
Habitat 3: Average similarity = 47.60%					
'*Schizoporella*' *spectabilis* (Bryozoa) ●	10.4	3.39	3.44	7.12	7.12
Buffonellaria turbula (Bryozoa) ●	11.00	3.36	4.24	7.05	14.18
Opaeophora lepida (Bryozoa) ●	3.40	2.42	7.22	5.09	19.27
Celleporella tongima (Bryozoa) ●	3.40	2.40	3.36	5.05	24.31
Cribellopora napi (Bryozoa) ●	3.40	2.38	3.49	5.00	29.31
Habitat 4: Average similarity = 53.76%					
Chrondropsis sp. 1 (Porifera)	81.89	2.37	5.32	4.41	4.41
Pyura spp. (Ascidiacea)	40.00	1.89	6.80	3.51	7.92
Lophopagurus laurentae (Paguroidea)	13.80	1.76	15.94	3.27	11.19
Sigapatella novazealandiae (Gastropoda)	13.00	1.63	11.81	3.04	14.22
Modiolus areolatus (Bivalvia)	10.20	1.56	25.93	2.90	17.12
Ostrea chilensis (Bivalvia)	20.00	1.48	3.69	2.75	19.86
Eunice spp. (Polychaeta)	10.20	1.44	4.24	2.68	22.55
Microporella agonists (Bryozoa) ●	7.60	1.41	16.66	2.62	25.17
Habitat 5: Average similarity = 61.11%					
Pyura spp. (Ascidiacea)	108.80	2.30	9.09	3.75	3.76
Crella incrustans (Porifera)	258.42	2.13	6.63	3.49	7.25
Modiolus areolatus (Bivalvia)	48.60	1.90	12.55	3.10	10.35
Chrondropsis sp. 1 (Porifera)	171.54	1.75	2.08	2.86	13.21
Actinothoe albocincta (Actiniaria)	33.40	1.64	10.15	2.68	15.89
Eunice spp. (Polychaeta)	16.80	1.45	16.26	2.37	18.26
Lophopagurus laurentae (Paguroidea)	19.20	1.43	8.59	2.35	20.61
Petrolisthes novaezelandiae (Galatheoidea)	13.80	1.29	10.62	2.12	22.73
Lophopagurus pumilus (Paguroidea)	15.60	1.22	8.30	1.99	24.72
Modiolarca impacta (Bivalvia)	13.40	1.21	2.95	1.98	26.70

A = average abundance 0.25 m^{-2}, see text for meaning of remaining symbols.

Figure 5: Figure showing (left to right): Two-Dimensional plot of n-MDS ordination of macrofaunal samples (using Bray–Curtis similarity measure of standardised, double square root transformed data) from sites of different habitat complexity (Habitat 1– 5 = least to most complex habitat). Arrows represents direction of succession in community structure; Table of the breakdown of average similarity, within sites of different habitat complexity (Habitat 1 – 5 = least to most complex habitat), into contributions from each taxon of the macrofauna assemblage sampled; species are ordered in decreasing contribution (cut-off applied at 25%). Grey dots mark bryozoan species (modified from Cranfield *et al.* 2004).

ordination plot by the horseshoe arrangement of the samples marked by the curved arrow.

The table included in Figure 5 shows the species that contribute the most to the community similarity of the samples taken at each of the five sites. The red dots show that bryozoan species are among the most important species that characterise the communities at the first three sites of relatively low complexity, before the relative importance of bryozoan species is replaced by other taxa such as bivalves (including oysters) and sponges that characterise the communities of sites of highest habitat complexity.

The results of this analysis allowed us to propose a model of habitat regeneration should oyster dredging cease at a site (assuming availability of colonising fauna, and physical conditions being suitable). This model is illustrated in Figure 6, in which the importance of bryozoans in that process of regeneration is highlighted.

This figure was designed to be a parallel to the classic model by Pearson & Rosenberg (1978) of the response of seafloor communities to organic disturbance; and we were pleased to see that was noticed by others, and it now sits alongside that model in one of the modern standard textbooks on Marine Ecology (Kaiser *et al*. 2011).

Bryozoans can constitute a significant habitat without the presence of sponges and bivalves, etc. Some bryozoan species are relatively large and complex in themselves, and can co-occur with others to form what are known as 'bryozoan thickets'.

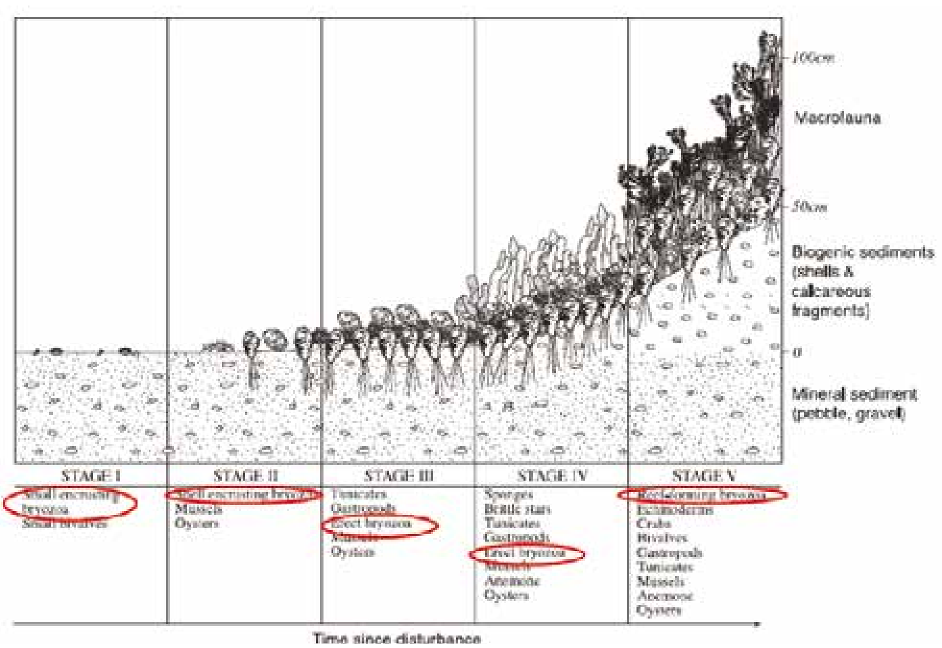

Figure 6: Diagrammatic representation of macrofaunal assemblage succession/ habitat regeneration on the seafloor of Foveaux Strait after dredging (modified from Cranfield *et al.* 2004).

These habitats can occur on the New Zealand continental shelf (Batson *et al*. 2000).

Bryozoan thickets

Bryozoan thickets are recognised by the regulations associated with the relatively recent New Zealand Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 as a 'sensitive environment', which resource users in the EEZ have to be aware of and take appropriate measures to mitigate any impacts their activities are likely to cause (http://www.legislation.govt.nz/regulation/public/2013/0283/latest/DLM5270660.html). In order to try and understand the relative importance of bryozoans as a habitat, Dr Gordon and I (along with her supervisors at the University of Otago) supported a PhD student, Anna Wood. One of the pieces of work that she undertook was to try and predict the distribution of habitat-forming bryozoans in the New Zealand region, to see what environmental variables control their distribution, and to also evaluate the risks of disturbance posed to these habitats (Wood *et al*. 2013).

For this study we again relied on Dr Gordon's knowledge of the life forms of the bryozoans, as well as that all-important species-level data set. Figure 7 is a picture of bryozoan habitat (granted it is a bit hard to see – they are not as colourful as corals) and the records of the 11 habitat-forming species in New Zealand waters identified by Dr Gordon. These records are relatively sparse, which is why we used habitat suitability modelling as a tool to tell us more about where the species may occur elsewhere.

Habitat suitability modelling takes the species records and combines them with environmental data to predict the probability that a species is present in an area. The map on the left of Figure 8 shows the records for one habitat-forming species, and the map on the right shows the predicted distribution of suitable habitat (where red is the highest level of predicted suitable habitat). This map shows that this particular species could actually be quite common on the shelf of the east coast of the South Island and on the slope of the southwest portion of the Chatham Rise. The set of graphs on the right of the figure show the environmental variables that are important for predicting the distribution of this species. In this case, the Sea Surface Temperature gradient – an indicator of the Southland Front and Sub-Tropical Front – and the mixed layer depth, were particularly important variables.

These same sort of outputs for all species not only allow us to predict where species may occur but also allowed a better understanding of the environmental conditions that control the distribution of habitat-forming species around New Zealand.

In terms of predicting where habitat-forming species may actually form notable habitat, such as bryozoan thickets, we produced composite predictions of habitat suitability for all species, reasoning that where habitat is suitable for the majority of species, a thicket is more likely to occur. The result of that analysis shows where up to eight species are predicted to co-occur, and some of the notable locations of these 'hotspots' are in the South Taranaki Bight, the Mernoo Bank, and off the southwest corner of the South Island (Figure 9).

The 'hotspot' map was compared with the distribution of fishing effort, which indicated that there were many places that fishing may already have impacted the habitat most suitable for the majority of habitat-forming bryozoans. So we next looked to see what protection might be afforded for these areas.

The maps in Figure 10 show the hotspots overlain with areas that receive protection, mostly from fishing. With a couple of exceptions, the hotspot areas are generally not currently afforded any protection. One area of particular note is shown in map E – the South Taranaki Bight – when a relatively large hotspot exists in an area that is already a place where drilling for hydrocarbons occurs, and where mining for ironsands was proposed. The first application for ironsand mining in that area was declined – but another proposal has been submitted recently (http://www.epa.govt.nz/EEZ/whats-going-on/current-applications/ttr-2016/Pages/default.aspx).

Conclusion

This research shows that the study of taxonomy and systematics provides information that is integral to the use of certain biodiversity metrics, provides for knowledge of life habits that can

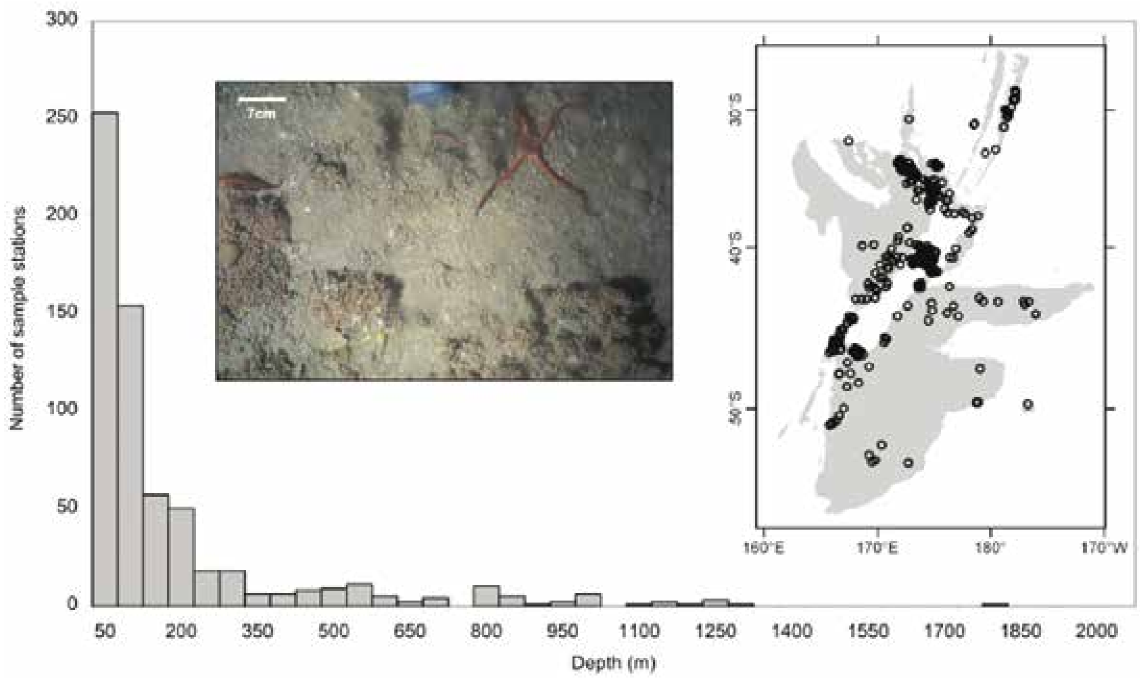

Figure 7: Summary distribution of collated bryozoan records in 50 m depth classes. The insert shows the geographic distribution of these sites, with gray shading showing water depths <2000 m, beyond which samples were excluded from the modelling. Photograph shows bryozoan thicket on seafloor (reproduced under Creative Commons from Wood *et al.* 2013).

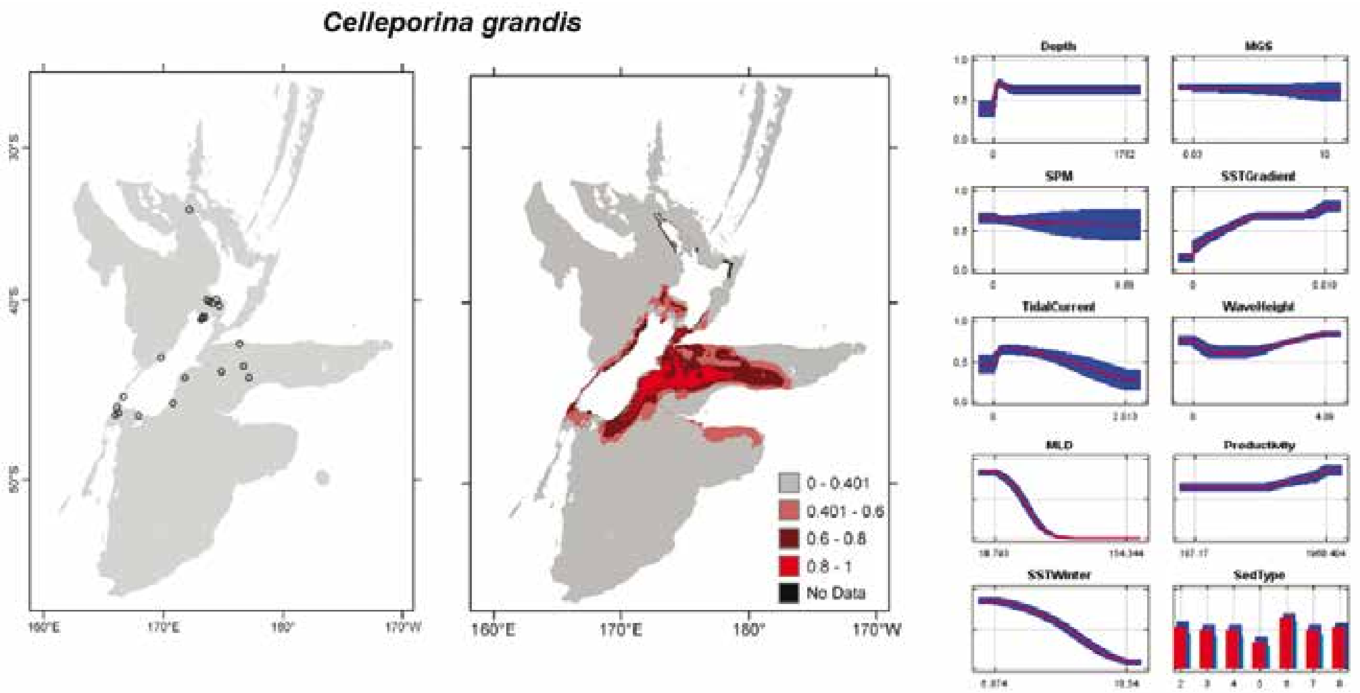

Figure 8: *Celleporina grandis* **known distribution (left), predicted suitable habitat (middle), and fitted responses curves (right) (reproduced under Creative Commons from Wood *et al.* 2013).**

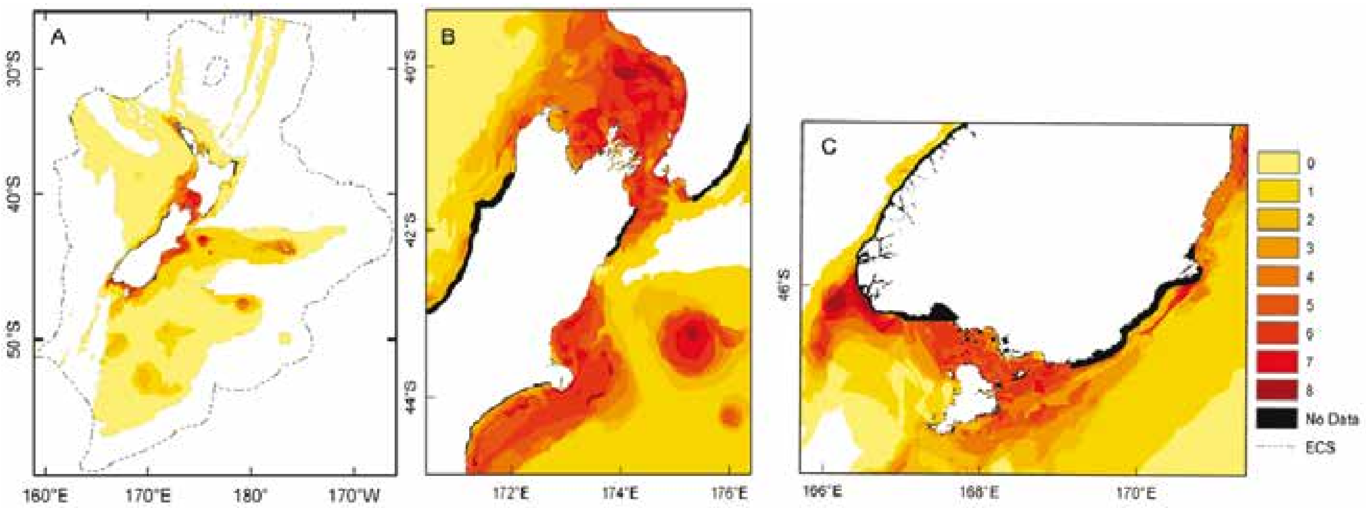

Figure 9: Predicted hotspots of habitat-forming bryozoans based on summed binary predictions of suitable habitat for multiple bryozoan species. (A) Extended Continental Shelf; (B) Greater Cook, Strait, Banks Peninsula and Mernoo Bank; and (C) around southern South Island, including Puysegur 'Bank', Foveaux Strait and Otago shelf (reproduced under Creative Commons from Wood *et al.* 2013).

be used to better understand disturbance impact and recovery dynamics, and morphological knowledge that can be used to identify and model the distribution of significant habitat-forming species. Ultimately, the results of these three studies, which are examples of many others working with Dr Gordon, generated information that could be used to guide conservation efforts for vulnerable communities and habitats.

Acknowledgements

Thanks to Dennis Gordon for sharing his knowledge developed over many, many years of dedicated study of bryozoan taxonomy and systematics. Thanks also to Daniel Leduc for inviting my contribution to the symposium *Systematics & Biodiversity: Past, Present* held as a tribute to Dennis, of which this report is a record.

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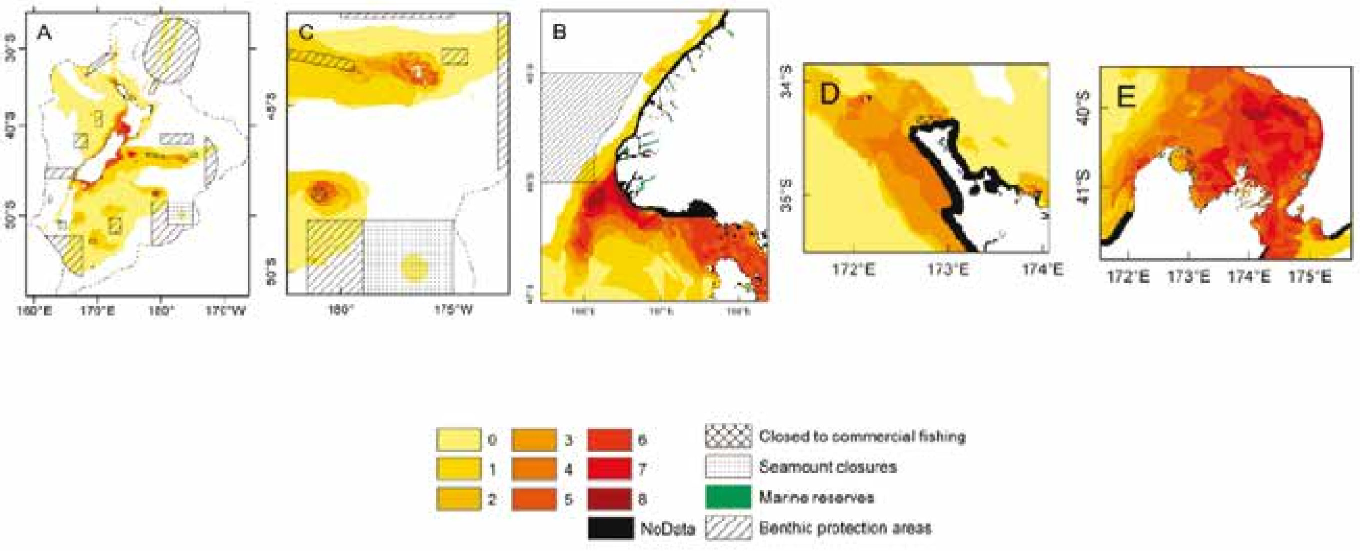

Figure 10: Figures showing the spatial relationship between predicted bryozoan hotspots and areas closed to commercial fishing (no trawl, Danish seine or commercial dredge (amateur dredge allowed)), seamount closures, marine reserves/marine protected areas, and benthic protection areas in the New Zealand. (A) across the Extended Continental Shelf; (B) west of Fiordland (south-west South Island); (C) on the eastern Chatham Rise, and around Chatham, Bounty and Antipodes Islands; (D) off northern North Island; and € off northern South Island (reproduced under Creative Commons from Wood *et al*. 2013).

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Taxonomic research, collections and associated databases – and the changing science scene in New Zealand

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The past two years have seen very important developments in the New Zealand science system. In particular, in this period we have seen the establishment of the National Science Challenges, the launch of the National Statement of Science Investment (NSSI), the reconfiguration of the Ministry of Business, Innovation and Employment (MBIE) contestable research funds (now the Endeavour and Smart Ideas funds), and most recently the establishment in the 2016 Budget of the Strategic Science Investment Fund (SSIF). At present consultation is under way on 'roadmaps' for conservation and environmental science, for the primary sector, and for biosecurity, recognising the need for sound science to underpin policy and decision-making.

In 2015 the Royal Society of New Zealand convened a panel to investigate the state of taxonomy and taxonomic collections in New Zealand, releasing a report of its findings in December 2015.[1]

When the Department of Scientific and Industrial Research (DSIR) was dis-established and Crown Research Institutes (CRIs) created, a number of collections and databases were assigned the status of being 'nationally significant' (NSCD). Although there are NSCDs that are taxonomically focused (housed in Landcare, NIWA, GNS, SCION), only about half of all taxonomically important collections are within the care of CRIs, with the remaining collections residing primarily in museums, particularly the Museum of New Zealand Te Papa Tongarewa (funded by the Ministry of Culture & Heritage) and major metropolitan museums (funded by rate payers), as well as smaller collections in some universities (funded through departmental funds or Performance-Based Research Funds (PBRF)). In addition a small live collection of microalgae is maintained at the Cawthron Institute for taxonomic and other purposes, and is recognised as nationally significant by MBIE.

At the level of individual organisations there are examples of where the science needs of end-users have been identified through consultative processes and where priority setting and engagement is very well embedded in research and resource planning. Despite the complexity of different funding streams, the taxonomy and collections sector is very clearly defined and there is a very high degree of collegiality across this science community. The Royal Society report highlighted the major issues facing the sector, especially the lack of strategic alignment between the funding of services and their delivery (refer to page 47 of the report). The Panel was convinced that a system-wide approach was needed to get better value from the current system and to develop strategic approaches to new investment.

MBIE states the Government's vision for the science system for 2025 is '*a highly dynamic science system that enriches New Zealand, making a more visible, measurable contribution to our productivity and wellbeing through excellent science*'. The establishment of the SSIF appears to align very well with the conclusions of the Royal Society panel. From the MBIE website we are told: '*The SSIF will support underpinning research programmes and infrastructure of enduring importance to New Zealand*', attributes that have been acknowledged by research providers and end-users about the taxonomy, collections and databases. However, there has been no indication that the evidence-based conclusions of the Royal Society report are being incorporated into the decisions that are shaping our future science system.

The Royal Society report provides many examples of the reliance of a number of sectors on the expertise and data within the taxonomy and collections community – ranging from export assurance, human health, biosecurity and environmental protection. The important contributions of the non-CRI sector, particularly the museums, apparently remains invisible to decision makers, yet within the CRI collections there are no vertebrate reference collections and only about one-half of all plant collections. In addition, the university sector provides critical collections (e.g. Lincoln University entomology, Otago

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[1] Nelson, W.A.; Breitwieser, I.; Fordyce, E.; Bradford-Grieve, J.; Penman, D.; Roskruge, N.; Trnski, T.; Waugh, S.; Webb, C.J. 2015. *National Taxonomic Collections in New Zealand.* Royal Society of New Zealand. 63 pp. + Appendices (66 pp.) ISBN 978-1-877317-12-5 www.royalsociety.org.nz/national-taxonomic-collections-in-new-zealand

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University herbarium) in parts of the country that do not have a CRI branch nearby. Having a distributed network of taxonomic collections for reference purposes is recognised as a key strength in our current system. However, the value and support for this network is not able to be realised, as there is no coordination or recognition of the cross-institutional linkages that would enable more effective outcomes.

The Royal Society Panel identified the corrosion of capability, and the fragility of our knowledge base, the prolonged period of disinvestment, and the consequent risks to New Zealand with regard to our ability to respond to biosecurity crises, to effectively manage species, habitats and ecosystems across terrestrial, aquatic and marine domains, and to contribute to a range of economic outcomes.

At this time when policy is being developed to address the long-term needs of New Zealand and how science can inform government decision making, it is unclear why the opportunities to tackle critical issues in the taxonomy and collections sector, particularly in relation to coordination, strategic alignment and funding, are not being addressed with urgency.

One advantage of working within New Zealand is the scale of our systems – it is possible to get all the key players around a table to work collectively for the national interest. The taxonomy and collections sector, although widely distributed institutionally and geographically, offers a critical platform of underpinning expertise and resources. The recognition of the need to support infrastructure, and the development of the SSIF, provide the opportunity to develop both a coordination model and a tailored approach to investment that recognises the nature of the activities of the taxonomic collections sector, and the time frames over which this work occurs.

Executive summary of *National Taxonomic Collections in New Zealand* (2015) Royal Society of New Zealand[2]

Biological collections, supported by world-class taxonomic expertise and research, provide the evidence base for New Zealand to respond effectively to present and future challenges.

The knowledge enshrined in the collections is needed in many spheres of New Zealand life, delivering essential information and valuable benefits, for example:

- The primary production sector requires accurate and authoritative information to provide proof that products are pest- or disease-free for export markets and ongoing access. The identification of pests, pathogens, and biological contaminants is critical for maintaining market reputation especially in relation to food safety. In addition, taxonomy is essential for the identification of species that may have economic potential or attributes that, for example, would be valuable under changed climate conditions. Also of economic value is the development of innovative products on the basis of biodiscovery from native biota; species identification and distribution information are crucial for such activities.
- Biosecurity, an important part of risk management for New Zealand's economy, environment, and human health, depends on accurate, authoritative and rapid identifications of invasive organisms such as weeds, pests, toxin producers, and pathogens. Collections and knowledgeable research taxonomists provide the primary material and vouchers needed. Without such capacity, response to biosecurity threats would be based on little more than guesswork.
- New Zealand has a clear international responsibility to identify, classify and protect its species, and meet international treaty obligations (e.g. Convention on Biological Diversity, Intergovernmental Platform on Biodiversity and Ecosystem Services, environmental reporting in the OECD). This includes the obligation to implement the agreed-upon New Zealand Biodiversity Strategy, which calls for the protection of natural ecosystems, flora, and fauna.
- Monitoring and managing changes in biodiversity and the environment are entirely dependent upon authoritative taxonomic data and expertise. These are prerequisites if New Zealand is to meet its obligations relating to environmental monitoring under the new Environmental Reporting Act.
- There are legislated requirements for accurate and timely information about species, their distributions, and their interrelationships (e.g. Resource Management Act, Hazardous Substances and New Organisms Act, Environmental Impact Assessments as part of regulations such as the Extended Economic Zone and Continental Shelf Environmental Effects Act). Further, New Zealand's ability to provide certainty about the effects of resource use and management in the primary sector (agriculture, horticulture, forestry, aquaculture, wild fisheries, and mining) is heavily dependent on biological collections and taxonomic expertise.
- Human health outcomes are directly influenced by proactive provision of critical identifications of and information about poisonous plants, toxic algal blooms, and other pathogens that could have serious health and economic consequences.
- The quality of New Zealand's research output in many areas of biological science and ecology depends on the ability to accurately identify the organisms being studied.

All of this relies on the interplay between taxonomists and physical specimens. It is an active process, involving research, and reference to scientifically validated reference collections, databases and literature. The evidence base must be authoritative, well documented, accessible, comparable over time, and supported by world-class taxonomic expertise.

Given the wide benefits that this research infrastructure enables, to what extent is strategic guidance being provided over its directions, standards and investment; is the funding and capacity of New Zealand's specialist taxonomic research optimal; and is sufficient taxonomic training being undertaken to meet New Zealand's needs in this area?

[2] www.royalsociety.org.nz/national-taxonomic-collections-in-new-zealand

The Royal Society of New Zealand convened a Panel of experts to investigate these questions and to provide recommendations on the current support, development, and management of New Zealand's taxonomic collections and their future needs, including the taxonomic research, information systems, and expertise vital to make them useful.

The Panel gathered evidence from 29 taxonomic collections housed in Crown Research Institutes (CRIs), the Cawthron Institute, museums and universities. These represent the majority of New Zealand's biological collections that are actively supported with taxonomic research. They contain over 12 million specimen lots* of vertebrates, invertebrates, plants, fungi, micro-organisms, and fossils. The Panel also undertook surveys of the taxonomic workforce, and taxonomy stakeholders, and referred to reports and publications from New Zealand and overseas.

Summary of findings

This investigation identifies inadequate and overall declining support for this nationally important resource. Erosion of investment, particularly evident in the CRI sector, has seen loss of national capability in specialised expertise in taxonomy and curation through redundancies, reduced hours, and non-replacement of retiring staff. In addition it has led to collections being closed or having limits put on access, and reduced ability to protect specimens and deliver services.

Continued decline in support for the collections is a real risk for New Zealand, especially if it continues to occur largely out of sight and incrementally until a major event in the future highlights deficiencies. It also means that New Zealand is limiting its opportunities to adopt new technologies and provide best-practice interoperability of data and information systems, both domestically and internationally.

The investment in collections and taxonomic research in New Zealand is fragmented. The key sources of investment are the Ministry for Business, Innovation and Employment (for CRIs and Cawthron Institute); the Ministry for Culture and Heritage (Museum of New Zealand Te Papa Tongarewa); City Councils (metropolitan and regional museums); Tertiary Education Commission (Performance Based Research Fund) and Universities (assorted research funds).

The biological collections' infrastructure (physical specimens, taxonomic research, tools and information systems, and associated activities) is largely invisible to the final beneficiaries as many services that rely on and access the collections' infrastructure are delivered through government agencies or other intermediaries. Even where services are provided directly, these are often provided through tools and information systems alongside the advice of taxonomy experts, with the physical collections and their curation and management needs largely unseen. The Panel has noted that Treasury guidelines for financial reporting of heritage and cultural assets do not cater well for the types of collections being considered here.

The Panel notes that there is a disconnect between the funding and delivery of services. There is no apparent strategic alignment between the setting of short-term output priorities of departments and agencies, and the long-term input investment priorities of those providing the main funding to the collections' infrastructure.

Despite their uniqueness and value, legal protection for collections exists only under the Museum of New Zealand Te Papa Tongarewa Act 1992, the Auckland War Memorial Museum Act, and Trust Board Acts of some metropolitan museums. In addition, the Protected Objects Act 1975 is now dated and provides protection for natural history specimens mainly in the area of sale and export outside of New Zealand.

There is no coordinated national process for assessing whether collections' research activities, and the collection development policies of individual institutions, meet national and stakeholder needs. Nor, in the absence of national scale oversight, are collections' infrastructure safe from individual institutional policy changes and priorities. The combination of eroding support, lack of formal protection, and reliance on individual organisations' prioritisation processes, poses a risk of unintentional consequences if not addressed. The Panel has observed several examples where decisions have been made or are being considered by individual organisations to stop or reduce activities to respond to their own budgetary constraints, and not necessarily acting in the country's long-term interests.

Demands on the biological collections' infrastructure and services are increasing both in New Zealand and overseas. For example, growing international trade increases biosecurity risk; increasing human and animal health risks driven by population, climate and immigration pressures; growing international demand for certified pest- and toxin-free food; global efforts to advance knowledge of ecosystem services and to contribute to regional biodiversity assessment; initiatives to identify and protect vulnerable marine ecosystems; and increasing research efforts to investigate the world's evolutionary biology. There is also increasing demand from communities, such as iwi resource managers, citizen science, and the natural resource sector to mobilise data about the distribution and abundance of species.

The specific requirements for access to the collections' infrastructure (both collection material and taxonomic expertise) are generally frequent but unpredictable. This means that significant numbers of biological specimens need to be proactively collected, stored, documented and kept useable, possibly for very long periods of time, to be available when needed. When they are required, speed of access to both information and taxonomic expertise is often paramount.

New Zealand's publicly funded taxonomic workforce is only funded to spend a small proportion of their time on taxonomic research, far below the standards of Australia and Canada. In our survey of 97 publicly funded taxonomists, 77% are funded to spend less than 25% of their time on taxonomic research and only 16% of the workforce is in the 20–40 age bracket. This situation poses a real risk for New Zealand, for example in terms of succession planning. This is compounded by concerns over whether graduates in biology are sufficiently equipped with an understanding of basic taxonomic principles.

The involvement of iwi Māori and scholars of Mātauranga Māori, in the care, development, and use of collections is minimal at present, and there is considerable potential for the collections to be used to further the integration of Māori cultural concepts in New Zealand society, and to allow for iwi development. In addition, there is an opportunity to build Māori and Pasifika capability and contributions to the contemporary science of taxonomy including the importance of traditional knowledge systems to complement that which has been collected in currently established collections.

*A "lot" is a group of specimens of one species or taxon that are from the same collection locality and collected at the same time.

Continuing declines in investment are limiting the ability of institutions to respond to existing demands, let alone meet new demands and opportunities. This means that New Zealand is not obtaining full benefit offered by emerging digital and analytical techniques, and molecular technologies. High priority has to be given to securing the current infrastructure, both physical assets and expertise.

The biological collections' infrastructure requires a long-term commitment and stable investment to work effectively. The annual cost of this is a very small fraction of the benefits that the collections enable. For example, an effective biological collections' infrastructure is critical in the defence of the economy, environment and society against pests, diseases, and weeds which currently cost New Zealand $2.45 billion annually, and in ensuring market access for New Zealand's $1.5 billion seafood exports.

The Panel's analysis of other countries' taxonomic infrastructure shows that New Zealand is not alone in the issues raised here. However, as a small and relatively well connected country, we should be able to do much better than we are.

Currently, New Zealand is not meeting its international obligations with respect to mobilisation of data and information sharing, nor is it leveraging opportunities that the international community provides. The Panel believes that central and local government have the major responsibilities for addressing the investment requirements, coordination, and protection for the collections. The majority of investment needs to come from the public as there is limited appetite for the private sector to pay beyond the cost of immediate service delivery, especially given that the collections require long-term investment and need to be accessible by a wide variety of public and private users. It is much more efficient for government to do this collectively on behalf of all users. The government also has a role to mitigate coordination failure that is a consequence of the fragmented system of collections' ownership, use, and investment. This includes both coordination within government and support for stronger national coordination. The government has a role to provide legislative protection to ensure that the evidence base provided by the collections is maintained and remains available for the long-term benefit of New Zealand.

Recommendations

The Panel is convinced that a whole-of-systems approach must be taken to interconnect providers, custodians, practitioners, stakeholders, and end-users. Thus the following recommendations need to be implemented as an integrated package to ensure the most effective and efficient use of existing and future resources, addressing coordination, investment, stewardship, protection, and training.

The collections should be recognised as national heritage assets and essential components of the New Zealand science system, underpinning a wide range of public and private benefits. The biological collections' infrastructure needs to be nurtured, protected, and accessible for current and future generations of New Zealanders, within an investment framework that recognises the intergenerational values of these assets.

The Panel recommends that:

System performance

1. New Zealand should retain a decentralised and geographically spread network of national taxonomic collections that enables integrated and close collaborative links with end-users.
2. New Zealand's taxonomic collections should be located in establishments that have clear commitment to stewardship to ensure long-term protection and ongoing curation.
3. New Zealand's taxonomic collections should be accessible for the benefit of New Zealand, reflecting their use across multiple public-benefit domains, while also meeting collection standards, policies, and protocols. Where charges are made (such as for specific access, or under commercial contract to specialist users and service providers), this should not limit access by others.
4. Government resource a mechanism that enables coordination and oversight of New Zealand's taxonomic collections by collection holders, to improve practices relating to standards, taxonomic research, training, biodiversity information systems, and to provide a source of advice to government and stakeholders.
5. A single point of responsibility within government is established to coordinate a coherent approach to policy and investment in the biological collections' infrastructure. This would also provide a channel for interaction and information exchange between the Government and collection holders.
6. Strong protection is provided for the collections that form part of our national biological collections' infrastructure.

Investment

7. The evidence and findings of this review are incorporated into the 2015 review of Core Purpose Funding for CRIs, reflecting the significance of the CRIs in managing these collections.
8. Government urgently address the immediate investment needs of the national taxonomic collections and research staff so that critical taxonomic expertise is restored, and that services and quality are not put at further risk.
9. Government adopt a strategic and more tailored approach to investment based on a set of principles set out in this report, which would provide greater certainty for collection holders in planning for both short and long term demands.
10. Substantial new investment is made to meet the growing demands on the taxonomic collections. This should address: i) the large backlog of curation and digitisation of existing collections' information; and ii) application of new technologies (e.g. for specimen and data analysis, integration and mobilisation of data, and development of appropriate informatics tools).
11. New investment is made to support training, such as internships, scholarships and fellowships, to attract high-calibre researchers into New Zealand taxonomy and collection management, and to ensure New Zealand has a strong and expert taxonomic workforce.

Is there a taxonomic crisis?

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Concern has been expressed around the world concerning the 'taxonomic crisis': that is, although biodiversity is being lost at an ever-increasing pace, species discovery and description (taxonomy) is facing a crisis. Recently, a number of papers have been published that suggest there is not a taxonomic crisis, based on electronic databases that contain uncritically recorded species synonyms and that do not make it clear who the taxonomist is on multi-authored papers. Claims that there have never been more taxonomists are likely to be incorrect especially if they are made by non-taxonomists not intimately familiar with the limitations of each electronic dataset and the taxonomic enterprise. In response to concerns in New Zealand about the precarious position of collections (scattered across several types of institution with separate funding sources) and associated taxonomic expertise, the Royal Society of New Zealand (RSNZ) convened a panel to look into the situation in New Zealand resulting in a report published in 2015. The panel confirmed that collections and taxonomy play an important role in a wide range of national activities (economic, biosecurity, human health, conservation, sustainable use, etc.). The RSNZ report noted the lack of strategic connection between science funders and priority setters and a lack of alignment between the funding of collections infrastructure and the delivery of services. The taxonomic workforce in New Zealand is characterised as ageing, male-dominated, and with very low numbers in the 19-30 age group. This workforce is mostly not doing taxonomic research (77% were funded to spend less than 25% on research and 59% could spend less than 10% on research) resulting in a zero to low published output for the majority. This suggests that qualified researchers are underused in New Zealand and risk not being up-to-date and in danger of eroding their capability. Compared with Canada in 2009 and Australia in 2003, New Zealand has the lowest proportion of researchers in the 20-40 age bracket. Compared with Canada, a very small proportion (4%) of researchers in museums can spend more than 50% of their time on taxonomic research in New Zealand (58% in Canada). A solution needs to be found to the problem created by diffuse responsibilities for taxonomic collections infrastructure and lack of strategic connection between science funders and priority setters. This solution should include the creation of a national co-ordination mechanism.

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Introduction

Concern has been expressed around the world concerning what has been call the 'taxonomic impediment' or 'taxonomic crisis' (e.g. Agnarsson & Kuntner 2007; Bortolus 2008). That is, although biodiversity is being lost at an ever-increasing pace, species discovery and description (taxonomy) is facing a crisis.

In the context of answering the question: 'How many species remain to be described globally?', some recent analyses (Joppa *et al.* 2011; Costello *et al*. 2012, 2013a, b) conclude that: more taxonomists are describing species than ever before, and the rate of species discovery per 'taxonomist' is falling. These authors used the decline in rate of species discovery to estimate the number of missing species. Some of their conclusions have become the subject of heated debate (Mora *et al*. 2013; de Carvalho *et al*. 2013; Bebber *et al*. 2014; Wheeler 2014) because the results imply there is not a taxonomic crisis. Here, the controversy is further investigated and the New Zealand state of affairs analysed.

Misinterpretation of data

The reaction of some taxonomists globally has been indignant, given their individual circumstances. For example, Quentin Wheeler (2014) of Arizona State University has witnessed the steady haemorrhaging of prestige, funding, and positions from taxonomy for more than three decades. He finds that advertisements seeking to hire taxonomists to do taxonomy and grants to do taxonomy for its own sake are essentially non-existent.

Bebber *et al.* (2014) and Mora *et al*. (2013) critiqued the analysis of Joppa *et al.* (2011) and Costello *et al.* (2013a). They question whether conclusions can be justifiably drawn from analyses of the apparent rate of new species discovery and whether conclusions can be drawn about the taxonomic work force. They contend that answers depend on several issues. First, it is important to know where, in the discovery process, a taxon of interest is currently situated – is species discovery in its earliest stages or at a mature stage where most species have been discovered? Second, synonyms that exist unquestioned in some databases need to be acknowledged as sources of overestimation of numbers of species (Löbl & Leschen 2014). Third, it needs to be recognised that the number of full-time professional

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taxonomists is not accurately represented by the total authorship of many taxonomic papers (Bebber *et al*. 2014).

Are there more taxonomists than ever before?

The contention that there are more taxonomists than there have ever been, has been analysed further. It is true that numbers of taxonomists are decreasing in some institutions of countries that formerly led in taxonomy (e.g. Anon. 2010). Nevertheless, in Asia and South America, numbers appear to be increasing (Costello *et al*. 2013a). But, the contention that taxonomists are increasing 'exponentially' (Joppa *et al*. 2011) is challenged by Bebber *et al.* (2014) who analyse the phenomenon of 'author inflation'.

That is, they found a tendency, with time, for the number of authors on a paper to increase in several research areas, including the taxonomy of flowering plants. They point out that the authors of papers are not necessarily the authority for the species description and, over the period from 1970 to 2011, the number of authors linked with species descriptions increased three-fold. At the same time the average number of species described per author decreased. They argue that these data show that, for flowering plants, there has been a nearly constant rate of description of species over the 40-year period and that global taxonomic capacity has remained largely unchanged. But, like other branches of science, authorship has increased as students, junior staff, laboratory assistants and technical staff are included as authors, as well as, with an increase in collaborative science, colleagues who provide, for example, molecular data.

Who speaks for taxonomists?

Behind the above controversies is disquiet over the misrepresentation of taxonomists and the systematics enterprise, leading de Carvalho *et al*. (2013) to question who should speak for taxonomists. Carvalho and co-authors contend that defining taxonomists as *people describing species new to science* is akin to defining racing car drivers as those who own a car. This uncritical view belittles the effort and scholarship needed to educate and support taxonomic specialists. Unintentionally, Costello *et al*. (2013a) undermine professional taxonomy in museums, institutes and universities, where professional collection-based research is undertaken, by his acceptance of this limited definition. 'Far beyond discovering and naming new species, taxonomy is driven by evolutionary hypotheses that generate predictive classifications and improve our understanding of biotic diversity through meticulous systematic revisions and homology assessments' (de Carvalho *et al*. 2013).

De Carvalho *et al*. (2013) assert that taxonomists are at the mercy of bioinformaticians, phylogeographers, ecologists and those who have recruited 'biodiversity' to their cause. As a result, the interpretation of biodiversity is at a crossroads and is currently failing to gain institutional support and recognition. The fate of systematics and collections-based research has not been improved by the support of bioinformaticians for innovative technical initiatives. The initiatives that have applied new technology to existing data (not generating new data – e.g. GBIF, WoRMS) have mopped up a considerable fraction of the money available during the Biodiversity Decade of the 1990s (Flowers 2007). These initiatives have represented additional IT chores for taxonomists who have been expected to act as unpaid data entry technicians.

In many countries the process of *dismissing taxonomy* is still on course to destroy their expertise in taxonomy despite the fact that taxonomy underlies the credibility of much of biological science (Flowers 2007; de Carvalho *et al*. 2013). Yet, accurate identifications supervised by an experienced systematist and scientific names linked to an appreciation of the phylogenetic position of taxa of interest are central to the longevity of conclusions from other biological sciences.

For New Zealand, many of the same trends are evident. This leads to the question of whether there are enough well-supported, practising taxonomists who are able to maintain and improve their skills and can thus provide the underpinning support for the whole biological science enterprise and society's interests.

RSNZ Report on National Taxonomic Collections 2015

In response to concerns about the precarious position of collections and associated taxonomic expertise in New Zealand, the Royal Society of New Zealand (RSNZ) formed a panel to look into the situation in New Zealand (Anon. 2015).

The panel found that taxonomic collections (scattered across several types of institution with different sources of funding) play an important role in the accurate identification and authentication of species which underpin a wide range of economic, biosecurity, human health, conservation, sustainable use, cultural identity, scientific credibility, and quality assurance activities, to cite a few examples. The RSNZ report noted a lack of alignment between the funding of collections infrastructure and the delivery of services (Anon. 2015: 47). That is, there is weak strategic alignment between the setting of output priorities by departments and agencies that are providing services and benefits, and the input priorities of those providing the main funding to the infrastructure of collections. There is also no obvious alignment between the input science funding to research organisations and collection infrastructure, despite that fact that New Zealand depends significantly on all of these biological collections.

No solutions to this situation have been proposed in the Conservation and Environmental Science Roadmap: Discussion Paper (Ministry for the Environment and Department of Conservation 2016). In this discussion document there is no mention of the RSNZ report. On page 35 it is noted, under the Biosecurity theme, only that 'The sustainability of taxonomy and systematics capability – and related infrastructure, such as collections – is a crucial issue that needs to be addressed' without presenting options for solutions. This is disappointing, given that the Conservation and Environmental Science Roadmap is where we would expect to see some strategic guidance to solving the problem of weak strategic alignment. The final roadmap document is due to be released in early 2017. The RSNZ report formulated a number of recommendations (Anon. 2015: 10). Among these is a proposal for a coordination and oversight mechanism undertaken by collection holders coupled with a single point of responsibility within government for interaction and information exchange. This would allow for coherent coordination and policy development and investment in collections' infrastructure and taxonomic capability.

The flawed characteristics of New Zealand's national taxonomic collections' infrastructure occur in a setting where some of the professional taxonomy workforce feels neglected and their ability to maintain their expertise is declining as are their effective numbers. Here, the real situation is evaluated based on the work of the RSNZ Panel (Anon. 2015).

New Zealand taxonomic workforce

To assess the state of taxonomic expertise in New Zealand the RSNZ panel undertook a survey of individuals in taxonomy-related activities in New Zealand (Anon. 2015: 38, Appendix 5).

One hundred and seventy three individuals responded, including 10% who were retired or volunteers and 22% in the 'other' category, which included individuals working in other occupations, self-employed or unemployed. That is, the sample population contained a wide range of skills from parataxonomists up to highly experienced taxonomy practitioners, a number of whom are not working directly in taxonomy.

From this survey, it is very difficult to be certain how many professional taxonomists are employed in New Zealand because the survey questions led to ambiguity in the self-reporting of expertise and employment and the sampling regime did not allow a reliable estimation of the total population of taxonomists. Nevertheless, the impression is that New Zealand potentially has a skilled population of taxonomists that is commensurate with most developed countries, given our population size. Since we are concerned with professional taxonomy practitioners, these were separated from the basic survey population based on their answers to the survey questions. This group of 101 respondents had a number of distinct characteristics.

Fifty two respondents were affiliated with CRIs + Cawthron Institute (15% were retired); 21 respondents were affiliated with Museums (16% retired); and 28 respondents were affiliated with universities (24% retired) (Fig. 1). When those who appear not to be publicly funded are removed, the taxonomy practitioner workforce comprised 97 individuals who could be available for urgent responses, e.g. biosecurity incursions.

This group is a male-dominated, ageing workforce with peak numbers in the 51–60 age group and very low numbers in the 19–30 age group (Fig. 2). Their expertise is spread across a wide range of taxa (Fig. 3), and when aggregated according to broad organism categories, they approximated the spread across the same broad organism categories in collection holdings.

Seventy seven percent of the workforce were funded to spend less than 25% of their time on taxonomic research and 59% were funded to spend less than 10% on taxonomic research. This suggests that highly qualified researchers are underused in New Zealand. They risk not being up-to-date, in danger of eroding their capability without sufficient time allocated to support their research and associated professional development (Table 1).

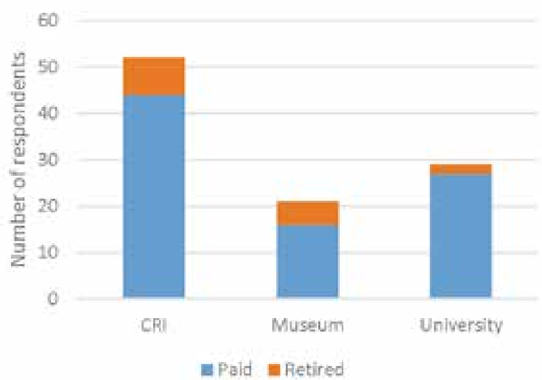

Fig. 1. Proportion of retired / volunteers amongst taxonomy practitioners (from RSNZ Report Anon. 2015).

The majority (70%) of practitioners report a zero to ten publication output (Table 2) probably related to their level of expertise, low level of taxonomy funding and/or the type of position they have. Thirty nine experienced individuals reported

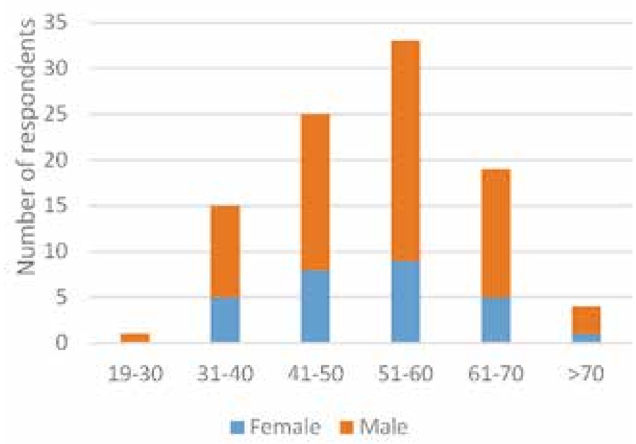

Fig. 2. Age and gender structure of employed publicly funded taxonomy practitioners (from RSNZ Report Anon. 2015).

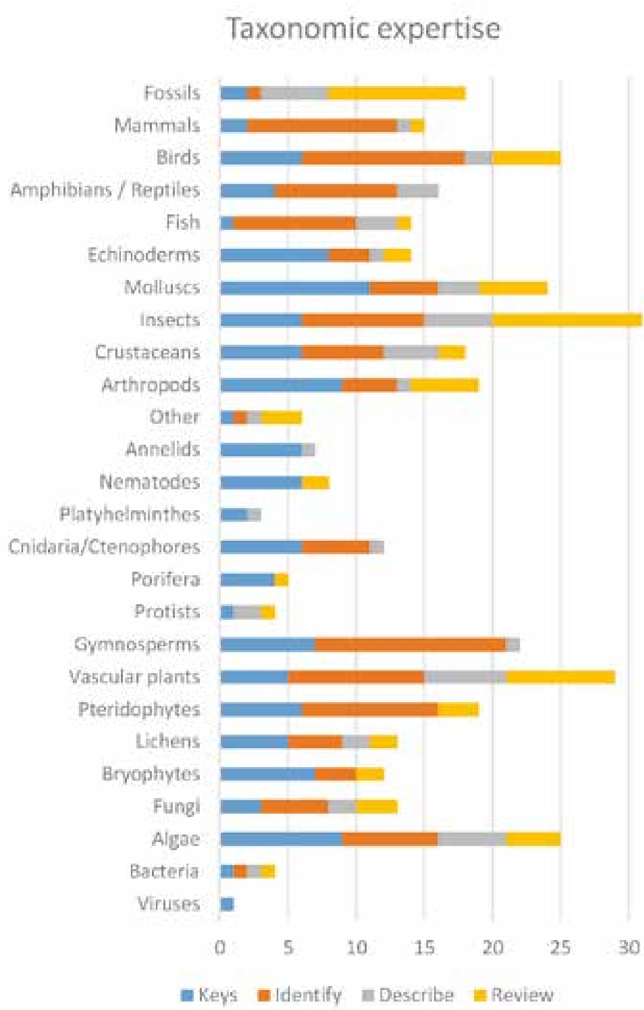

Fig. 3. Highest taxonomic level attained by 97 publicly funded practitioners report against higher level taxa / groups. Horizontal axis is number of reports. Note that some individuals have skills relating to several taxa so the numbers do not add up to total respondents. Keys = can recognise species with keys or reference materials, Identify = can identify species, Described = have written species descriptions, Revise = have written a taxonomic revision. (From RSNZ Report Anon. 2015).

Table 1. Number of publicly funded practitioners reporting being able to spend a range of their time on taxonomic research (from RSNZ Report Anon. 2015).

Time	Numbers	%
0%	7	7
<5%	25	26
10%	25	26
25%	17	18
50%	13	13
75%	10	10
100%	0	0
Total responses	97	100

a total accumulated output of more than 20 journal articles and a small number had the highest output of taxonomic revisions.

Compared with a survey in Canada in 2009 (Anon. 2010) and Australia in 2003 (Anon. 2003/2006), New Zealand has the greatest imbalance in its taxonomic workforce, with 16% in the 20–40 age bracket (Table 3) compared with 36% in Canada and 23% in Australia. Both Canada and Australia appear to have been more regularly recruiting younger taxonomists.

Patterns of time spent on taxonomic research in New Zealand and Canada, at selected types of institution, indicate that there is a vastly larger proportion of New Zealand taxonomists who are underutilised in their speciality (Table 4).

Looking forward

New Zealand's aim should be to achieve a healthy, internationally connected, professional employed workforce in New Zealand that includes a basic number of professional taxonomists who are able to contribute to accurate identification and authentication of species relevant to the national interest. These individuals should also have enough funded research time to be regular contributors to new species discovery. As well as species discovery, these individuals should be contributing to knowledge of the evolution and relationships (systematics) of the New Zealand flora and fauna in relation to the rest of the world.

Table 2. Numbers of publicly funded practitioners who have published varying quantities of papers, reviews and books/book chapters (from RSNZ Report Anon. 2015).

Output	0	1–5	6–10	11–20	>20
Journal articles	1	32	6	17	39
Reviews	21	24	10	2	4
Books/chapters	20	34	10	5	4

Table 3. Comparison of the proportional age structure of the taxonomy workforce of New Zealand, Australia (2003), and Canada (2009) (from RSNZ Report Anon. 2015).

Age range, years	New Zealand	Canada	Australia
20–30	1%	11%	10%
31–40	15%	25%	22%
41–50	26%	20%	30%
51–60	34%	26%	24%
61–70	20%	13%	15%
>70	4%	6%	-

Table 4. Proportion of employed research taxonomists who are funded to spend > 50% of their time on taxonomic research from RSNZ Report Anon. 2015).

Institution type	New Zealand	Canada
Museum	4%	58%
Universities	2%	32%
Government laboratories and CRI + Cawthron Institute	19%	49%

This will not be achieved unless misunderstandings about the role of taxonomic collections infrastructure and associated taxonomic/systematic science can be corrected. We need to better characterise the potential workforce through the promulgation of a definition of a professional taxonomist/systematist and associated professions and how they should be trained.

A further, well designed survey, that is clear about definitions, of how individuals are employed, their qualifications, characteristics, output and what is expected of them in their work should be undertaken, aimed at getting a better idea of the total taxonomy population.

The lead ministries need to acknowledge and own the problem created by diffuse responsibilities for taxonomic collections infrastructure and the lack strategic connection between science funders and priority setters.

A way forward needs to be formulated based on the recommendations in the RSNZ report (Anon. 2015) that includes an overall strategy and policy and creation of a national co-ordination mechanism (*see* Executive Summary reprinted in this volume, pages 80–82).

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Taxonomy and systematics: an essential underpinning of modern fisheries management

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Accurate and reliable identification of the full range of fish and invertebrate species that are caught in New Zealand waters lies at the core of the fisheries Quota Management System (QMS). Species identification is required for accuracy of catch reporting and keeping track of quota by commercial fishers, for keeping to bag limits in the recreational and customary sector, and for compliance and sustainability purposes. It is also needed by many in the marine science community, particularly those in fisheries science. As New Zealand's environmental obligations to national and international agreements continue to grow, accurate species identification has extended to non-QMS fish species, benthic invertebrates, and protected species. Furthermore, whole-fish identification is no longer sufficient, particularly where consumers require assurance that a fish in the kitchen has been caught from a sustainable source.

The requirement for accurate identification is of course a no-brainer, however, it is not necessarily easy to achieve and new species of marine organisms are still being discovered in New Zealand waters at a significant rate, with no sign of abating (Gordon *et al*. 2010). In addition, there is the requirement to know if species are endemic or not; if they are invasive or transient; how closely related they are to other species both here and around the globe; how adaptable and resilient they are to fishing pressures and environmental change; how they are distributed and the degree of connectivity among populations; and how we may be able to trace them from the ocean to the kitchen table.

To address these requirements, informed and definitive species identification based on sound taxonomic expertise and well-managed and accessible voucher specimens and records is needed. Further development of genetic methods that enable species identification from small components of fish, and differentiation between closely related species, is also needed.

Use of marine taxonomic services and systematics by MPI

Marine taxonomy and systematics is important to the Ministry for Primary Industries (MPI) on a number of levels (Figure 1).

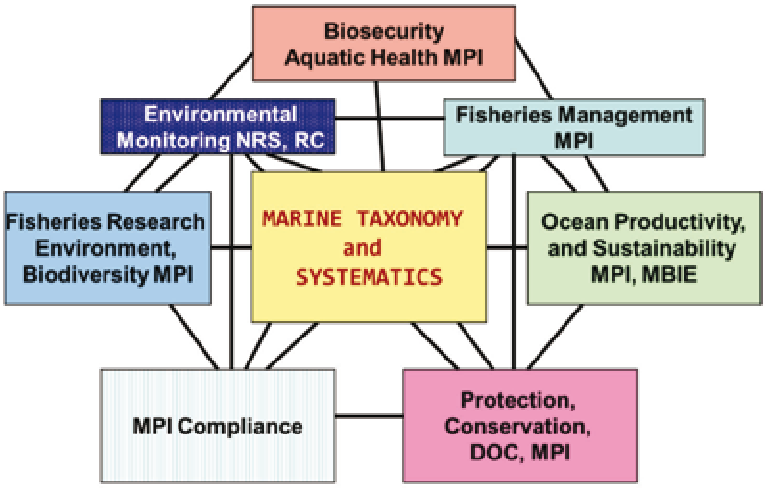

Figure 1. Broad relationships between marine systematics (including taxonomy, identification services, collections and databases) and government end-users. NRS: Natural Resource Sector. NRS Agencies include Ministry for Primary Industries, MPI; Ministry for the Environment, Statistics New Zealand, Environmental Protection Agency, Land Information New Zealand, Department of Conservation, DOC; Ministry for Business, innovation and Employment, MBIE. RC: Regional Councils

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Mary Livingston has worked as a marine scientist for 36 years. The first 20 years were as a marine researcher at the National Institute of Water & Atmospheric Research, followed by 16 years as a principal scientist at the Ministry of Primary Industries (MPI). Although not a taxonomist, she has seen the importance for robust identification and collection systems for marine fish and other organisms during her career. In her current role as Chair of MPIs Biodiversity Research Advisory Group she has ensured that such work remains part of fisheries core business.

Under the Fisheries Act 1996, the Ministry for Primary Industries (MPI) is responsible for that management of 600+ fish stocks comprising about 100 different fish species. When the QMS was first introduced in 1986, the number of fish stocks and species was far fewer (26 species, see Mace *et al*. 2014), and one might think that the taxonomy of these species was relatively well known. But, since 1986, at least 5 quota species have been identified as more than a single species, requiring legislative changes on how species and fish stocks are managed. Clearly, stock assessments and abundance surveys depend on accurate identification of the species.

In addition, estimates of by-catch and of non-QMS species is required, including benthic invertebrates. As MPI moves towards a more integrative approach to managing fish stocks and the environmental effects of fishing (see the Environmental Principles of the Fisheries Act 1996), the need for species identification, particularly protected species and seabed fauna, has increased.

The operational links between MPI and marine taxonomy gives MPI the capability to advise and inform research projects; prepare and train fisheries observers and compliance officers for both the Exclusive Economic Zone (EEZ) and the high seas; develop evidence for court cases; give consumers confidence in the market chain; and provide MPI with the basis for ecological habitat characterisation and protection measures. To achieve this, MPI has commissioned a wide range of at-sea identification guides that draw on the taxonomic expertise of ichthyologists and marine invertebrate taxonomists in New Zealand (Table 1). We have also contributed to the publication of a number of taxonomic studies (also listed in Table 1) and databases.

Some of the taxonomic resources being developed now cover organisms found in remote deep-sea habitats, from which a growing database of images and video is being developed at NIWA. Examples of camera shots obtained from different parts of the seabed shows how specimens may look in their natural environments (Figure 2). Combining data from images and preserved specimens is helping develop resources for use by non-experts.

Other applications of taxonomy relevant to MPI

Meeting national and international commitments has further increased the use of taxonomic services in MPI over the past fifteen years. For example, surveys have been undertaken to map marine biodiversity under the New Zealand Biodiversity Strategy (2000) which is part of New Zealand's contribution to the Convention for Biological Diversity, CBD) and the Census of Marine Life (e.g. Clark & O'Shea 2001). Datasets, voucher specimens and samples from all biodiversity research surveys have resulted in a mass of material that has been physically preserved and housed in the Te Papa Fish Collection and NIWA National Invertebrate Collection. All data are held in databases either at MFish or at NIWA, and accessibility is being continuously improved. Most data have also been entered into international databases such as OBIS, WoRMS or FISHBASE (Table 1).

New Zealand has also been exploring the possibility of developing a Tier 1 National Statistic for Marine Biodiversity (Tier 1 statistics information can be accessed at http://www.stats.govt.nz/about_us/who-we-are/home-statisphere/tier-1/principles-protocols.aspx) as an index to track changes in marine biodiversity and our success in Halting the Decline in Biodiversity (New Zealand Biodiversity Strategy 2000). At this stage the best that can be produced is a biodiversity knowledge index (Costello *et al*. 2010, Lundquist *et al*. 2015). Until we can identify unprocessed material and develop trends in abundance for key indicator species, the status of New Zealand's marine biodiversity will remain elusive.

Table 1. At-sea identification guides published by MPI and other taxonomic works and databases sourced or held by MPI. (QMS: Quota Management System; VME: vulnerable marine ecosystems).

Field Identification Guides published by MPI	Target audience	Reference
Fish 1	Commercial, public, science	McMillan *et al*. 2011a
Fish 2	Commercial, public, science	McMillan *et al*. 2011b
Fish 3	Commercial, public, science	McMillan *et al*. 2011c
QMS fish species	Commercial, public, science	Paulin *et al*. 1996
Ross Sea fishes	Commercial, science	Marriott *et al*. 2003
Coral (deep water)	Commercial, public, science	Tracey *et al*. 2014
Coralline algae	Commercial, public, science	Harvey *et al*. 2005; Farr *et al*. 2009
Macro-algae	Commercial, public, science	Nelson 2013
Non-fish bycatch	Commercial, public, science	MFish unpublished
NORFANZ on-board guide	Science	Clark & Roberts 2008
Bryozoans	Commercial, public, science	Smith & Gordon 2011
VMEs	Commercial, science	Tracey *et al*. 2008, Tracey & Parker 2010
Deep-sea crabs	Commercial, science	Naylor *et al*. 2005
Deep-sea invertebrates	Commercial, science	Tracey *et al*. 2005
New Zealand sea pens	Commercial, science	Williams *et al*. 2014
Marine Invasive Taxonomic Service	Commercial, public, science	Gould & Ahyong 2008
ID Guides and fact sheets for a range of marine species	Public	https://www.niwa.co.nz/coasts-and-oceans/marine-identification-guides-and-fact-sheets
Major taxonomic resources used by MPI	**Target audience**	**Reference**
Fishes of New Zealand (Books)	Commercial, public, science	Roberts *et al*. 2015
NZ Inventory of Biodiversity (Books)	Public, science	Gordon 2009, 2010, 2012
BIODS database (MPI)	National	Metadata publicly available, data available from MPI on request
World Register of Marine Species (WoRMS) database	International	http://www.marinespecies.org/
SPECIFY database (NIWA)	National	https://edit.niwa.co.nz/our-services/online-services
MARLIN metadatabase of fisheries and biodiversity databases held at NIWA on behalf of MPI	National	https://marlin.niwa.co.nz/

Figure 2. Examples of infauna and epifauna that can be identified from images of the seabed during the Chatham-Challenger Project Oceans Survey 20/20, 2006. Top left: Soft sediment infauna burrows; Top right: *Paleodictyon*, **Bottom Left: black coral; Bottom right: shallow offshore reef system. Image source: NIWA Deep-Towed Imaging System.**

International issues

Taxonomic work has been required in New Zealand to meet ongoing obligations to the United Nations Convention of the Law of the Sea (UNCLOS) including the extension of the continental shelf and Areas Beyond National Jurisdiction (ABNJ). MPI is a major player in the management of the Ross Sea toothfish fishery through the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR). CCAMLR takes an ecosystem-based approach to assessment of the fishstocks, and has required the mapping (and identification) of benthos and other fauna in the Ross Sea Region. The Food and Agriculture Organisation (FAO) have developed best practice guides for fishing on the high seas to protect Vulnerable Marine Ecosystems. New Zealand's obligations to the FAO are implemented through the South Pacific Regional Fisheries Management Organisation (SPRFMO, and has further extended the need for taxonomic services (Tracey & Parker 2010).

The global effects of climate change and ocean acidification have necessitated far wider activity on taxonomic identification of vulnerable fauna, particularly for deep-sea corals (e.g. Tracey *et al*. 2014). Collectively, these burgeoning needs have resulted in increasing stretch on taxonomic and systematics skills and services in New Zealand and around the globe. Taxonomic work, coupled with an understanding of the functional role of organisms and community complexes in the ecosystem, helps MPI and other agencies to distinguish between environmental changes that require adaptation, and the effects of fishing (and other activities) on biodiversity that may require mitigation. Ecological changes in the ocean brought about through long-term climatic cycles such as the Southern Oscillation, the Inter-decadal Pacific Oscillation, or human-induced global warming and ocean acidification, also require robust taxonomic and systematic knowledge to understand the connectivity between different populations and how we can best protect the biodiversity that is subject to these changes.

In recent times, the work of taxonomists has been assisted by the development of new tools such as genetic barcoding and environmental DNA (Gordon 2013; Heimeier *et al*. 2010). They cannot substitute for morphological taxonomy but have great value in providing insight into speciation, evolutionary proximity, forensic sourcing and the spread of unwanted species (Woods *et al*. 2013). In addition, genetics plays an important role in compliance. For example, eel species that have been filleted and packed are indistinguishable, but genetics can uncover their identity as well as their provenance (Smith *et al.* 2008) (Figure 3).

Spatial Marine Protection

Habitat classification and biodiversity characterisation of the ocean is another realm of resource management that MPI has been exploring as tools to manage the footprint of fishing. Habitat classification is improved significantly when biological data layers beyond the physical Marine Environment Classification (MEC; Snelder *et al*. 2006) are included (Fish optimised MEC: Leathwick *et al*. 2006; Benthic optimised MEC: Leathwick *et al*. 2012; Bioregionalisation in the Ross Sea: Sharp *et al.* 2010). This work, combined with the identification, distribution and abundance data of species, provides a powerful tools for marine spatial planning and protection from multiple threat sources, including fishing.

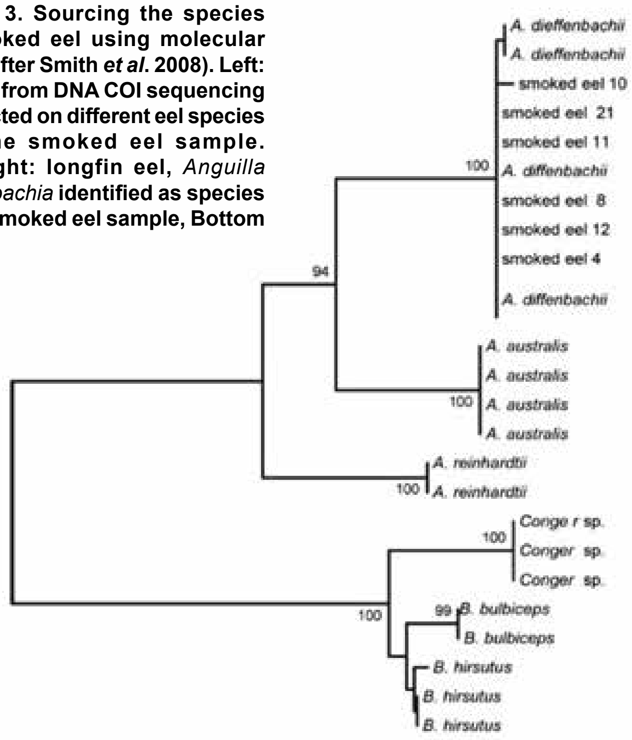

Figure 3. Sourcing the species of smoked eel using molecular tools (after Smith *et al*. 2008). Left: results from DNA COI sequencing conducted on different eel species and the smoked eel sample. Top right: longfin eel, *Anguilla dieffenbachia* identified as species in the smoked eel sample, Bottom right.

Spatial Marine Protection is a significant international and national issue, currently dogged not only by political pressure, but also a lack of knowledge of species identification and distribution, and the role of different species in the ecology of the ocean. Samples from New Zealand's Benthic Protection Areas remain unanalysed for example and will likely contain further species new to science (Clark *et al*. 2014). Identifying and sorting the back-log of samples held by Te Papa and the NIWA Invertebrate Collection is an important step towards understanding the distribution of biodiversity and the efficacy of different protection measures in New Zealand waters. For example, collections of voucher specimens and samples held at Te Papa and at NIWA comprise over 40,000 specimen lots from seamount studies conducted under the Census of Marine Life (Gordon *et al*. 2010).

Increasing the efficiency of identification work

Scientists recognise that taxonomy is a highly specialised area of science and are doing their best to develop methods and tools that can speed up identification, mapping and quantification of species, but there is a long way to go. The provision of these fundamental data is seen as an underpinning service. At present our capability is insufficient to fully meet our biosecurity and environmental planning needs, ecological mapping needs, environmental assessment, and sustainable development of ocean resources. This issue is not new and has been reported elsewhere (Bradford-Grieve 2008).

There are many calls on science funding to address marine resource management issues and taxonomy remains a serious knowledge and skills gap (Mace *et al*. 2014). A recent report from the Royal Society by the National Taxonomic Collections in New Zealand Expert Panel (2015; see http://www.royalsociety.org.nz/media/2015/12/Report-National-Taxonomic-Collections-in-New-Zealand-2015.pdf) drew the following conclusion:

> 'To preserve and build NZ taxonomic collections we must invest in core infrastructure, support collaboration and provide long-term professional development and job security.'

Further, an updated New Zealand Biodiversity Strategy and Action Plan 2016–2020 has been released (https://www.cbd.int/doc/world/nz/nz-nbsap-v2-en.pdf). One of the goals listed is to 'Reduce pressures on biodiversity and promote sustainable use'. National Target 5 of the Strategy is 'Biodiversity is integrated into New Zealand's fisheries management system' with the following Key Actions that will impact on MPI and fisheries management:

- By 2020, New Zealand will have moved towards an ecosystem approach to fisheries management that includes enhanced recording of bycatch from the sea and improved understanding of the rates of change in marine biodiversity.
- By 2017, implementation of the Fisheries Operational Review will begin, including a number of important initiatives that will contribute to the sustainability of fisheries and enhance biodiversity.
- By 2020, demonstrable progress will have been made towards managing the impacts of bottom trawling and dredging on the seabed.

Government has recognised the need to take a more strategic approach to data sharing and infrastructure including taxonomic collections, both for economic sector reasons and for the protection of biodiversity for future generations. The message put out by the Royal Society above seems to have had some impact on funding which means that New Zealand will be better placed to meet the targets identified in the New Zealand Biodiversity Strategy and Action Plan 2016–2020. Improvement in this area will help to support marine resource management such as fisheries and biosecurity and is welcomed.

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Systematics expertise and taxonomic status of New Zealand's freshwater insects

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Introduction

Insects are important to ecosystem functioning in freshwater habitats. They have a rich diversity, fill every ecological niche, and as predators and scavengers and the prey of larger species, they play a vital role in nutrient cycling. There is no doubt that aquatic insects are under considerable threat in New Zealand (Grainger *et al*. 2014, Joy & Death 2014, Weeks *et al*. 2016, Collier *et al*. 2016). Some freshwater species are iconic to New Zealanders, like the ubiquitous sandflies with aquatic larvae (Craig *et al*. 2012), but also known to many systematists worldwide are New Zealand's endemic species, like the primitive dragonfly *Uropetala chiltoni* Tillyard (Petaluridae) or the ice worm *Zelandochlus latipalpis* Brundin (Chironomidae). To most biologists and almost any informed layperson, aquatic insects (along with a number of other invertebrates) are well-known biological indicators of water quality. The exact number of freshwater insects is unknown, but estimates range from 640–800 described species in New Zealand (McFarlane *et al*. 2010, Weeks *et al*. 2016). They exhibit intriguing adaptations to their stream environments that include symbiotic relationships (commensalism and phoresy) of chironomid midge larvae with mollusks, flies and mayflies (Forsythe & McCallum 1978, Winterbourn 2004, Cranston 2007), live birth (viviparity) in the caddisfly *Triplectides cephalotes* (Walker) (Pendergrast & Cowley 1966; Morse & Neboiss 1982) and adaptations to torrential water velocities (e.g. Blephariceridae) that make them interesting model organisms for ecological and evolutionary study (Buckley *et al*. 2015, McCulloch *et al*. 2016). New Zealand's long geographic isolation has led to high levels of regional and national endemism (Gibbs 2006), and biogeographic studies of aquatic insects have helped to reconstruct the geologic and climatic histories of New Zealand's ancient terrains and weathered landscapes.

Unwise land-use and water management (for example, inadequately responding to pressures from agriculture, mining and urbanisation) degrades water quality, alters flow regimes and disrupts connectivity within and among freshwater systems, all posing threats to New Zealand aquatic organisms. Concomitant with global climate change, a grim picture is emerging for the future of many aquatic organisms. Furthermore, introductions of alien species such as the mosquito fish *Gambusia affinis* (Baird and Girard) and the diatom *Didymosphenia* can markedly alter insect communities (e.g. Kilroy & Unwin 2011).

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Rich Leschen [top left] is a systematist at Landcare Research specialising in beetles (Coleoptera). His primary research is to describe New Zealand's beetle fauna and classify the species in global context to better understand their phylogenetic relationships, evolutionary history and ecology.

Kevin Collier [not pictured] is a freshwater ecologist with the Environmental Research Institute at the University of Waikato. He has spent over 25 years studying stream invertebrates and over this time has been involved in every assessment of aquatic invertebrate conservation status carried out in New Zealand.

Russell Death [top right] is a Professor in Freshwater Ecology in the Institute of Agriculture and Environment – Ecology at Massey University.

Jon Harding [bottom left] is a Professor of Freshwater Ecology at the University of Canterbury. He has been working on the effects of human activities on stream ecosystems for over 25 years and has conducted research in New Zealand, USA, Tonga, Singapore and Nigeria. He specialises on the ecology of stream invertebrates and is especially interested in regionally endemic freshwater species on Banks Peninsula.

Brian Smith [bottom right] is a freshwater entomologist at NIWA in Hamilton. He has over 22 years' experience in the taxonomy and ecology of aquatic insects particularly the winged adult stage. Brian's main research interest is the taxonomy of caddisflies but is also investigating the oviposition requirements of adult aquatic insects and how this knowledge can be applied to improving stream restoration success.

Aquatic ecosystems have a full range of microhabitats, such as this riffle in a high-energy stream that will be filled with insect predators, scavengers, scrapers, and filter feeders (photo by Crystal Maier).

Calls for mitigation to protect and conserve freshwater ecosystems and diversity via legislative action have been made (Peart & Brake 2013, Weeks *et al*. 2016) but knowledge from the natural sciences is often marginalised in such discussions (Dijkstra 2016) and, in New Zealand, the legislative process is complex and disjointed (Brown *et al*. 2015, Wallace 2016). Furthermore, the research focus and ecological understanding of many New Zealand aquatic insects is poor or absent, with nearly 90 taxa considered to be 'data deficient' (Grainger *et al*. 2014).

Taxonomy is one branch of the sciences that has been eroded by the lack of adequate funding. There is also general apathy towards the once-thriving discipline, partly perhaps due to molecular methodologies which some assume lessen the need for formal taxonomic description. Systematic studies now take a back seat to more lucrative and/or high-profile research; additionally invertebrates are less appealing than the larger fauna, which also hinders conservation and taxonomic work on invertebrates (Collier *et al*. 2016).

If we are to monitor the status of New Zealand freshwater species, identify factors that contribute to their decline or eventual extinction, or use them as proxies for water quality, investment in formal taxonomy for freshwater insects and other aquatic organisms is critical. Why? A valid, robust taxonomic name and description for a species underpins the language of biology. That Latin name gives an organism an identity that can be referred to across disciplines (and languages) and as a binomen it communicates its phylogenetic placement and location in classification, placing that species into a wider comparative framework for further study.

Since the dissolution of the Department of Scientific and Industrial Research (DSIR) and the formation of the Crown research institutes (CRIs), systematic studies of freshwater insects in New Zealand have been undertaken by a small community of freshwater ecologists and amateur researchers, keen to pursue these studies outside their core work or on personal time. But we are very concerned that the recent deaths and retirements of key workers will have a negative impact on the conservation, taxonomic and ecological studies of aquatic insects, one of many topics discussed during a recent meeting of New Zealand scientists concerned about the conservation of freshwater insects, held at Massey University. The systematics community has proposed a scheme to create a viable systematics future in New Zealand (Nelson *et al*. 2015), but here we focus on and briefly review the status of freshwater insect systematics research.

Taxonomic status and expertise

The insects of freshwater ecosystems represent most insect orders, including collembolans. The list of New Zealand's Insecta by McFarlane *et al*. (2010)* is more restricted to include 'aquatic' taxa, i.e. as those having one or all of their life stages living in the water. Arranged by numbers of species already known and estimates for the number of species remaining to be described or discovered are: Diptera (265 / unknown), Trichoptera (249 / 10–50), Plecoptera (120 / 20), Coleoptera (83 / 25**), Ephemeroptera (51 / 10), Odonata (15 / 0), and Neuroptera (5 / 0) with one species each in Megaloptera, Mecoptera, and Lepidoptera.

In New Zealand, there are currently no researchers at CRIs, public museums or universities who are employed *specifically* to monograph or revise freshwater insect groups, and many who have contributed are amateur workers (e.g. Winterbourn 2014). Tragically, the deaths of three diligent amateurs have left a large portion of the freshwater insect fauna without specialists: Ian McLellan (Plecoptera; unaffiliated [Patrick & Pawson 2009]), John Ward (Trichoptera; Canterbury Museum [Patrick 2016]), and Keith Wise (Neuroptera, Megaloptera, Trichoptera; Auckland Museum; [Early 2012]). Terry Hitching, an amateur ephemeropterist, continues his work, but the systematics research on freshwater insects has significantly slowed.

There are freshwater ecologists in New Zealand who have extensive taxonomic knowledge and have contributed occasionally to the systematics of freshwater insects (e.g. Ian Henderson, Trichoptera and other groups; Ian Boothroyd, Chironomidae) and to the New Zealand Threat List for freshwater insects (Grainger *et al*. 2014). Also, immature stages of most freshwater insects can be identified to genus-level using the keys in Winterbourn *et al*. (2006) and the online resources by the late Stephen Moore (2013) and NIWA staff (Anon. 2016). However, as for most insects, accurate species identification requires examination of the genitalia of mature adult males and comprehensive knowledge of faunas outside of New Zealand.

* McFarlane et al. (2010) also included Phthiraptera (47 spp.) in their tabulation of aquatic species, but these vertebrate parasites are excluded here (Ricardo Palma, New Zealand's specialist, recently retired from Te Papa, but continues his work).

** R. Leschen (unpubl. estimate of new species of Dytiscidae, Hydraenidae, Hydrophilidae, and Elmidae).

An adult caddisfly (Trichoptera), ***Oeconesus maori*** **McLachlan, one of few species with a larva that eats wood (photo by Brian J. Smith).**

Unfortunately, systematics research that is required to identify, and therefore help conservationists save vanishing species, is very limited.

Freshwater insect systematics at the 11th hour

The world is undergoing an unprecedented biological crisis (Wilson 1985; Dudgeon *et al*. 2006). Society is faced with ethical, practical, and economic decisions that balance the decline of natural environments with economic gain. The description and naming of New Zealand freshwater biota is particularly critical because much of the diversity has not been formally described, their geographic distributions have not been fully mapped, and their ecologies little understood or documented. Despite relatively strong programmes in freshwater ecology at five New Zealand universities, there is no formal training in taxonomy in any New Zealand institute, and emerging students lack understanding of the basic practice of the naming of species, classification, and comparative biology. While taxonomy underpins biological thought and communication how can freshwater insect taxonomy proceed without local expertise?

Dispensing with formal taxonomic names or providing informal names for species awaiting description has several drawbacks (Leschen *et al*. 2009); as does recognising species based solely on genetics. DNA-based studies, for example, may help reconstruct phylogenetic relationships, identify geographic limits of populations and corroborate species status, but morphological characters are needed to identify the organisms of interest. Without formal taxonomic treatment of species, the biological status of informally recognised entities is vague, and adds to uncertainty of their conservation status.

Insect-based indices of aquatic ecosystem health are based on measures that condense taxonomic information to individual metrics and require, at best, genus-level identifications. The Macroinvertebrate Community Index (MCI) (Stark 1985, Stark *et al*. 2001) is limited for insect conservation because it does not differentiate between threatened and common species that occur within a genus or higher levels of taxonomy for some groups. Furthermore, most of the national water quality monitoring with the MCI is focused on waterways that are already severely degraded by anthropogenic impacts and thus unlikely to provide refugia for rare or threatened species. The water quality monitoring also focuses on the in-stream larval stage that is often more difficult to differentiate into species level classification necessary to find rare species. In the environmental assessment for the proposed Mokihinui River dam no species of conservation interest were found with MCI sampling until a taxonomic expert collected and examined adult insects, whereupon nearly a dozen new species to science were discovered (Death 2012).

What is or can be done about the taxonomic impediment for freshwater insect studies? Despite the attraction of economically driven research, some ecologists have and continue to contribute to taxonomic studies either by undertaking targeted taxonomic research or via collaborations in their spare time (examples given above). Studies on aquatic hydreanid beetles by Juan Delgado, a beetle specialist in Spain, and Ricardo Palma, a New Zealand entomologist, and on elmid beetles by Paul Lambert, a technician at NIWA, Crystal Maier (Field Museum of Natural History, Chicago), and one of us (R. Leschen) are two examples of crossover research that could effectively close some of the taxonomic gaps in some freshwater groups. While taxonomy based solely on genetics is problematic (e.g. Collins & Cruickshank 2013), joint work between technologists and naturalists could address specific taxonomic issues, like some of the work we have been involved with (e.g. Hogg *et al*. 2009). However, such work is piecemeal and lacks cohesive national-level strategy.

The larva of the caddisfly (Trichoptera), ***Pycnocentrodes aureolus*** **McLachlan, builds a case of minute sand grains held together by silk spun from special glands in the head, and is further weighed down by a lateral line of larger sand grains (photo by Brian J. Smith).**

Future freshwater systematics

Freshwater research is vibrant in New Zealand, not only as an academic pursuit, but fuelled by the necessity for monitoring the health of the environment. If focus can expand to include taxonomic studies that contribute to the conservation of our unique and ancient insect faunas, the benefits would be far-reaching. As it stands, the ratio of species knowledge to environmental decay may be skewed towards extinction for some species, and we can only hope that protection of umbrella species, such as mudfish or blue duck, will have flow-on effects for freshwater invertebrates. Meanwhile, freshwater insect taxonomy may continue at a snail's pace and remain an after-hours activity for crossover researchers. Our hope is that the tide will turn for the environment and that the need for freshwater insect systematics capacity will be realised in New Zealand, especially for larger groups that presently lack expertise, despite the erosion of funding and perceived lack of relevance by some agencies. In the past, the New Zealand Freshwater Sciences Society used to run taxonomic fairs where people could bring species to experts for identification, but this may be no longer feasible without expertise existing for some groups. Empowerment of enthusiastic amateurs and scientists to share their zest for aquatic insects by engaging the public and participating in local surveys or Bioblitz will be central to raising general awareness of stream insect biodiversity.

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An adult beetle (Coleoptera), ***Hydora musci*** **Lambert, Maier & Leschen which is semi-aquatic as an adult and its larvae are associated with mosses at the edge of streams (photo by Crystal Maier).**

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Small organisms create big problems for taxonomists

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The age of travelling naturalists such as Wallace, Darwin, and von Humboldt who explored newly discovered continents and islands and described their animal and plant biodiversity is now well and truly over. Understandably, the work of early explorers usually focused on the large and conspicuous organisms that they saw; as a result, we now have a good knowledge of the diversity of these large organisms, although a relatively small number of mammals, birds, and fish species continues to be described every year across the globe.

In an attempt to find more new and exotic species, biologists have more recently turned their attention to environments which until not long ago were inaccessible or difficult to sample, such as the polar regions and the deep sea. In these environments, undescribed species and higher taxa are abundant and the diversity is sometimes very high. However, less remote environments are also home to undiscovered biodiversity. Instead of standing on the bow of a ship scrutinising the horizon (à la Jacques Cousteau), we now need to crouch down, sift through unsightly piles of often smelly dirt and debris, and spend hours bent over a microscope. We need to pay more attention to the very small organisms right under our nose, and we need to think small.

Roundworms, or nematodes, are perhaps the best example of small, abundant, and highly diverse organisms about which we still know very little (Figure 1) – both their diversity and their role in ecosystems. It has been claimed that nematodes are the most numerous animals on the planet, leading the famous nematologist Nathan Cobb (1914, p. 472) to write:

> *…if all the matter in the universe except the nematodes were swept away, our world would still be dimly recognizable, and if, as disembodied spirits, we could then investigate it, we should find its mountains, hills, vales, rivers, lakes, and oceans represented by a film of nematodes. The location of towns would be decipherable, since for every massing of human beings there would be a corresponding massing of certain nematodes. Trees would still stand in ghostly rows representing our streets and highways. The location of the various plants and animals would still be decipherable, and, had we sufficient knowledge, in many cases even their species could be determined by an examination of their erstwhile nematode parasites.*

This image conjured by Cobb shows just how adaptable and widespread nematodes are; despite their simple body plan, which consists of a tube (a one-way gut) inside a tube (the outer body wall or cuticle), nematodes have adapted to an incredibly diverse range of ecological niches and environments ranging from ocean trenches, Antarctica, the deep subsurface biosphere of the Earth's crust, hot springs, and as parasites of animals and plants (e.g. Borgonie *et al*. 2011). Species have even been described from unlikely habitats such as beer mats and bottles of unpasteurised apple cider vinegar (e.g. the so-called 'vinegar eels' *Turbatrix aceti*, which have more recently also been noticed in kombucha cultures).

Despite their ubiquity, we still know relatively little about the diversity of nematodes in many parts of the globe. In New Zealand, the known diversity now stands at around 750 species, mainly from plant and vertebrate hosts and soils. The true total is likely to be several times that number (Yeates 2010), with over 1000 species estimated to be present in continental margin sediments alone (Leduc *et al*. 2012). Such is the gap in our knowledge of nematode taxonomy that it is possible to find new species in the vicinity of urban areas; a case in point is the recent discovery of several new intertidal nematode species just outside NIWA's Greta Point campus in Central Wellington (Leduc & Zhao 2016). This lack of knowledge of easily accessed habitats exists because the taxonomy of free-living marine nematodes in New Zealand has, until recently, been investigated only sporadically by visiting overseas experts (Gwyther & Leduc 2008). At present, there are very few specialists residing in New Zealand actively studying the diversity of small organisms, including highly diverse and widespread groups such as harpacticoid copepods, kinorynchs (mud dragons), and loriciferans (Figure 2).

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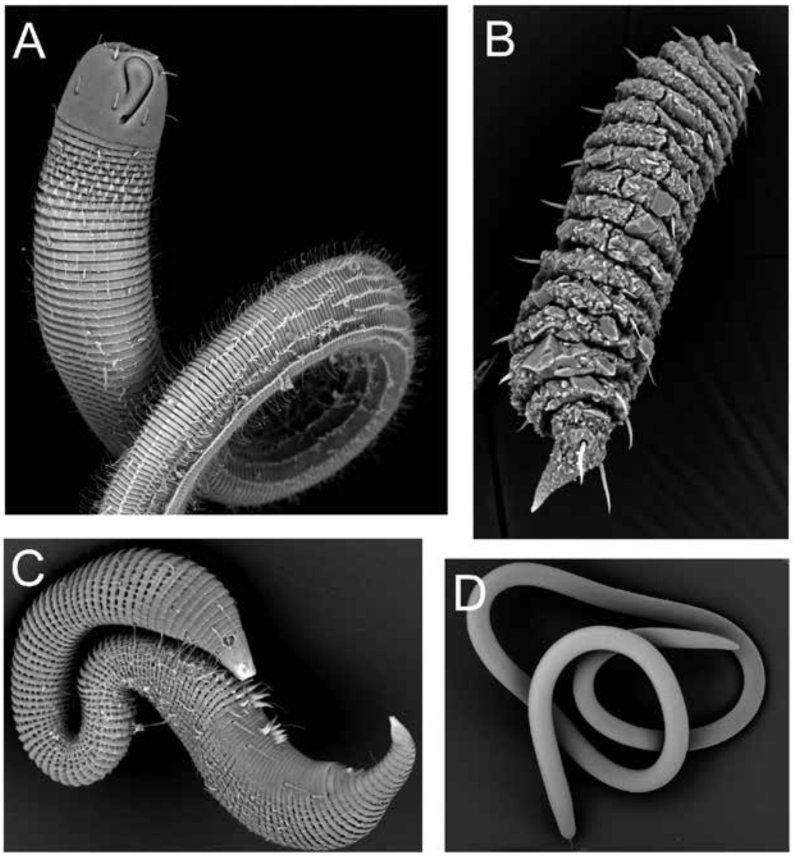

Figure 1. Examples of nematode morphology. A: ***Desmodorella verscheldei*** **from Hataitai beach, Wellington; B: an unidentified species of the genus** ***Desmoscolex*** **from Chatham Rise; C:** ***Epsilonema rugatum*** **from Hataitai Beach; D:** ***Trophomera*** **cf.** ***marionensis*****, a parasite of amphipods in the Kermadec Trench.**

Although the prospect of so much undiscovered biodiversity is exciting for taxonomists, the magnitude of the knowledge gap is daunting. How can we hope to describe and name the many thousands of tiny species that surround us and understand their roles in ecosystems, given the large amount of work involved in sampling, preserving, describing and publishing every new taxon, and the small number of taxonomists currently employed in New Zealand? There are no easy answers to this question. The ease with which new species can be discovered makes this country very attractive for visiting taxonomists from other parts of the globe, which are often more than happy to look at New Zealand material and contribute to the description of our native fauna. However, any serious attempt at addressing this taxonomic challenge will require developing the means to support our own resident experts over the long term. In addition to growing our pool of experts, we should be aiming to incorporate new technologies, some of which lend themselves particularly well to the study of small and numerous organisms. Environmental DNA (eDNA) metabarcoding provides a powerful tool to complement the morphological approach to taxonomy. This method, which is based on the bulk extraction of DNA sequences from water or sediment samples combined with high-throughput sequencing technologies, has already revealed unsuspectedly high levels of biodiversity in shallow and deep marine environments (Fonseca *et al*. 2010, Sinniger *et al*. 2016). The metabarcoding approach has the potential to expand our knowledge of the diversity of small organisms, but it is essential that it be integrated with morphology-based taxonomy in order to grow the taxon-linked sequence database against which bulk eDNA samples can be compared (Dell'Anno *et al*. 2015). Far from superseding so-called 'traditional' taxonomy, the emergence of new molecular technologies increases the need for morphology-base taxonomy for the foreseeable future. It is also clear that taxonomists need to incorporate molecular sequence data in their species descriptions whenever possible in order to maximise the uptake and integration of their science by the wider scientific community.

At this point, some of you may be wondering why we should go through all this trouble to describe and understand the diversity of tiny life forms which seem to have no obvious use; what does it matter that their diversity is high or low, that some species occur in some places but not others, or that we lose some species we never knew existed in the first place? These are legitimate questions to ask, which perhaps taxonomists could do a better job of answering – taxonomy, after all, is largely paid for by public funds. We value large species because we can see them and they therefore are part of our identity. Certain species are considered to be attractive, others useful, and some rather tasty.

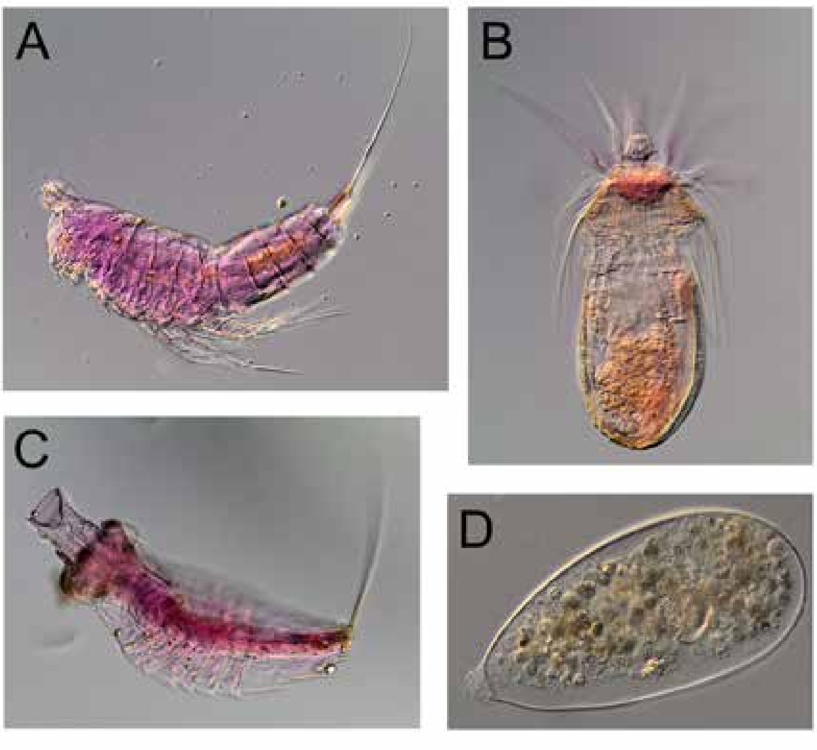

Figure 2. Examples of common, diverse, yet poorly known small organisms in New Zealand. A: Harpacticoid copepod, a highly diverse group of crustaceans; B: loriciferan, a phylum only discovered in the 1980s; C: kinorynch, or mud dragon, a group superficially similar to crustaceans but in fact a separate phylum; D: gromiid, a type of unicellular organism distantly related to the much better known foraminiferans.

On the other hand, small organisms such as parasitic nematodes have attracted a lot of attention because they result in financial loss from lost productivity. This is hardly an argument for conservation, although it has been shown that eradicating the parasites of charismatic host species may do more harm than good (Spencer & Zuk 2016). But what about free-living species living in aquatic sediments with which we don't seem to have any direct interactions? Although most of us are not aware of it, aquatic sediments provide many ecosystem services that benefit us in a very real way, including nutrient cycling, carbon sequestration, and absorption and detoxification of pollutants (Snelgrove *et al*. 2014). Ecological science has demonstrated that these services are largely driven by microscopic life forms such as bacteria, protists and small animals (e.g. Beaulieu 2002), and that maintaining the diversity of these organisms is essential to preserve the functional integrity of ecosystems (Balvanera *et al*. 2006, Isbell *et al*. 2011). Recent evidence also suggests that even coexisting cryptic nematode species (i.e. species which cannot be distinguished based on morphology alone) can have different ecological niches and thus different ecological roles and influence on ecosystem function (Derycke *et al*. 2016). Thus, better characterising the diversity of small organisms is something we need to do if we are to better understand not only how ecosystems work, but also how to protect them.

It is clear that taxonomists still have big problems to solve. There are, after all, plenty of blank spaces to fill on the map, and the age of exploration is not yet over, at least not for biologists interested in the smaller biota. New Zealand is still a great place to be for taxonomists, particularly if one is interested in describing and understanding the diversity of life that underpins the functioning of healthy ecosystems.

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Integrative, next-generation, collaborative vascular plant systematics in New Zealand

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Systematics is a synthetic science which focuses on species delimitation, taxonomy, classification, and phylogeny, with an additional aim of understanding underlying evolutionary and biogeographic patterns and processes. Systematic research has many downstream benefits including underpinning conservation management, biosecurity and health. In this short overview article, I will give a brief synopsis of integrative systematics, in which multiple data sets are used to robustly test species limits in a statistical framework, and illustrate why I think we need integrative systematics in New Zealand. I will then discuss examples from my own systematics research, especially on the flowering plant families Plantaginaceae (*Ourisia, Plantago, Veronica*) and Boraginaceae (*Myosotis*), as well as from other vascular plant systematics research being done by colleagues in New Zealand and elsewhere. Through these examples, I will show how using an integrative systematics approach to analysing morphological, molecular, cytological and other data sets can aid species delimitation and new species discovery, and allow inferences into questions regarding such diverse themes as diversification, variability and conservation of threatened species, polyploidy (whole genome duplication) and biogeography of New Zealand vascular plants. I will also argue that the future of systematics should not only be integrative, but also next-generation and collaborative, and that such forward-looking, cooperative research – and the institutional and governmental investment to support it – is essential for New Zealand.

What is integrative systematics?

Systematics is a synthetic science which focuses on the naming (taxonomy), classification, and phylogeny (evolutionary relationships) of species. The core aspects of systematics research are species discovery and description; testing and defining species limits; determining species relationships; naming and classifying species; and providing the fundamental systematic information, collections and databases that form the essential backbone to studies in all other biological fields. On any given day, systematists might be in the field collecting specimens and samples; in the herbarium measuring morphological characters on voucher specimens or actively contributing new material and data to our substantial institutional collections and databases; in the lab extracting DNA or generating sequences; or in front of the computer writing grant proposals, performing statistical analyses on different data sets, or writing up and submitting results as scientific papers, floras and faunas, or books. Increasingly, systematists are also communicating their latest discoveries with the public, government and other relevant end-users via newsletters, articles, reports, lectures, websites, blogs and social media. Systematics research has the additional benefit of elucidating evolutionary patterns and processes, including understanding the origins and biogeography of our flora and fauna (Stuessy 2009; Schlick-Steiner *et al.* 2014). Systematics research also provides fundamental knowledge for biosecurity, human health, conservation and threatened species management, sustainability, and economics, among others (Royal Society of New Zealand 2015).

The main questions systematists are trying to answer are: How many species are there in a particular group? What distinguishes them? How are they related to one another? Where do they come from? To answer these questions, systematists have historically used information from multiple data sources, including standard and time-tested methods (e.g. morphology) as well as new methods and ideas such as next-generation sequencing. Thus, systematics has always been a synthetic and integrative science, and indeed over the last century, different terms have been used to describe these inherent qualities, such as 'statistical systematics', 'biosystematics,' 'experimental taxonomy', 'new systematics' and 'comparative biology' (Stuessy 2009). 'Integrative taxonomy' came into use mostly in the zoological systematics literature when molecular data were being increasingly incorporated into systematics research, and use of the term was partly a reaction against the idea that DNA barcoding might go beyond aiding species identification to eventually replace (rather than enhance) taxonomy (e.g. Dayrat 2005, Will *et al.* 2005; Pires & Marinoni 2010). At about the same time, a renewed discussion was taking place among systematists about the best way to delimit species while also considering their evolutionary history (e.g. the general lineage concept of de Queiroz (2007)).

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Over the last 15 years, 4000 papers using the terms 'integrative taxonomy' or (less frequently) 'integrative systematics' have been published (Google Scholar search performed by the author in October 2016), with increasing numbers of papers each year (see Pante *et al.* 2015). Several thorough reviews provide an excellent summary of the development and current status of integrative systematics (e.g. Dayrat 2005; Valdecasas *et al.* 2008; Padial & De La Riva 2010; Padial *et al.* 2010; Schlick-Steiner *et al.* 2010; Fujita *et al.* 2012).

Integrative systematics can be defined as being a science that incorporates as many available sources of data as possible to develop and test species hypotheses (Dayrat 2005; Will *et al.* 2005; Yeates *et al.* 2011), and includes analyses of multiple types of data including DNA, morphology, habitat, chromosome number, and others. This definition effectively equates analyses of multiple data sets with integrative systematics and is used by many systematists, including myself in this article. An integrative framework allows systematists to treat species boundaries as hypotheses to be tested with different pieces of evidence – simultaneously and/or consecutively – to find agreement and correlation among different data sets. Such an approach is generally more robust for delimiting species than relying on one type of data only, and when data sets do not agree, discrepancies may help bring to light underlying biological or evolutionary processes (Schlick-Steiner *et al.* 2010). Integrative systematics research can include a range of analysis methods and data sets. At its most basic level, integrative systematics can test species concepts based on previous (descriptive) morphological-based taxonomy with phylogenetic analyses of one or few sequenced DNA markers (or DNA fingerprinting), and there are several New Zealand examples of such studies from plants (Tay *et al.* 2010a; Prebble *et al.* 2012; Brownsey & Perrie 2014; Ohlsen *et al.* 2015) and animals (Trewick 2008; Boyer *et al.* 2011). A further step towards increased integration includes using multivariate statistical analyses of morphological data that are analysed in conjunction with those of molecular and other data sets – from the same individuals, when possible – to revise species limits and taxonomy, including some examples from my own research (Meudt 2008; Meudt 2012; Meudt *et al.* 2013; see below for more details). In these and other studies, integrative systematics is often an iterative process of continually testing and retesting species boundary hypotheses with new data sources (Yeates *et al.* 2011).

Some recent reviews have suggested that current integrative systematics methods are rather qualitative, not repeatable, and ad hoc, and suggest that truly integrative systematics should entail quantitative co-analyses of different types of data generated from the same individuals (e.g. Padial *et al.* 2010; Yeates *et al.* 2011). The integrative systematics of the future should include quantitative methods that provide objective assessments of species limits in a statistical framework, both for analyses of morphological or molecular data alone as well as for co-analyses of molecular, morphological and other data sets. For molecular data, many analytical methods currently exist to test species limits for single or multiple molecular markers; for a nice review with a focus on lichens see Leavitt *et al.* (2015). Many advocate the use of the multispecies coalescent model as the standard approach for species tree estimation using sequences from multiple genes, in which hypotheses about species relationships and species limits can be tested by integrating multiple genetic data sets to identify evolutionary lineages (e.g. Knowles & Carstens 2007; Carstens & Dewey 2010; Fujita *et al.* 2012; Jones 2016; Leaché *et al.* 2014; Jones *et al.* 2015; Fujisawa *et al.* 2016). Such approaches are not always possible, because it may not always be feasible to acquire DNA sequences of multiple or even single genes for the individuals under study; or, when available, such data are not sufficiently variable or taxonomically useful; or the necessary models and software to analyse them are not yet fully developed (although much progress has been made over the last decade). But the fact that integrative systematics is moving to incorporate such methodologies, where appropriate and feasible, is encouraging. Even more promising is the recent progress regarding new integrative systematics methods for co-analyses of multiple sources of data (such as genetic, morphological and ecological niche modelling data sets) to test species boundaries by combining multivariate and clustering techniques (Edwards & Knowles 2014) or using a Bayesian framework (Solís-Lemus *et al.* 2015). These and other such methods are the way forward for integrative systematics (e.g. Yeates *et al.* 2011), and further investigation and developments in this area are warranted and welcome (Jones 2016).

Why do we need integrative systematics, particularly in New Zealand?

Although New Zealand is small in size, the country has a rich and diverse biota with high endemism, with an estimated 49,579 total native species, of which over half are endemic (Table 1; Gordon 2013). Endemism is particularly high for certain groups such as gymnosperms (100%) and flowering plant species (84%) (Wilton & Breitwieser 2000; McGlone *et al.* 2001; Wilton *et al.* 2016). Even more astounding is that systematists estimate that over 65,000 species have yet to be discovered or described in New Zealand (Table 1), which means we are not even half way there yet to knowing and documenting our biodiversity! Although the majority of these undiscovered species are animals or fungi, my focus in this overview is constrained largely to vascular plants, since it is the group of organisms that I work on and am most familiar with. Plant systematists estimate that nearly 1200 New Zealand plant species remain undescribed (Table 1), and of these, about 300–400 are angiosperms (flowering plants). Furthermore, the current *Flora of New Zealand* (Allan 1961) was published 55 years ago and is well overdue for a major rewrite, and many of New Zealand's plant genera have not had recent taxonomic revisions. The good news is, this rewrite is now under way. Since 2014, new taxonomic treatments – particularly of ferns and mosses – based on new systematic data are being published in an online New Zealand eFlora (http://www.nzflora.info/), an exciting collaborative development. As our knowledge of the systematics of New Zealand fauna, fungi, non-green algae and other organisms are in a much worse state than vascular plants (Table 1), that the need

Table 1. New Zealand's rich biota (from Gordon 2013).

Kingdom	Total no. species	No. native species (%)	Percent native species that are endemic	No. undiscovered species
bacteria	701	??	??	??
protozoans	539	516 (96%)	4.7%	770
Chromista	4,208	3,921 (93%)	7.2%	4,695
plants	7,555	4,970 (66%)	48.2%	1,175
fungi	8,395	6,402 (76%)	26.0%	23,525
animals	36,017	33,770 (94%)	68.0%	35,340
TOTAL	57,415	49,579 (86%)	55.2%	65,505

for sysetmatics research – ideally using integrative systematics methods – is undeniably clear.

New Zealand has a unique combination of both oceanic island features (e.g. small area, long isolation from continental land masses, and topographic and climatic diversity) as well as continental features (including a long fossil record), which have shaped the history of the flora and fauna in myriad ways. New Zealand's flora and fauna have diverse origins, including a mixture of older, Gondwanan elements as well as more recent components (e.g. McGlone *et al.* 2001). For many New Zealand flowering plant lineages, both the fossil record and molecular phylogenetic studies show evidence of dispersal to New Zealand within the last 5–10 million years, which coincides with a period of tectonic activity and glacial-interglacial cycles (Winkworth *et al.* 2005). During this time, plant survival would have depended on the ability to cope with changing environments, and many would have gone extinct. But other plant lineages probably encountered great opportunities for rapid expansion and diversification into new forms and habitats (also likely accompanied by hybridisation) to produce much of the remarkable morphological and ecological diversity of the present day flora (Winkworth *et al.* 2005).

These recent species radiations offer both challenges as well as opportunities for the practising vascular plant systematist. In particular, species limits may be blurred because certain data may not be taxonomically useful or well-resolved in a certain group, different data sets may not agree with one another, and confounding biological and evolutionary processes are also at play. Plants of closely-related species can often interbreed, and this lack of reproductive barriers facilitates hybridisation, which is sometimes also accompanied by whole genome duplication (polyploidy). Hybridisation can obscure species boundaries when hybrids later interbreed with their parental species, but to further complicate matters, it can also lead to the formation of new species. Furthermore, it is important to remember that speciation is an ongoing process, so it may be difficult to delimit species when species are at the beginning or middle stages of that process, especially given that many of our New Zealand plant genera are the result of recent and rapid divergence and have low DNA sequence diversity at standard DNA sequencing markers. However, this recent diversification is the reason why New Zealand is arguably one of the best places in the world to investigate evolutionary processes.

My own research to date has focused on several New Zealand flowering plant genera: native mountain foxgloves (*Ourisia*), hebes (*Veronica*), plantains (*Plantago*), and forget-me-nots (*Myosotis*). These genera contain multiple, closely-related and mostly endemic species that have diversified within the last few million years. I have used an integrative approach including analyses of comparative morphology, DNA (genotyping and sequencing), pollen, chromosome number, geography and habitat to infer the phylogeny, identify lineages, test species limits, discover and describe new species, and revise the taxonomy of these genera. For example, using a combination of molecular phylogeny (Tay *et al.* 2010a; Tay *et al.* 2010b), genotyping using DNA fingerprinting (Meudt 2011), statistical analyses of morphology (Meudt 2012), and new chromosome counts (Murray *et al.* 2010), my colleagues and I provided evidence for eleven native New Zealand species of *Plantago* in three separate evolutionary lineages. In this case there was a striking congruence among the data sets, and our integrative approach allowed us to also discover and describe a new species, *Plantago udicola* Meudt & Garn.-Jones, which has a unique chromosome number ($2n = 96$), and is ecologically, genetically and morphologically distinct (Meudt 2011). We used a similar approach to confirm the previous descriptive morphology-based taxonomy (Meudt 2006) of the 13 endemic mountain foxgloves (*Ourisia*) from New Zealand and one from Tasmania, and elevate a subspecies to species rank based on the new molecular evidence from DNA fingerprinting (*Ourisia calycina*; Meudt *et al.* 2009); readjust species and subspecies limits and taxonomy in the snow hebes (*Veronica*) of subalpine New Zealand and Australia, including reducing one species into synonymy based on morphology and molecular data (Meudt 2008; Meudt & Bayly 2008); and revise the taxonomy of the *Myosotis petiolata* species complex, including discovery and description of a new subspecies *Myosotis pansa* subsp. *praeceps* Meudt *et al.* based on molecular and morphological analyses (Meudt *et al.* 2013).

In some instances, however, this combination of molecular and morphological approaches has not provided enough variation for phylogenetic reconstruction or species delimitation, and additional methods are being explored. The New Zealand hebes are in the plant genus *Veronica,* which has the most (124) native species in New Zealand (Wilton *et al.* 2016) and is our largest and arguably most loved plant species radiation. Although there has already been much effort and many years of collaborative research on hebes, there are still several systematic issues that need to be resolved in this genus, perhaps in part due to whole genome duplication (polyploidy) and hybridisation which are blurring some species boundaries. Despite several studies (Wagstaff *et al.* 2002; Albach & Meudt 2010; Meudt *et al.* 2015b) we still do not have a fully resolved phylogeny of New Zealand *Veronica.* For our latest *Veronica* research (Mayland-Quellhorst *et al.* 2016, see below), we sequenced 48 new nuclear markers and 48 new microsatellite markers, each in 48 different individuals, to validate the newly-developed sequencing markers. We have only just begun detailed analyses of this data, but some of these markers appear to be quite variable for New Zealand *Veronica,* which will make them extremely useful for improving species delimitation via documented interspecific genetic differences, resolving the phylogeny, and answering questions about the evolution of polyploidy in the genus. We have also recently estimated the genome sizes of a number of New Zealand and Australian *Veronica* species for the first time and analysed these data phylogenetically to show that New Zealand hebes have experienced genome downsizing (DNA loss), which is associated with both polyploid radiation and higher rates of diversification (Meudt *et al.* 2015b). When used alongside chromosome counts, genome size can be very useful in systematic studies of *Veronica*, and perhaps other New Zealand genera, but to date only about 5–8% of New Zealand plant species have known genome sizes (http://data.kew.org/cvalues/), and most of those were published by Brian Murray (University of Auckland, now retired).

New Zealand forget-me-nots (*Myosotis,* Boraginaceae) are another group with very low levels of genetic variation for standard sequencing markers, which have frustratingly told us very little about species identities and relationships (Winkworth *et al.* 2002; Meudt *et al.* 2015a). Although species in the *M. petiolata* complex were able to be distinguished using DNA fingerprinting, this molecular method was not useful for other species in the genus (Meudt *et al.* 2015a). The majority of the

40+ New Zealand native forget-me-not species are threatened or at risk, with many exhibiting very restricted geographical ranges and/or occupying very specific habitats (de Lange *et al.* 2013; Meudt *et al.* 2015a). About two dozen putative new species have been given informal tag names (Druce 1993) and need to be studied in detail. All of this means *Myosotis* is a very high priority for systematics and conservation research, and is the focus of most of my current research (http://collections.tepapa.govt.nz/topic/3714). In addition to adding to morphological data sets, generating additional data sets will be critical for revising the taxonomy of this group. Recently I have shown that pollen morphology is useful for delimiting forget-me-not species groups and in some cases individual species (Meudt 2016). Jessie Prebble's recently completed PhD thesis on pygmy forget-me-nots is also a significant milestone, as it bridges systematics, population genetics and conservation, and is integrative in nature (Prebble, unpubl. thesis, defended November 2016). A novel aspect of this research is that morphological data from both herbarium specimens and live plants were compared. In addition to developing novel microsatellite DNA markers from next-generation sequencing data (Prebble *et al.* 2015), over 500 pygmy forget-me-nots were genotyped, and this data was analysed alone and in parallel with morphological and ecological niche modelling data using integrative statistical methods (Edwards & Knowles 2014). In the last chapter of the thesis, a taxonomic revision is proposed based on all available data. These chapters are currently being prepared for submission to scientific journals for publication. The data have already been used to make a submission to the New Zealand Threat Classification panel (J.M. Prebble, pers. comm.), which will ultimately help the Department of Conservation (DOC) undertake conservation management of these species to help protect them. Overall, Jessie Prebble's PhD thesis is a great example of New Zealand vascular plant integrative systematics, and it also exemplifies both next-generation and collaborative systematics, which are explored in more detail in the following two sections.

What is the role of next-generation sequencing in systematics?

'Next generation' is a fashionable phrase of the moment in biological research, and is being used to describe recent developments in diverse fields from crop breeding and biogeography to medicine and cancer. Often the phrase refers to next-generation sequencing (NGS), which over the past decade has caused a genomic revolution in all fields of biological research, including systematics (Harrison & Kidner 2011; Straub *et al.* 2012; Soltis *et al.* 2013; Barrett *et al.* 2016). In 2012, an entire issue of the *American Journal of Botany* was dedicated to 'Methods and Applications of Next-Generation Sequencing in Botany' (http://www.amjbot.org/content/99/2.toc). NGS allows systematists to generate and analyse unprecedented amounts of molecular sequence data which may allow whole genome phylogenetics and population genetics analyses, species delimitation via quantitative methods, better interpretation and comparisons of data sets, and perhaps even the detection of the genetic basis of interspecific differences. Although systematists should (and increasingly do) incorporate NGS data sets into their integrative taxonomic research, just as the integrative taxonomists warned a decade ago, we should be wary of equating next-generation sequencing (on its own) with next-generation systematics.

NGS methods and analyses also require significant resources (high performance computing, Unix/Linux operating systems), constant upskilling, and multidisciplinary collaboration, and are currently hindered by a substantial bioinformatics bottleneck. For many NGS methods, the bioinformatics bottleneck refers to a lack of access to essential computing resources (in some cases, the appropriate resources may not yet exist) and key skills to analyse the data. Although collaboration with colleagues who have bioinformatics skills is one option, upskilling is equally important (Barrett *et al.* 2016): 'It is very important for students to acquire adequate training in using Unix/Linux operating systems and at least one high-level programming language like Perl, Python, or Shell... Perhaps one of the most important things students can do at this point of time is to complement the obvious requirement of competence in taxonomy/systematics with expertise in genomics, informatics, and computational biology…' (Soltis *et al.* 2013, p. 895). When reading 'students', we should read 'all systematists'! It is difficult, however, to stay up-to-date, as NGS technologies are rapidly changing: 'Systematists are now faced with what may seem a bewildering array of next-generation sequencing (NGS) options… Most will be outdated or upgraded in the next several years, but the power of these current instruments is astonishing… [T]he field is moving so quickly that current techniques and applications will be rapidly superseded by upcoming advances…' (Soltis *et al.* 2013, p. 886–887).

There are numerous NGS platforms that systematists use, and these have been compared and discussed at length elsewhere in the literature (e.g. Glenn 2011). Irrespective of the platform, there are essentially two main methodological NGS approaches currently in use, i.e. restriction-enzyme-based methods and targeted methods. For both approaches, the central aim is to generate markers from a reduced representation of the genome, as we are not yet at the stage where we can sequence an entire (nuclear) genome. Examples of restriction-enzyme based methods (Davey *et al.* 2011) are restriction-site associated DNA sequencing (RAD-Seq; Baird *et al.* 2008; Peterson *et al.* 2012) and genotyping by sequencing (GBS; Elshire *et al.* 2011). Targeted methods include genome skimming, whole chloroplast DNA sequencing, high-throughput *de novo* transcriptome sequencing (RNA-Seq; Mortazavi *et al.* 2008), sequence/exon capture, Hyb-Seq (Weitemier *et al.* 2014), and anchored phylogenomics (Lemmon *et al.* 2012). Although these methods show great promise (e.g. Uribe-Convers & Tank 2016), I find few published examples of their use in New Zealand systematics to date (e.g. RAD-Seq in plants: Roda *et al.* 2013; and animals: Herrera & Shank 2016; note some studies using these methods are in progress and as yet unpublished, and GBS has been used in New Zealand in some horticultural and agricultural applications). RNA-Seq has been used to understand evolutionary questions in crops (e.g. cotton and soybean) as well as natural systems, including New Zealand plants (*Pachycladon,* Voelckel *et al.* 2012) and animals (stick insects, Morgan-Richards *et al.* 2016). My colleagues and I have recently used RNA-Seq to develop novel sequencing markers in New Zealand and European *Veronica* (Mayland-Quellhorst *et al.* 2016) that may provide additional data sets to improve the phylogeny and resolve problematic species limits when used in an integrative context. Finally, many plant microsatellite markers have also been developed recently for New Zealand plants using NGS genomic data (e.g. McLay *et al.* 2012; Van Etten *et al.* 2013, 2014; Prebble *et al.* 2015; Pilkington & Symonds 2016; Breitweiser *et al.* 2015), but whether these and/or RNA-

Seq data and markers developed from them are effective for integrative systematics remains to be seen.

How can we foster collaborative systematics in New Zealand and beyond?

During an Olympic year, I once heard a botanist at a conference say that if systematics were an Olympic sport, it would be decathlon. Just as one decathlete is expected to excel in ten different disciplines, so systematists use a wide array of methods in their research. And just as the decathlon evolved from sports with fewer events such as the pentathlon and heptathlon, so systematists continue to add new data, methods and skills to their systematic toolkits. Thus, superficially, this analogy does seem to speak to both the nature and breadth of the work integrative systematists do. But upon further thought, the decathlon may not be the best model. First of all, only men can compete in the Olympic decathlon! (NB: Taxonomists in New Zealand as a group are a 'male-dominated, aging workforce'; Royal Society of New Zealand 2015.) Secondly, although systematists do a lot of their own research, they also collaborate. Although mixed-gender medley relay races do exist at some swimming or track and field competitions (not yet including the Olympics), probably no current sport can truly embody all aspects of integrative systematics as practised today.

Collaboration is important in systematics when using both standard methods as well as new techniques, and it is probably essential for research involving NGS and bioinformatics. It is likely that all systematists (and indeed all scientists) have all had both positive and negative experiences when collaborating. When it works well, collaborative systematics has very important benefits for systematists individually and collectively, and of course for the organisms under study. There are many benefits of practising collaborative systematics, including contributing additional data sets to an integrative research framework, filling knowledge/skill gaps for a particular project, facilitating upskilling, enabling the sharing and passing on of knowledge and experience, and creating synergy which allows more systematics research to get done together than when working alone.

Collaboration is particularly important in New Zealand, where the small systematics community is physically isolated from colleagues in other countries, capability and funds are declining, and contestable research grants for systematics and other collection-based research are non-existent (Royal Society of New Zealand 2015). Furthermore, systematists at universities, museums and Crown Research Institutes are all under pressure to conduct systematics research in addition to teaching, working on exhibitions, and completing contracts. Because of limitations in resources and available expertise, coordinated, cross-institutional prioritisation at the national level regarding what systematics research should be done, on which organisms, to what degree, and by whom, is crucial, but does not yet occur (Royal Society of New Zealand 2015). Given these circumstances, it can sometimes be difficult for systematists to collaborate even though collaboration may help them achieve more fruitful results in their research projects. Nevertheless, it is clear that collaborative plant systematics is happening in New Zealand; that is, systematists routinely collaborate with other systematists and with non-systematists on integrative systematics research. Below I will mention some examples of this, but I will also argue that more can be done to foster increased collaboration at the local, national, regional and international levels by systematists themselves, their institutions, other organisations, and the government.

Some examples of synergy and collaboration from my own work are: recent collaboration on *Veronica* with New Zealand, German and Spanish colleagues (Meudt *et al.* 2015b; Mayland-Quellhorst *et al.* 2016); co-supervision of students Mei Lin Tay (MSc) and Gustavo Hassemer (PhD) on *Plantago* involving collaboration with scientists from Victoria University and Auckland University, and the University of Copenhagen and Museum of Natural History Denmark, respectively (Murray *et al.* 2010; Tay *et al.* 2010a; Tay *et al.* 2010b; Hassemer *et al.* 2015); and systematics research on *Myosotis*, including co-supervision of PhD student Jessie Prebble, collaboration with scientists from Te Papa, Massey University, DOC, city councils, among others (Meudt *et al.* 2013; Meudt *et al.* 2015a; Prebble *et al.* 2015). Recent collaboration on New Zealand *Veronica* systematics is a subset of other current and past complementary collaborations, many of which have had Northern + Southern Hemisphere and trans-Tasman components (e.g. Wagstaff *et al.* 2002; Bayly & Kellow 2006; Garnock-Jones *et al.* 2007). New Zealand fern systematics is another good example of collaboration between New Zealand and Australia (e.g. Perrie *et al.* 2014) and within New Zealand (e.g. Te Papa and DOC; Brownsey *et al.* 2013). Research on the New Zealand everlasting daisies (tribe Gnaphalieae) is an early and still ongoing example of integrative, collaborative systematic research by staff at Landcare Research and colleagues on a group of flowering plants. In their PhD theses, both Ward (1981) and Breitwieser (1990) argued that the taxonomic confusion in this group – especially in terms of generic boundaries – would require using as many and varied characters as possible, and, to this end, morphology, anatomy, isozymes, flavonoid chemistry, pollen, chromosome counts, molecular phylogeny, and microsatellites have so far been employed (e.g. Haase *et al.* 1993; Ward 1993; Breitwieser & Sampson 1997; Ward & Breitwieser 1998; Breitwieser *et al.* 1999; Dawson & Ward 1999; McKenzie *et al.* 2004; Breitwieser *et al.* 2015).

Postgraduate student co-supervision is a great way to collaborate, particularly between institutions (Royal Society of New Zealand 2015), and can be hugely beneficial for all involved. Systematists at Te Papa, for example, have successfully co-supervised a number of postgraduate plant systematics students to completion of their Honours, MSc and PhD degrees in collaboration with New Zealand and overseas universities. Plant systematists must also continue to build upon regional professional networks, e.g. Australasian Systematic Botany Society (ASBS; http://www.asbs.org.au/) and Council of Heads of Australasian Herbaria (CHAH; http://www.chah.gov.au/). At the regular meetings for these organisations, formal and informal hands-on workshops are critical for transfer of knowledge and skills among colleagues. Attending other specialised annual meetings in New Zealand can also foster upskilling in the latest molecular analysis techniques as well as collaboration with the wider evolutionary biology community (e.g. Annual New Zealand Phylogenomics Meeting http://www.math.canterbury.ac.nz/bio/events/; New Zealand Molecular Ecology Conference http://www.nzmolecol.org/). Unfortunately the Systematics Association of New Zealand (SYSTANZ; http://www.math.canterbury.ac.nz/bio/pages/SYSTANZ/) has not been active for some time, and the informal New Zealand Plant Radiation Network (NZPRN; https://nzprn.otago.ac.nz/NZPRN) does not meet regularly; these organisations hold great promise for collaboration among systematists, but it seems that lack of time and resources in a small community, rather than a lack of interest, is what is currently holding them back from doing more.

In addition to professional organisations and annual conferences, New Zealand systematists can also come together in smaller groups to continue or start new collaborative projects, or to visit each other's institutions to learn and share expertise, or run a hands on workshop; this could also be expanded to include the greater Australasian/Pacific region. Although this does occur to some degree, currently there is a lack of investment, coordination and funding for taxonomic collections and research at the national and regional levels – as well as significant time and financial pressures at some institutions – preventing more of this type of collaboration from happening (Royal Society of New Zealand 2015). To this end, establishing a 'systematics collaborative mobility fund' to specifically fund New Zealand systematists to undertake such collaborative professional development and travel would be a step in the right direction. There is a precedent for such funding schemes for European systematists, e.g. the Biotechnology and Biological Sciences Research Council's (BBSRC) now defunct 'Systematics Initiatives' Collaborative Scheme for Systematics Research (Co-Syst) and Systematics and Taxonomy (SynTax), or the current EC-funded SYNTHESYS project (http://www.synthesys.info/). In New Zealand, the establishment of such a scheme could be a small but important part of the recommended creation of a nationally coordinated and financially supported 'whole-of-systems approach' to address investment, coordination, protection, stewardship, and training in New Zealand's biological collections and systematics research (Royal Society of New Zealand 2015).

As to international collaboration opportunities, there is very limited funding available to New Zealand systematists (e.g. in New Zealand: http://www.royalsociety.org.nz/programmes/funds/international/, and elsewhere: https://www.humboldt-foundation.de/web/home.html). And even when external funding is available, it may be difficult for many systematists to take advantage of such opportunities due to other institutional and work commitments. Instead, it is perhaps more common that international colleagues come to New Zealand for meetings, training, upskilling, field work, sabbaticals and other collaborative activities, and this should continue to be encouraged and supported by New Zealand systematists and their institutions. Nevertheless, there are examples of New Zealand systematists going overseas for upskilling. For example, I received an Experienced Researcher Fellowship from the Alexander von Humboldt Foundation in 2012 to work in Dirk Albach's lab at the University of Oldenburg, Germany for 18 months. I was fortunate that I had the support of my family, colleagues and employer to take on what was a highly rewarding experience and collaboration which still continues today. I recently pieced together travel funding from several sources to return to Europe on a short trip to reconnect with my European colleagues and attended two international conferences, which provided some much needed and highly productive face-to-face meetings (http://blog.tepapa.govt.nz/2016/10/12/botany-travels/). Prior to that, in 2004, receiving funding for two years through the United States National Science Foundation International Postdoctoral Research Fellowship (https://www.nsf.gov/od/oise/iprffapp.jsp) was vital in helping me establish my systematics career and collaborative networks in New Zealand. No doubt there are many other examples of New Zealand systematists and their institutions benefitting from such international exchanges, and in general they are taking advantage of such opportunities as best they can, given current funding and capability constraints. Critically, institutions and government must support and invest in new resources and programmes to create more possibilities for current and future systematists (Royal Society of New Zealand 2015).

Conclusions

Systematics is an exciting, challenging, dynamic, and important science, which combines new and traditional methods to discover and delimit species, and address relevant evolutionary questions. Integrative systematics uses comparative analyses of multiple data sets to robustly test species limits in a statistical framework. Ideally such a framework would include quantitative co-analyses of genetic data together with data from morphology, geographical distribution, chromosomes, anatomy, microscopy, and other data sets. Systematists are increasingly incorporating new methods into their integrative research toolkit, including next-generation sequencing, which require significant computer resources, training and upskilling for bioinformatics and data analysis. Collaboration is also critical for integrative and next-generation systematics research, and systematists, institutions, professional societies and government can and should foster more exchanges within New Zealand as well as with Pacific and Australasian nations and beyond. I argue that the current and future way forward for systematists to effectively and confidently resolve taxonomically challenging groups is by using integrative, next-generation and collaborative systematics, and that such an approach is critical in New Zealand.

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News

Royal Society of New Zealand's Hutton Medal awarded to Professor Wendy Nelson

Professor Wendy Nelson MNZM FRSNZ, Programme Leader for Marine Biological Resources at NIWA and Professor at the School of Biological Sciences at the University of Auckland, has been awarded the Hutton Medal by the Royal Society of New Zealand for significantly expanding the knowledge of New Zealand's seaweeds, also known as marine macroalgae.

In a career spanning 35 years, she has discovered and documented the diversity of New Zealand flora throughout the region, from Te Rangitahua/Kermadec Islands to the Subantarctic Islands, and conducted research on taxonomy, evolution, algal ecology, alien seaweeds, and seaweed aquaculture and commercial harvesting.

Her work on the ancient lineage of Bangiales, a type of red algae that includes Japanese nori seaweed, has resulted in New Zealand being recognised as a centre of diversity, requiring a reinterpretation of evolutionary relationships between world species.

Over the past decade her research has focussed on the ecological importance of coralline algae, a calcified group of red algae, which form key habitats for a wide range of coastal organisms and are critical to the settlement and development of species such as pāua, but are vulnerable to climate change. She has also campaigned hard to get the most aggressive weeds eliminated from our coastal waters.

In 2013 she published a popular guide to New Zealand seaweeds, making her extensive knowledge accessible to others[1].

In 2015 she chaired a major review by the Royal Society of New Zealand on biosystematics and taxonomic collections[2].

On being awarded the Hutton Medal, Professor Nelson said she had had the very good fortune to work with exceptional colleagues throughout her career. Moreover, she felt that New Zealand is an extraordinary place to work as a marine botanist with such diverse marine systems to study.

'Our long isolation from other land masses and dynamic geological history have all contributed to the evolution of a rich and intriguing marine flora, and there is still a great deal to be discovered.

'Macroalgae are critical to the health and well-being of coastal ecosystems – and it is important to discover and document our flora, understand how coastal systems function – in order to be stewards of coastal environments for future generations.'

[1] Nelson, W. 2013. New Zealand Seaweeds: An Illustrated Guide. Wellington, Te Papa Press. ISBN: 978-0-9876688-1-3

[2] Nelson, W.A.; Breitwieser, I.; Fordyce, E.; Bradford-Grieve, J.; Penman, D.; Roskruge, N.; Trnski, T.; Waugh, S.; Webb, C.J. 2015. *National Taxonomic Collections in New Zealand.* Royal Society of New Zealand. 63 pp. + Appendices (66 pp.) ISBN 978-1-877317-12-5 www.royalsociety.org.nz/national-taxonomic-collections-in-new-zealand

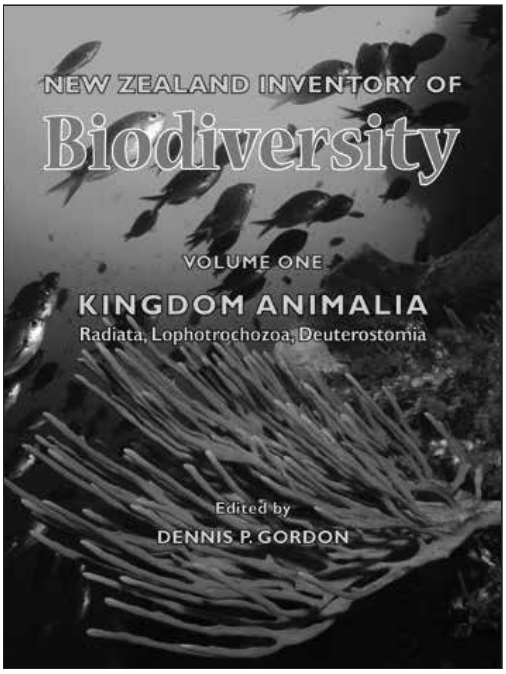
Book review

Dennis P. Gordon (Editor)

New Zealand Inventory of Biodiversity

Reviewed by Geoff Gregory

New Zealand was the first country to catalogue its entire living and fossil biodiversity, with the release from Canterbury University Press of the third and final part of *New Zealand Inventory of Biodiversity* in 2012.



Volume 1 of *New Zealand Inventory of Biodiversity.*

The whole inventory was edited by NIWA biodiversity scientist Dr Dennis Gordon, and was the culmination of an international effort he led involving 237 other authors from New Zealand and overseas. It offers the first review of New Zealand's entire complement of known species of animals, plants, fungi and micro-organisms – some 56,000-plus living and 14,000-plus fossil species – and covers all life in all environments, from the Cambrian to the present day, including both native and naturalised alien species.

The three volumes were associated with Species 2000, an international scientific project which aimed to record all named species on Earth in one online list called the *Catalogue of Life*. The New Zealand component was launched in February 2000 at the *Species 2000: New Zealand* millennial symposium in Wellington.

At its completion, Dr Gordon said, 'I didn't anticipate that this project would take so long, but it should not be surprising that a 1758-page review and inventory of all of life through all of time in New Zealand, involving specialists in 19 countries, has taken a decade to come to completion.'

Volume 1 catalogues the branches of the animal kingdom that include living and fossil sponges and corals, worms and shellfish and their relatives, and vertebrates – the fishes, amphibians, reptiles, birds, and mammals.

Volume 2 mostly deals with the major branch of the animal kingdom known as *Ecdysozoa* (moulting animals), which includes spiders, centipedes and millipedes, crustaceans, insects and related marine worms.

Volume 3 deals with the remaining groups of life – bacteria, protozoans, algae, plants and fungi.

Dr Gordon himself was lead author of the chapter in Volume 1 dealing with his own speciality, the Bryozoa, and he has also written chapters on several of the lesser-known small creatures in this volume and among the Protozoa in Volume 3 to ensure that the books provide comprehensive coverage of all life forms. He was justifiably proud of Volume 3, which dealt with a lot of challenging microscopic groups that had never been scoped or reviewed before for this part of the world.

Each of the three case-bound volumes is beautifully illustrated, with appropriate line drawings, half-tones and colour photographs.

The three books can be purchased as a boxed set from Canterbury University Press:

Gordon, D.P. (Ed.) 2009–2012. *New Zealand Inventory of Biodiversity* (boxed set containing three volumes). Canterbury University Press, Christchurch.

ISBN 978-1-927145-28-9

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Association of Scientists

EARLY NOTICE

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Beyond the Usual Suspects…

Wellington, early May 2017

The conference programme and registration details will be available early in 2017 at www.scientists.org.nz