Taxonomy and systematics: an essential underpinning of modern fisheries management

Mary Livingston*
Ministry for Primary Industries, PO Box 2526, Wellington 6140

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).

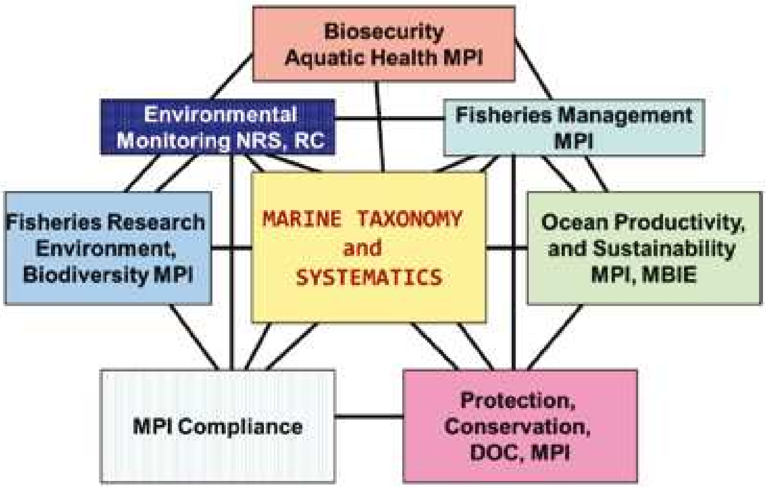


Figure 1. Broad relationships between marine systematics (including taxonomy, identification services, collections and databases) and government end-users. NRS: Natural Resource Sector. NRS Agencies include Ministry for Primary Industries, MPI; Ministry for the Environment, Statistics New Zealand, Environmental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

* Correspondence: Mary.Livingston@mpi.govt.nz

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).

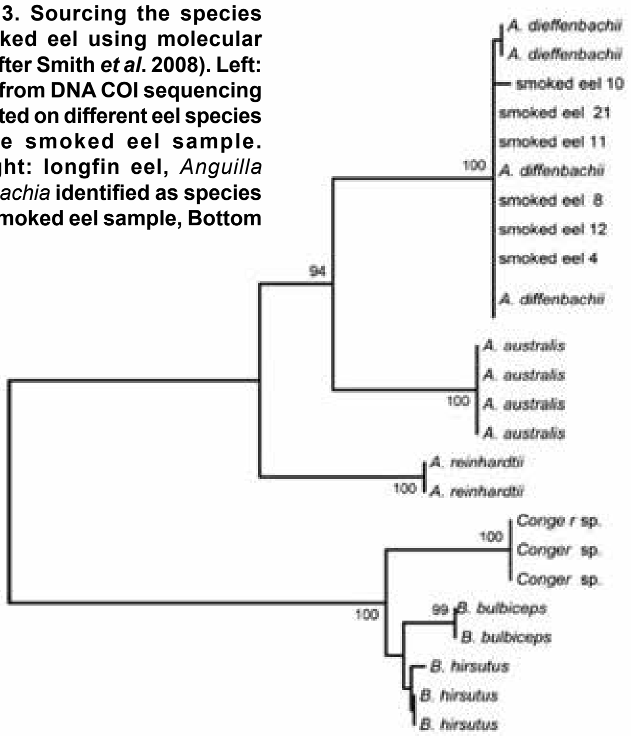
The global effects of climate change and ocean acidification have necessitated far wider activity on taxonomic identification of vulnerable fauna, particularly for deep-sea corals (e.g. Tracey *et al*. 2014). Collectively, these burgeoning needs have resulted in increasing stretch on taxonomic and systematics 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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