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.

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

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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
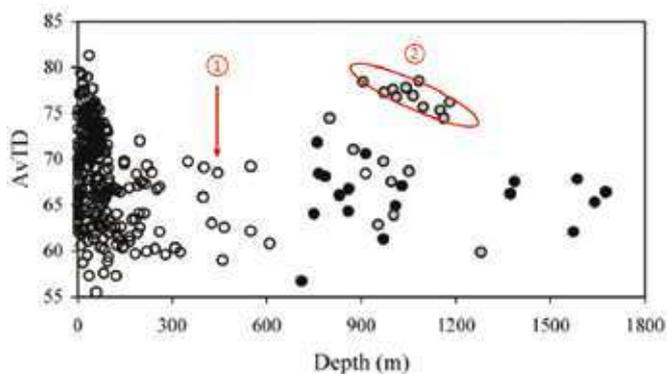
measures of taxonomic distinctness. This latter hypothesis we and others have taken up elsewhere using the VarTD metric (e.g. Brewin *et al.* 2009), while the hypothesis about slope instability controlling regional patterns of biodiversity in the New Zealand region is still to be addressed (three unsuccessful 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 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).
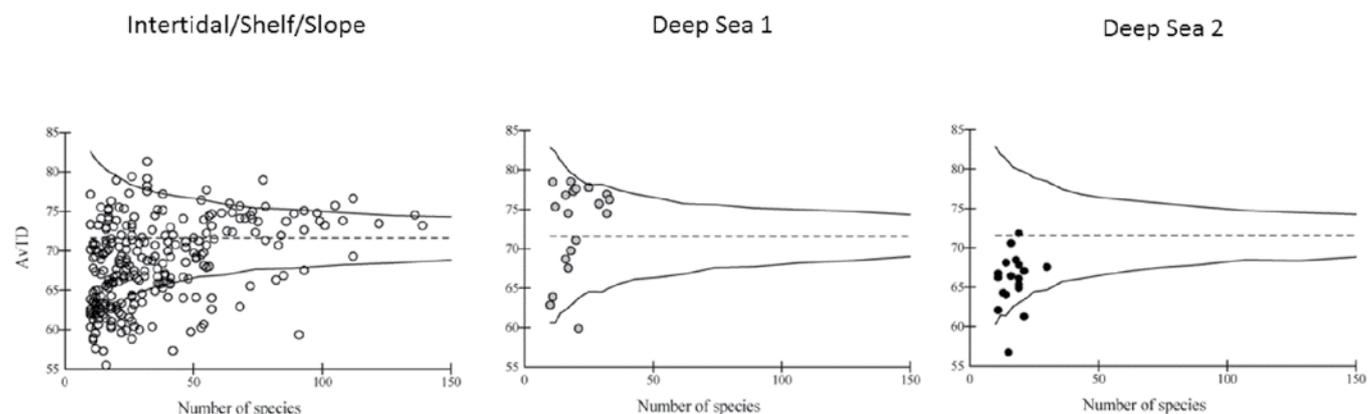
Figure 2: Plots showing the departure from the theoretical mean AvTD, and 95% confidence funnel, of stations in the New Zealand region with ≥10 species of Bryozoa for Inter-tidal/Shelf/Slope (open circles), Deep sea 1 (solid grey circles), Deep sea 2 (solid black circles) communities (modified from Rowden *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).
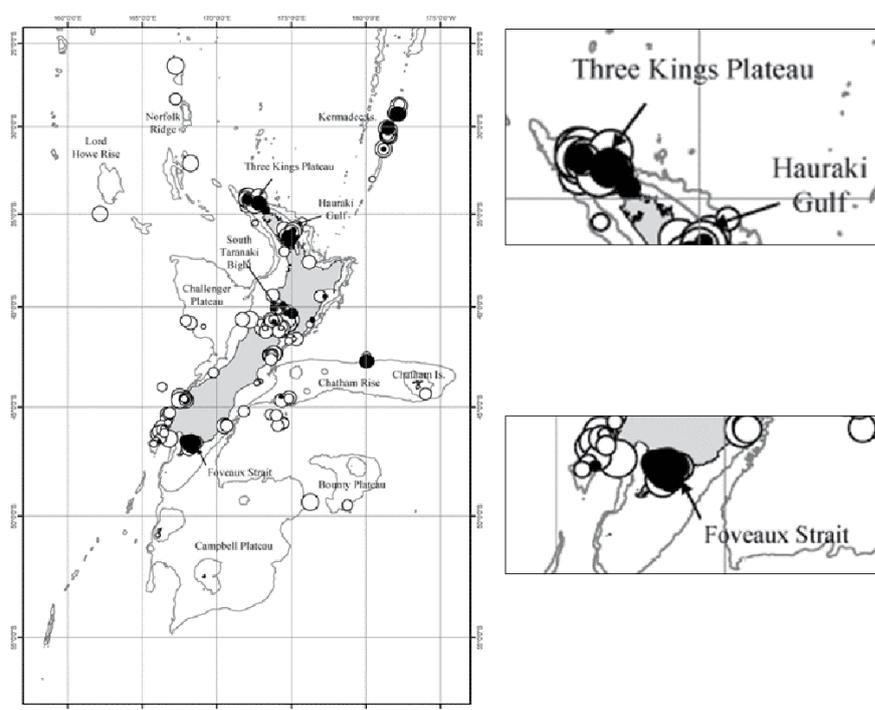
and colleagues from NIWA had postulated in an earlier paper – that over a hundred years of oyster dredging had reduced sea-floor habitat complexity in Foveaux Strait, and this had had a profound impact on the structure of seafloor communities (Cranfield *et al.* 1999).

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
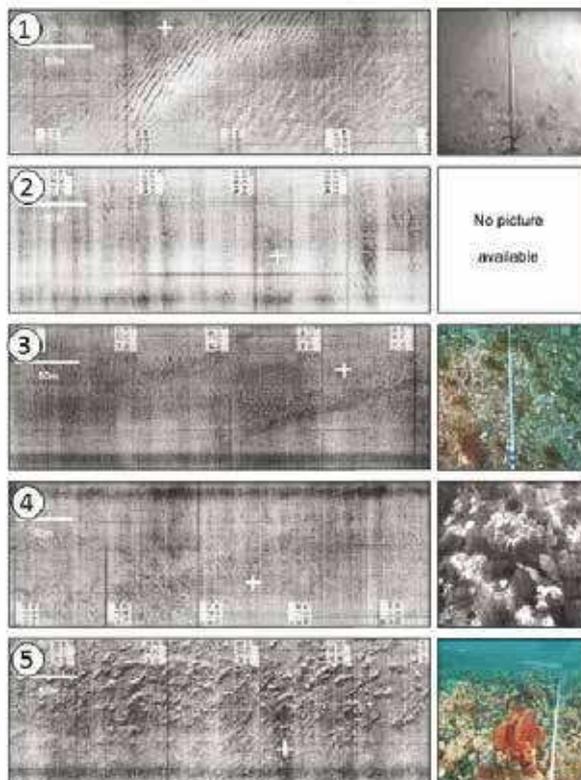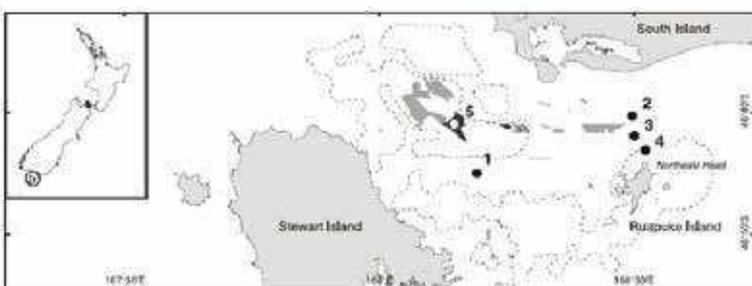

Figure 4: Figure showing (anti-clockwise from top left): Photograph of oyster dredge; Inset map showing location of Foveaux Strait in New Zealand, and main map showing the position of the five sampling sites in Foveaux Strait (numbered according to rank habitat complexity). Light grey shading demarcates 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	$\bar{S}_i$	$\bar{S}_i/SD(\bar{S}_i)$	S_i %	ΣS_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 novaezealandiae (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 novaezealandiae (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.
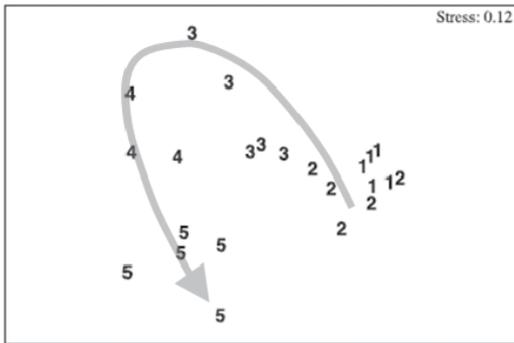

Figure 5: Figure showing (left to right): Two-Dimensional plot of n-MDS ordination of macrofaunal samples (using Bray–Curtis similarity measure of standardised, double square root transformed data) from sites of different habitat complexity (Habitat 1– 5 = least to most complex habitat). Arrows represents 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).
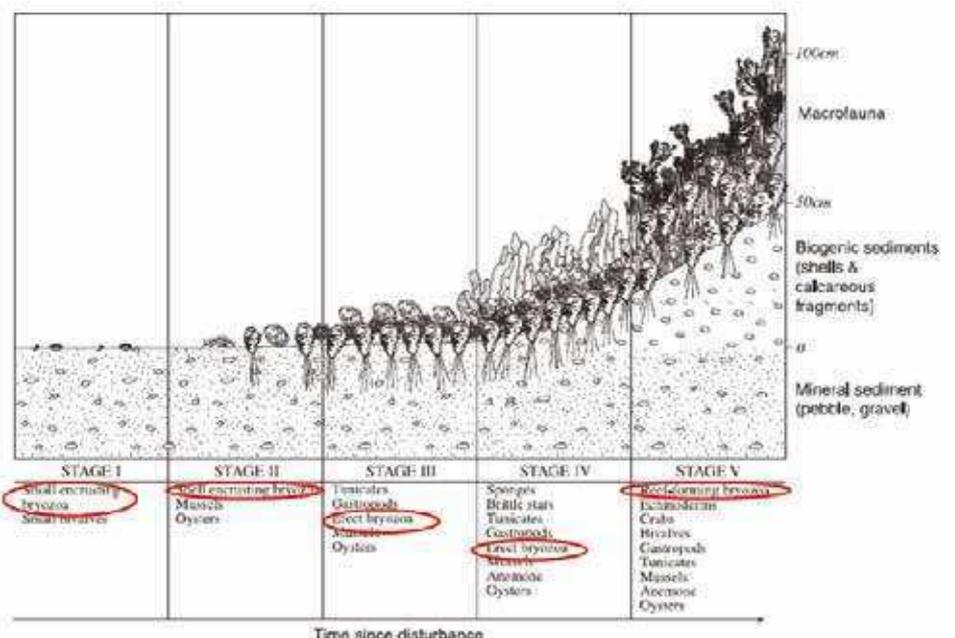
These habitats can occur on the New Zealand continental shelf (Batson *et al*. 2000).

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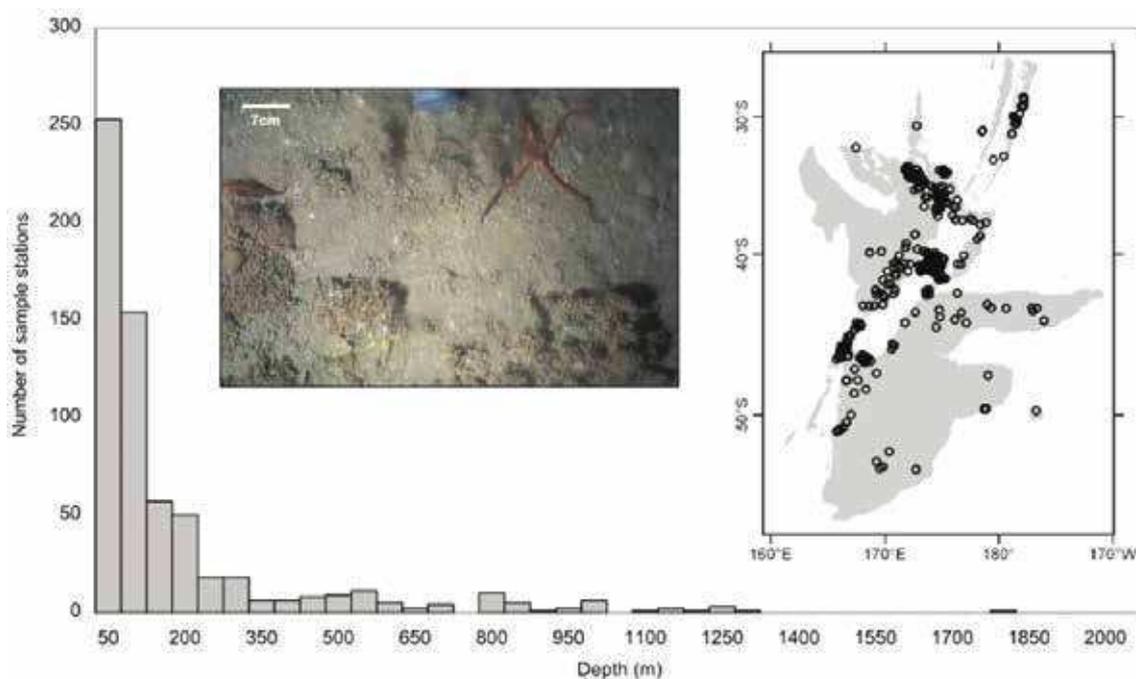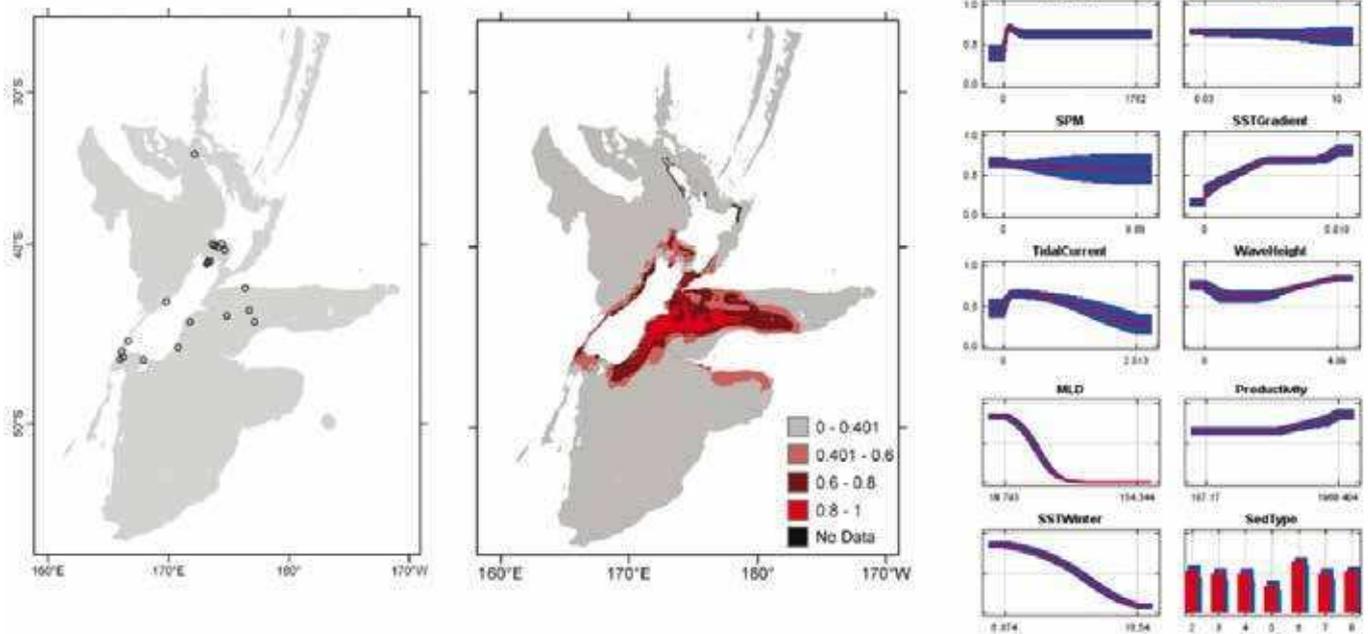
Figure 8: *Celleporina grandis* **known distribution (left), predicted suitable habitat (middle), and fitted responses curves (right) (reproduced under Creative Commons from Wood *et al*. 2013).**
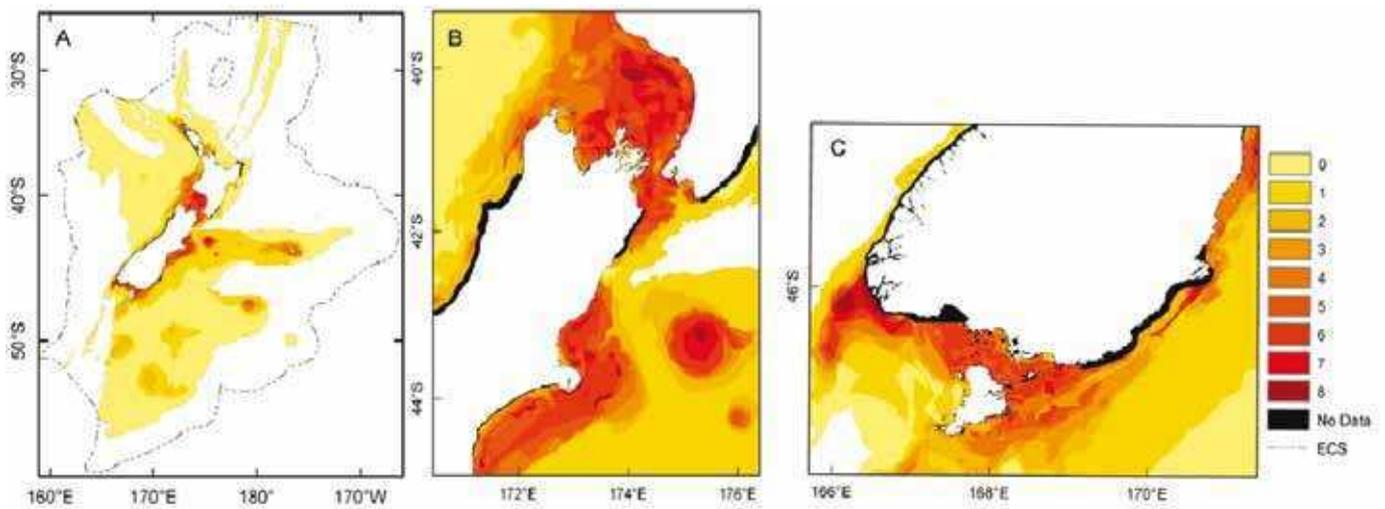

Figure 9: Predicted hotspots of habitat-forming bryozoans based on summed binary predictions of suitable habitat for multiple bryozoan species. (A) Extended Continental Shelf; (B) Greater Cook, Strait, Banks Peninsula and Mernoo Bank; and (C) around southern South Island, including Puysegur 'Bank', Foveaux 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.

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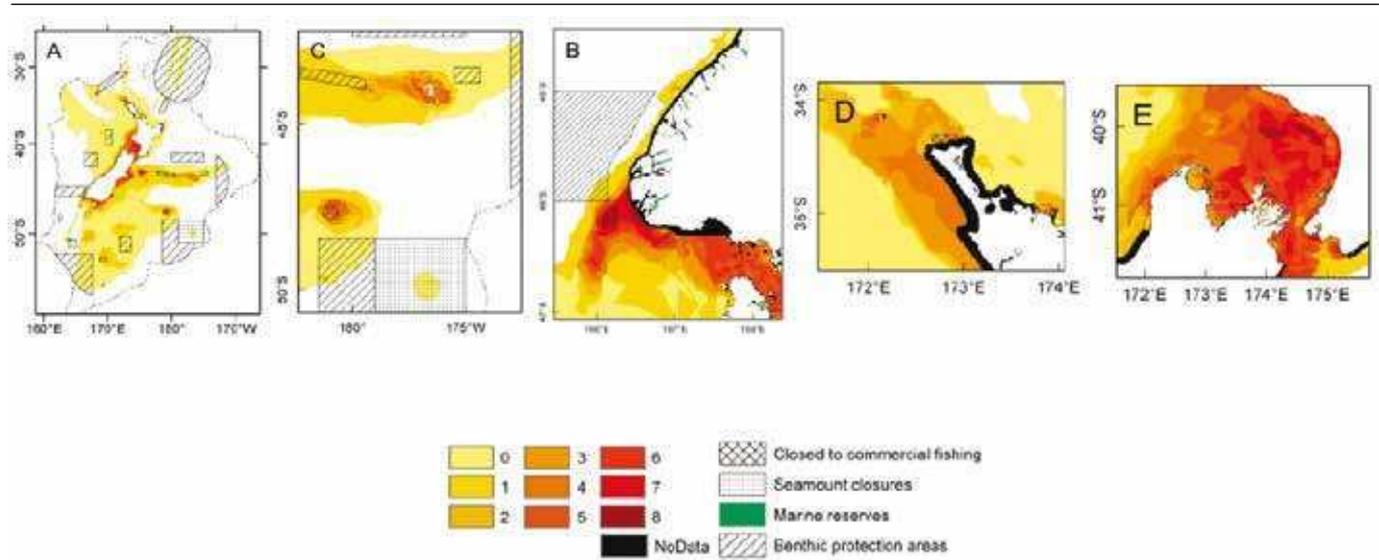
Figure 10: Figures showing the spatial relationship between predicted bryozoan hotspots and areas closed to commercial fishing (no trawl, Danish seine or commercial dredge (amateur dredge allowed)), seamount closures, marine reserves/marine protected areas, and benthic protection areas in the New Zealand. (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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