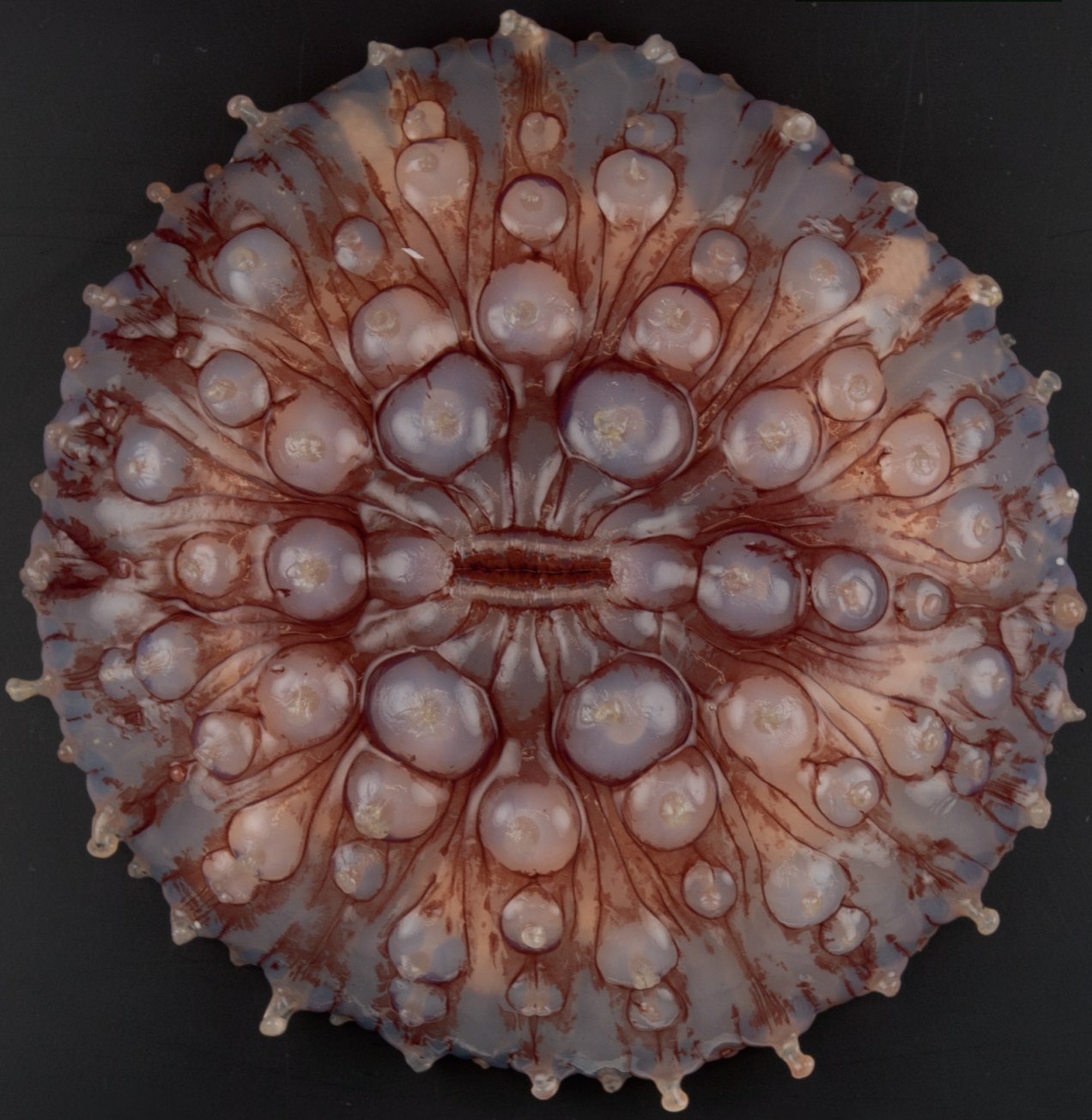
National Taxonomic Collections in New Zealand

December 2015

the Royal Society of New Zealand
Te Apārangi



Cover image: Close-up detail of *Corallimorphus niwa* Fautin, 2011. This unusual animal is between a sea anemone and a coral, featuring short rounded tentacles and a slit-like mouth. It was collected in 2007 on the Chatham Rise from its muddy deep-sea habitat as part of the Ocean Survey 20/20 Chatham / Challenger Biodiversity and Seabed Habitat Project, jointly funded by the New Zealand Ministry of Fisheries, Land Information New Zealand, National Institute of Water & Atmospheric Research (NIWA), and Department of Conservation. It was described as a new species in 2011 by Dr Daphne Fautin from the University of Kansas, following a visit to the NIWA Invertebrate Collection in 2008.

Image credit: Owen Anderson, NIWA. Ocean Survey 20/20 Chatham / Challenger Biodiversity and Seabed Habitat Project.

A message from the President of the Royal Society of New Zealand

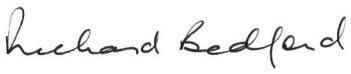
It gives me great pleasure to release this report by the Royal Society of New Zealand's Expert Panel on National Taxonomic Collections in New Zealand.

Taxonomy - the essential science that identifies and names New Zealand's diverse flora and fauna, and determines what is native and not native to New Zealand - is intrinsic to preserving biological heritage. New Zealanders' national identity, economic prosperity, environmental management and health and wellbeing depend on this science along with the many millions of specimens in the collections that record this country's flora and fauna.

This report brings together a very wide range of inter-disciplinary evidence about the current state and future potential of our taxonomic collections and proposes what is needed to ensure they can continue to serve New Zealanders into the future. The report is timely given the recent release of the National Statement of Science Investment, which sets out the government's role and strategic intent to increase its investment in science that demonstrates excellence and impact. The evidence set out in this report provides a compelling case for government investment in the collections, along with the experts and infrastructure that support them.

I encourage the government to pay attention to the immediate risks to the collections and taxonomy expertise identified in the report. I also encourage the government to consider the range of recommendations for lifting system performance and realising greater benefit from the collections, as it develops its future science investment strategy.

I would like to thank Professor Wendy Nelson FRSNZ for so ably chairing the review through the process of evidence gathering and writing, and the members of the expert panel for taking on this sizeable task and freely giving their time, effort and expertise. The knowledge and capability of our expert panel members is impressive and has contributed greatly to the credibility of this work. I would also like to acknowledge the Panel's efforts in consulting widely on its work including the workshops in Auckland, Wellington, Christchurch and Dunedin that sought views of collection holders, taxonomists and policy makers.



Professor Richard Bedford QSO FRSNZ
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This report has been prepared under the Royal Society of New Zealand's function to provide expert advice on important public issues to the Government and the community, as set out in its legislation.

Acknowledgements

The Panel would like to thank the Society's expert advice team, Dr Marc Rands and Dr Roger Ridley, as well as Richard Meylan for their valuable support and assistance. The Panel would also like to thank the collection holders, government departments and many stakeholders who have contributed to the report. Special thanks are given to Dr Stephen Goldson and Dr Joanne Daly for reviewing the report for the Society, and to Sir Peter Gluckman for his advice.

Contents

Appendices

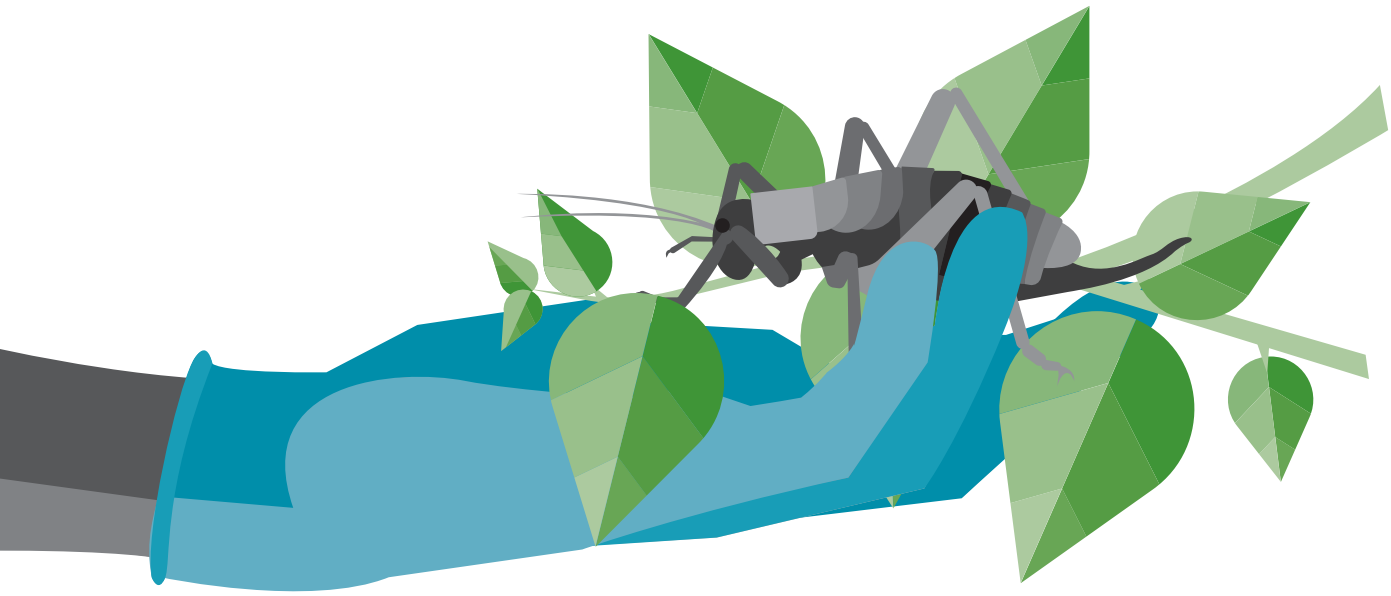
Appendices are available at: www.royalsociety.org.nz/national-taxonomic-collections-in-new-zealand.

Glossary of terms

Collection management	Management of all collection policy and tasks, including loans, database management, data retrieval, registration, maintenance, collection acquisition, collections analysis, collection promotion, and training.
Curation	Process of identifying and storing specimens according to the taxon-specific and collection-organisation methods. Physical collection maintenance, and the facilitation of access, are included in this activity.
Endemic, exotic, indigenous, native	Endemic: restricted/unique to, e.g. found only in New Zealand; exotic: from outside New Zealand; indigenous: presence in New Zealand is the result of natural processes, with no human intervention; native: found naturally in New Zealand.
Specimens and lots	A specimen is a sample of an organism or fossil, and can range from a colony through to a piece of a single individual. A "specimen lot" is a group of specimens associated at some taxonomic level which are from the same collection locality.
Systematics	Scientific discipline that classifies and names the diversity of life, and provides a conceptual framework for the evolutionary classification and relationships of species. Systematics includes taxonomy (naming), phylogeny (evolutionary relationships) and classification, as well as collections.
Taxonomic collection	Taxonomic collections contain biological samples and specimens stored primarily for taxonomic research of biota and for scientific reference. They include plants, animals, micro-organisms and their fossils, together with their associated data and archival material. Collections include living and dead material (e.g. plant and seed collections, culture collections, skeletons, exoskeletons, shells, eggs, feathers, tissue, blood and skin).
Taxonomic data	Information that accompanies a specimen or sample (or all specimens from a sample). Usually includes date of collection, geographic location, coordinates, names of collectors, habitat notes, altitude or depth of collection, geological level for fossils, and for marine specimens the equipment used; data on parasites and commensals will record host species; planktonic specimens will include capture depth range and possibly time of day.
Taxonomic information systems	Organised collections of data on, for example, nomenclature, morphology, images, literature, taxonomic and molecular characterisation; provenance and other 'label' and identification meta-data associated with specimens.
Taxonomic research	Scientific discovery, description, naming and classification of organisms.
Type material	Type materials are particular specimens to which the scientific name of that organism is formally attached, anchoring the definition with a detailed published description. Type material must be lodged in a publicly accessible research collection and be available to scientists for examination.
Voucher specimen	Any specimen that serves as a representative of a species name applied in specific instances. These specimens, with their catalogue numbers, are retained for future reference in an accessible collection.

Executive summary

New Zealand should strive to have deep and comprehensive knowledge of its biota across its lands, fresh waters, and surrounding seas that: defines New Zealand's evolution, uniqueness and cultural icons; allows New Zealand to sustainably manage its natural resources and economic opportunities; protects New Zealanders' health and wellbeing; and allows New Zealand to stand tall in the international community in meeting its global obligations.



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 worldclass 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?

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[1] 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.

1 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.

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.

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

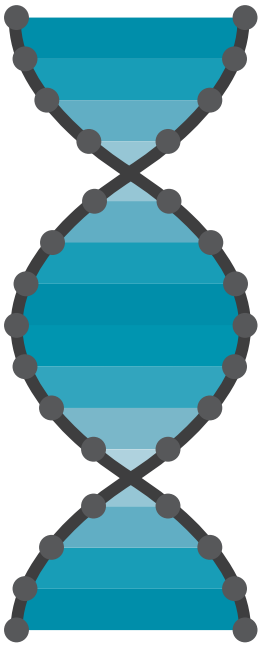
7. The evidence and findings of this review are incorporated into the 2015 review of Core Purpose Funding for CRIs, reflecting the significance of the CRIs in managing these collections.
8. Government urgently address the immediate investment needs of the national taxonomic collections and research staff 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.

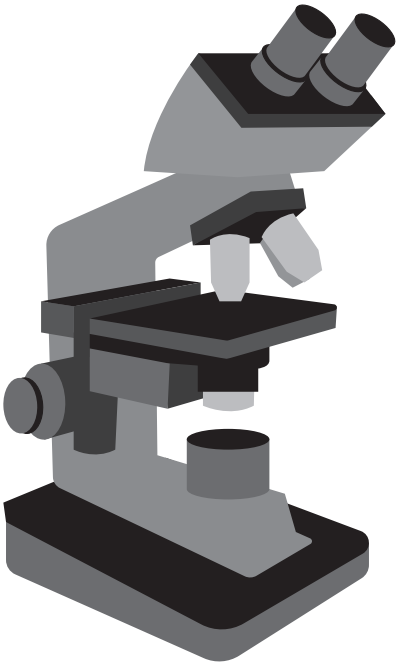
Introduction

Context

New Zealanders live in a country remote from other land masses, with rich, diverse and unique biological ecosystems that have developed over millions of years. After splitting from other continents 80 million years ago, evolution in New Zealand has taken a unique course, resulting in plants, animals and ecosystems that are found nowhere else in the world. Until the arrival of humans, New Zealand had the longest period of isolation of any non-polar landmass on the planet.

New Zealand is a recognised biodiversity hotspot and, as such, is of supreme interest and importance from a global perspective. However, the taxonomic understanding of the New Zealand biota is undeveloped compared to other advanced economies. Māori have a relationship with the natural world including a body of knowledge and scholarship (Mātauranga Māori) about species and their relationships (whakapapa) that extends across the Pacific region. All species are considered taonga (treasures), with some representing tupuna (ancestors) or acting as guardians associated to the spiritual realm.





Need for a review

New Zealand's national taxonomic collections and taxonomic expertise are vital to its economy and society. Biological collections, taxonomic research, and the associated databases and biodiversity information systems provide the scientific baseline that underpins the management of New Zealand's unique biodiversity and living economic resources, including both native and introduced species. They ensure ecological science is reproducible and enable New Zealand to meet its legislative and international obligations[2].

Knowledge of New Zealand's past and present living biological systems, and their place within global biodiversity and evolution, are fundamental to New Zealanders' lives, to define its natural history and heritage, support economic growth, manage risks to health and living environments, and to educate the next generation of New Zealanders. 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 to further the integration of Māori cultural concepts in the collections specifically.

Concerns have been raised repeatedly about the maintenance and development of this nationally important New Zealand resource. Responsibilities for funding of the collections, databases and associated research are diffuse. Adequate provision of expert taxonomic knowledge of New Zealand's species has declined, and there is no obvious policy oversight of either capability or the collections themselves. The full value of the collections to New Zealand's economy and society is not being realised and there is increasing possibility of permanent damage through lack of proper maintenance.

In spite of this, demands on biological collections are increasing both in New Zealand and globally. Examples of why this is so include the biosecurity requirements of international trade; rising (rather than falling) rates of new species discovery as new science and technologies come on stream; risks to sustainability and biodiversity; management of human and animal health risks driven by growing population densities; climate and immigration pressures; growing international demand for certified pest- and toxin-free food; and global demand to advance knowledge of the world's evolutionary biology. Alongside such demands, advances in science and technology are broadening the impact and use of collections.

2 For example, New Zealand's obligations with respect to the Convention on Biological Diversity, Intergovernmental Platform on Biodiversity & Ecosystem Services, and its commitment under the Global Taxonomic Initiative (GTI).

Taxonomy and systematics

Taxonomy and systematics are the sciences of organismal diversity. Taxonomy is the science of naming organisms, and systematics the science of working out their relationships to each other. To avoid confusion in this report, we use the term "taxonomy" for both sciences.

Taxonomy is the hypothesis-driven scientific discipline that discovers, describes, and interprets biological diversity within globally recognised classification systems. Accurate names for organisms are critical for accessing all other types of biological knowledge and its effective application.

Repeatable and testable experiments and observations in the biological sciences are reliant on taxonomy and the associated specimens. Taxonomic research addresses questions about the evolution of organisms and seeks to resolve the relationships among species.

Taxonomic knowledge is critical for conservation, biosecurity, ecological assessment, human health, and sustainable ecosystem management. Habitat mapping, research on ecosystems services, and environmental risk assessment, as well as the assessment of the impacts of climate variability and/or climate change, need to be based on knowledge of both the unique biodiversity native to the New Zealand archipelago, and those species introduced by humans.

Expert panel and scope

Over the past ca. 35 years, the challenges and needs of national taxonomic collections and issues of taxonomic capability in New Zealand have been raised on a number of occasions. For example, the Proceedings of the Royal Society of New Zealand (Volume 113, 1985) contains a report from the Ad Hoc Committee on National Collections which called for designating "Collections of National Importance", criteria, curation standards, legislative protection of collections, and a register of living plant and animal collections[3]. A number of surveys have measured specific effort in collection management/maintenance, the taxa being studied, and relative proportions of descriptive, molecular, and evolutionary relationship work being carried out in terrestrial, marine, and freshwater environments. All reviews have noted that taxonomic/biosystematics research is vital to New Zealand's economic and environmental wellbeing, and, without exception, reported on the need to arrest declining capacity in this field.

In February 2015, in the face of concern over the extent to which such strategic considerations had been ignored, the Royal Society of New Zealand Council convened a panel of leading experts (the Panel) to assess the state and future needs of New Zealand's nationally important taxonomic collections.

The focus of the Panel was to reaffirm the significance of New Zealand's national taxonomic collections; review the value currently being gained from them and their potential future value; assess the level and quality of taxonomic training in New Zealand and any impediments; and provide recommendations on the most effective process for supporting, developing and managing our taxonomic collections, databases, information systems, and research for the future. Details are provided in Appendix 1.

3 Brownsey & Baker (1983); SYSTANZ (1985); Review Committee on Biosystematics and Ecological Science (1989); Conway Powell Consulting Ltd (1994); Penman (1995, 1996, 2002); Crampton & Cooper (2010); Lester *et al.* (2014).

For the purposes of the review, the Panel concentrated on those publicly funded collections of samples and specimens retained for taxonomic research purposes. These are collections of natural history samples (plants, animals, micro-organisms, and their fossils), tissues and other physical samples (e.g. DNA libraries), together with their associated data and digital imagery. In this report the collections, the taxonomic research and the associated activities, are collectively referred to as the biological collections' infrastructure.

There are other collections of biological material which are of critical importance to New Zealand but that do not fall within the scope of this paper (e.g. Margot Forde Germplasm Centre, AgResearch; Plant & Food Research germplasm collection; New Zealand Indigenous Flora Seed Bank). The primary focus of these collections as well as ex situ collections (e.g. botanical gardens) is not on taxonomy but rather on providing genetic resources for breeding programmes, genomic research, and the conservation of genetic resources. Collections primarily for public education, teaching or reference, that do not also support taxonomic research, were also considered to be outside the scope of this paper.

Defining characteristics

Biological collections are critical to the practice and application of taxonomy, containing vital reference specimens, and allowing species to be identified and studied. To be of greatest value, collections need to represent the distribution of species in time and space, as well as reflect such characteristics as morphological variation, stages in development, and reproductive maturity. Advances in technology are revolutionising the way in which biodiversity data are being discovered, described, and documented, analysed, and disseminated[4]. Detail of the international conventions, duties and responsibilities associated with taxonomy, nomenclature, and accepted names is provided in Appendix 2.

Some of the issues traversed in this review are applicable to other research and data infrastructure. However, there are four characteristics that are common to the biological collections' infrastructure covered in this report. These are:

(i) Requirement for long-term secure storage of physical specimens. It is crucial that collections are readily accessible for New Zealand's research and management initiatives[5]. There are important space requirements, as well as health and safety considerations, associated with biological collections.

(ii) A requirement to provide for taxonomic research in order to discover, describe, name, and classify species and acquire new insights into the origin and relationships of species. Without such associated activity, much of the collections' infrastructure will have little impact and the value will erode over time.

(iii) Many specimens are irreplaceable e.g. type specimens (Appendix 2), while others would be difficult and expensive to replace if destroyed. The value of specimens often lies in the timing and context in which they were collected (for example, specimens collected on James Cook's first visit to New Zealand[6]).

(iv) The use of a particular set of specimens may be sporadic and cannot be anticipated in advance. For example, the arrival of a new potential pest threat may trigger the need for study of comparative material of closely related New Zealand, or foreign, species.

While Government stakeholders may contribute funding for their use of and access to collections, they are not in a position to fund the general maintenance of the wider collections' infrastructure so that it is ready to meet unknown future needs.

4 Abebe *et al.* (2014); Boyle *et al.* (2013); Faith *et al.* (2013); Graham *et al.* (2004); Frey (2009); Kress (2014); Krishtalka & Humphrey (2000); Lees *et al.* (2011); McCarthy (1998); Newbold (2010); Ponder *et al.* (2001); Pyke & Ehrlich (2010); Ward (2012).

5 As noted by Schilthuizen *et al.* (2015) because the scholarship of biodiversity includes scrutinising earlier work, evaluating what was written before, and adding new information and insight, it should always be possible to return to specimens. They are the primary evidence for the information presented. A crucial part of taxonomic scientific activity is being able to re-examine primary data and question the conclusions of previous work.

6 Housed at Auckland War Memorial Museum, Landcare Research, and Museum of New Zealand Te Papa Tongarewa.

Evidence

The Panel's analysis, conclusions, and recommendations set out in this report are based on evidence obtained from the following:

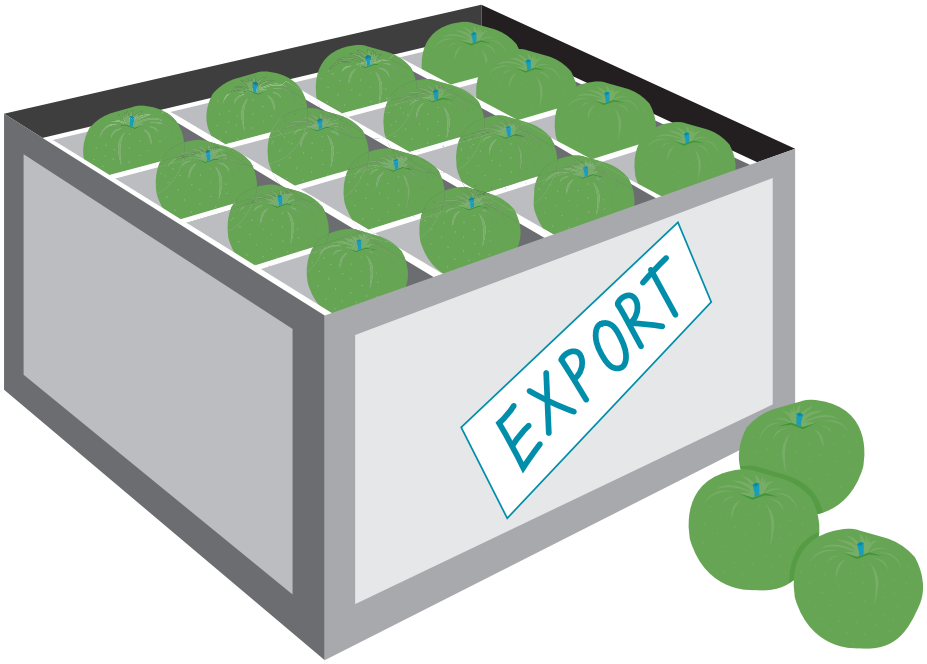
- A consultation on future needs for New Zealand, asking the question: What would an effective system for supporting, developing, and managing our taxonomic collections, databases, information systems, and associated research be in 2035? (a list of organisations and individuals consulted is provided in Appendix 3)
- A survey of holders of critical taxonomic collections (Appendix 4)
- A survey of the taxonomic workforce based on the approach taken by the Council of Canadian Academies (Appendix 5)
- A survey of University taxonomic training conducted by Universities New Zealand (Appendix 6)
- Consultation with a wide range of government users, funders, and policy makers, and research organisations (Appendix 3)
- Four workshops held in Auckland, Wellington, Christchurch, and Dunedin, to present the findings and preliminary conclusions of the Panel, and to canvass views of the wider community interested in collections, taxonomy, and their applications.

Published data and reports from New Zealand and international studies, in addition to resources available electronically, were also collated and reviewed for relevance to the Panel's remit and the New Zealand situation. A summary of the recent history of CRI biological collections is provided in Appendix 7.

Benefits to New Zealand

Taxonomic knowledge underpins New Zealand's economic, environmental, social, and cultural fabric. Legislative requirements and policy initiatives committed to by the Government (see box on page 20) require taxonomy. Taxonomic knowledge provides the credible scientific basis for delivery of key public services, and underpins operations in a number of government agencies. Delivery of these services is at risk if access to national capability is inadequate or fails.

The following selected examples of the use of taxonomic knowledge are evidence of the benefits to New Zealand and specific user groups.



Economic benefit

Despite being only 6% of GDP in 2014, agriculture, fishing, and forestry dominated New Zealand's exports[7], and are a particular focus for Māori investment[8]. The primary production sectors require accurate and authoritative taxonomic information for many reasons, for example: (i) obtaining market access for fish under the banner of sustainable fisheries and ecosystem-based management requires accurate taxonomic names; (ii) identification of pests, pathogens, and biological contaminants is critical to an efficient primary sector and to market reputation especially in relation to food safety; (iii) enhancing New Zealand's resilience is enabled by identification of species with attributes that will be suited to changing climate conditions; and (iv) the development of innovative products with economic potential from our native biota. All of these must be based on our ability to definitively identify New Zealand's biota and its distribution.

Fossil dating of New Zealand's sedimentary basins

New Zealand's sedimentary basins, both on land and offshore, are important current or potential sources of oil and gas. To predict, discover, and recover such resources, it is essential to know the geological age of the prospective basin strata. New Zealand's National Paleontological Collection has identified successions of key fossils which can be used to date basinal strata from outcrops and wells. (See Appendix 8)

7 Statistics New Zealand (2014).

8 www.mbie.govt.nz/what-we-do/maori-economic-development/mefs.pdf.

Relevant legislation and policy initiatives

National legislative requirements

Biosecurity Act 1993

Biosecurity Strategy for New Zealand 2003

Conservation Act 1987

Conservation Law Reform Act 1990

Environmental Reporting Act and Environment reporting framework

Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012

Fisheries Act 1996

Forests Amendment Act 1993

Hazardous Substances and New Organisms Act 1996

Marine Mammal Protection Act 1978

National Parks Act 1980

Marine Reserves Act 1971

Native Plants Protection Act 1934

Plant Variety Rights Act 1987

Protected Objects Act 1975

Queen Elizabeth II National Trust Act 1977

Reserves Act 1977

Resource Management Act 1991

Trade in Endangered Species Act 1989

Treaty of Waitangi and Claims to the Waitangi Tribunal

Wild Animal Control Act 1977

Wildlife Act 1953

International legislative commitments, Multi-lateral agreements

Antarctic Treaty

Convention of Biological Diversity

Convention on the Conservation of Albatrosses and Petrels

Convention on International Trade in Endangered Species of Wild Fauna and Flora

GATT Trade Related Aspects of Intellectual Property Rights

Global Biodiversity Information Facility

Convention on Migratory Species

Convention on the Conservation of Antarctic Marine Living Resources

Convention for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean

Convention on the Conservation of Southern Blue Fin Tuna

Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean

The Convention on Wetlands

Intergovernmental Platform on Biodiversity & Ecosystem Services

United Nations Convention on the Law of the Sea

World Heritage Convention

Major Policy Initiatives

A National Strategic Plan for Science in Society – A Nation of Curious Minds

National Science Challenges (The Deep South; New Zealand's Biological Heritage; Sustainable Seas)

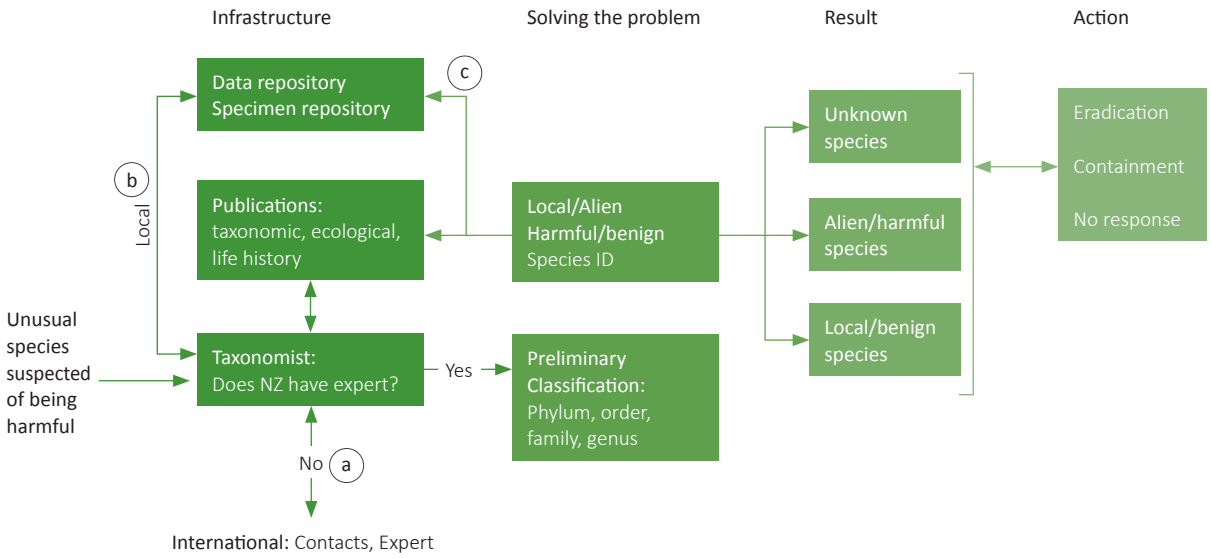
New Zealand Biodiversity Strategy

New Zealand Threat Classification Strategy

Biosecurity

Biosecurity is an important part of risk management for New Zealand's economy, environment, and for human health. Effective biosecurity depends on accurate, authoritative, and rapid identifications of invasive organisms such as weeds, pests, toxin producers and pathogens. Irrespective of whether invasives have 'escaped' from deliberate introduction or arrived accidentally, timely and effective responses depend on knowledge of species' current and potential distributions[9]. Collections and taxonomic experts provide a critical resource for validating the occurrence and identity of taxa collected in New Zealand and around the globe. For example, a range of organisms such as insects and fungi have impacts on forest health in both indigenous and plantation forestry, and comparative material (e.g. housed in Scion's collections) is vital for understanding and managing risks.

Collections house the primary comparative material and voucher specimens used for DNA analyses, and the associated research provides the evidence for decisions about which type of response should be triggered, e.g. i) eradication; ii) containment; or iii) no response as the organism is naturally occurring within the New Zealand ecosystem. In all cases, the economic value of correct species identification is vast. MPI is currently updating the Government's biosecurity strategy. Stakeholder engagement in "Biosecurity 2025" has highlighted taxonomy and diagnostics as key science areas needed for biosecurity[10]. An example of the role of biological collections' infrastructure in biosecurity responses is outlined in the figure below:



Biological Hazard Identification and action: Inter-relationships of collections, databases, and taxonomic workforce: a) not absolute expert but knows enough to provide a partial identification, and thus direct to appropriate overseas expert; b) check reference specimens and deposit reference vouchers; c) quality control. Note: if any one of the infrastructure elements is absent, the system will not work.

9 www.biosecurity.govt.nz; ww.epa.govt.nz/new-organisms/Pages/default.aspx.

10 K. Charles, MPI (Pers. Com.).

Importance of collections and taxonomy for identifying pests and disease

The information used to support biosecurity decisions made by the Ministry for Primary Industries (MPI) relies on collections and the application of taxonomy to describe and name species. MPI provides assurances on the safety of animal and plant based trade and manages significant risks to New Zealand from plant and animal pests and diseases, on land and in the water, and including zoonotic and food-borne problems. Material held in nationally important collections and derived information in published papers and databases is used by MPI as essential procedure when conducting investigations. Collections and data held by a number of organisations are of critical importance, including those managed by ESR, Landcare Research, NIWA, Scion, and Te Papa. Further detail is provided in Appendix 8.

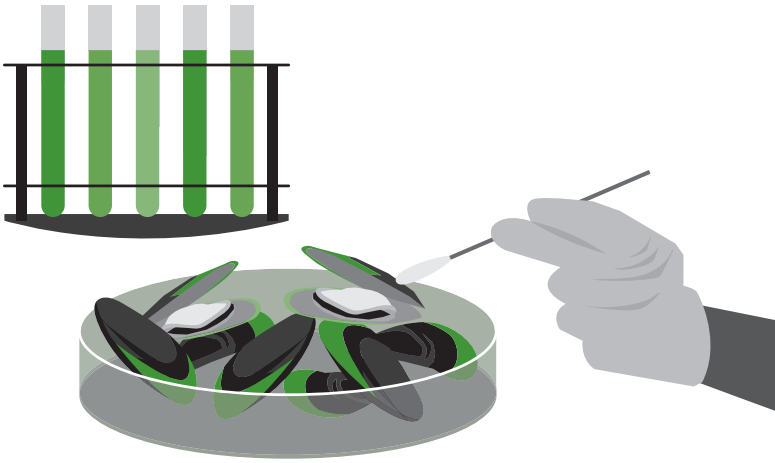
Protecting humans and animals from cyanotoxins

Dog deaths (>100) at rivers across New Zealand in the last decade have been linked to ingestion of cyanobacterial mats. Two toxin-producing species have been isolated by referring to the freshwater cyanobacterial collection at the Cawthron Institute. Establishing the link between benthic cyanobacteria and dog deaths, and the identification of the toxic species, has led to development of monitoring programmes in risk areas, with warning signs and closures of water bodies used to reduce poisoning events. The identified toxins are also toxic to humans. (See Appendix 8).

Human health

Taxonomy and biological collections underpin a wide range of human health outcomes (e.g. consequences of biosecurity breaches such as painted apple moth or fruit fly invasions requiring pesticide use; public reaction to exotic insects or spiders found in supermarket fruit). One of the anticipated impacts of global climate change is the increasing prospect of tropical bacterial and viral pathogens spread by introduced mosquitoes[11].

The Cawthron Institute's collection of toxic microalgae provides economic benefits to New Zealand by enabling the protection of domestic and export consumption of seafood, thus ensuring market access for New Zealand's $1.5 billion seafood exports. New Zealand needs to take a strategic approach to the range of threats the nation faces and have an appropriately equipped taxonomic workforce and knowledge base.



11 http://haifa.esr.cri.nz/assets/Modelling-the-Health-Impacts-of-Climate-Change-Report.pdf.

Conservation

The New Zealand biota comprises approximately 50,000 described naturalised species split about 60:40 between terrestrial and aquatic environments. At least 9,000 undescribed species are known and it is estimated that many more species remain to be discovered[12]. New Zealand is recognised for its unique biota, a high proportion of which is not found anywhere else in the world[13]. Fifty two percent of New Zealand's terrestrial and aquatic species are endemic to the New Zealand region[14]. Although 33% of New Zealand's land is legally protected for the primary purpose of conserving biodiversity[15], 9.7% of vascular plant taxa are still classified as Nationally Threatened, and 28% as At Risk[16].

At a national level the Treaty of Waitangi recognises the value of the natural world to Māori and, through the principles referred to in statutes, creates a responsibility for the protection of all taonga (treasured elements) and the ability of Māori to contribute to their continued existence, especially through the practise of rangatiratanga. Furthermore, New Zealand has an 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). New Zealand also has an obligation to implement the New Zealand Biodiversity Strategy which calls for the protection of natural ecosystems, flora, and fauna. Collections and taxonomic research support biodiversity agencies through access to voucher specimens associated with surveys, data on species distribution, assistance with management of threatened species, and assessment of ecological integrity and ecosystem services. Recognition of species, their attributes, and variability is essential to evidence-based management decisions.

12 Gordon (2013).

13 Costello *et al.* (2010).

14 Costello *et al.* (2010); Gordon (2013) (the proportion of endemism in New Zealand species is estimated to be: 26% for Fungi, 38% for all marine species, 46% for marine Animalia, 68% for all Animalia, 78% for vascular plants and 91% for terrestrial Animalia).

15 www.mfe.govt.nz/more/environmental-reporting/land/area-native-land-cover-indicator/legally-protected-conservation.

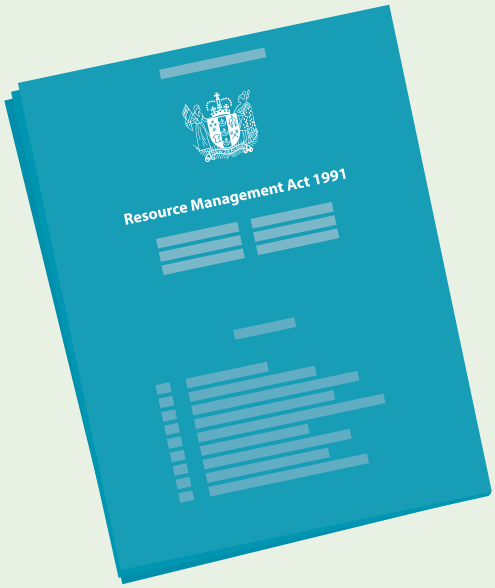
16 de Lange *et al.* (2013).

Recognising New Zealand's marine-biodiversity and influencing policy for protection

A 1999 taxonomic survey of an area of seafloor adjacent to Kapowairua Spirits Bay revealed the most biodiverse marine region for New Zealand, with exceptional species richness of sponges and bryozoans (about one third of all known New Zealand species), with high levels of locally unique species. The discovery of the hotspot led the Ministry of Fisheries to close the area with the greatest number of species to fishing methods that cause disturbance to the benthos.
(See Appendix 8)

Environmental management

Regional Councils and other Unitary Authorities are creating/revising Regional Pest Management Plans. Landcare Research's collections and data provide Councils with plant species distribution, habitat information, and the identification, surveillance, and distribution records of invasive ants and wasps. These analyses rely heavily on biological collections, expertise, and taxonomic research findings. Landcare Research's biological collections also provide research and tool development for Regional Councils' biocontrol of weeds, helping to determine suitable biocontrol agents both within New Zealand and internationally.
(See Appendix 8).



New Zealand's Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS)

The New Zealand marine region is 4.4 million square kilometres and about 20 times the size of the country's land area[17], and is one of the world's largest Exclusive Economic Zones (EEZ)[18]. It encompasses a broad range of ecosystems and habitats.
The Environmental Protection Authority (EPA) is responsible for managing the environmental effects of restricted activities in the EEZ and the Extended Continental Shelf e.g. prospecting and exploration for minerals, extraction of minerals, aquaculture, carbon capture and storage, and marine energy generation. Although the marine realm is seen as offering new opportunities, the lack of information about activity impacts on species and ecosystems as well as on iwi and fishing interests has resulted in the EPA recently declining applications for marine consents. Scientists estimate that as much as 80% of New Zealand's indigenous biodiversity may be found in the sea, yet less than 1% of our marine environment has ever been surveyed.

Museum exhibitions of marine specimens attract thousands of people

Exhibitions of marine specimens at Te Papa and the Auckland Museum attract large numbers of visitors. A particular emphasis is always placed on taxonomic research, new species discoveries, and the taxonomic knowledge that is required to identify our fauna. As an example, the Moana – My Ocean exhibition at the Auckland Museum, which was open to the public for four months in 2013, was visited by ca. 140,200 people. The review by the Auckland Council Technical Support Unit concluded that for every $1 invested by the museum, $4.66 of social, environmental, and economic value was created. Te Papa's digital outreach programme on the colossal squid reached 700,000 online viewers in September 2015 alone. (See Appendix 8).

17 www.epa.govt.nz/eez/Pages/default.aspx.

18 www.teara.govt.nz/en/interactive/6967/new-zealands-exclusive-economic-zone.

Sustainable use

The Resource Management Act, Environmental Impact Assessments (e.g. as part of regulations such as the EEZ and Continental Shelf Environmental Effects Act), and other legislative[19] and international agreements require knowledge of species, their distributions, and their interrelationships. 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) requires the knowledge generated through the biological collections' infrastructure.

New Zealand's culture and identity

Enjoyment, recreation, and a strong sense of national identity are associated with New Zealand's natural environment. New Zealand's national icons – kiwi, kauri, koru and silver fern, cabbage trees, wētā, kahikatea, pāua, and kina – are drawn from the natural world. Environmental branding, such as the 100% Pure campaign by Tourism New Zealand, is a major marketing advantage and the foundation of the tourism industry. To many people, biodiversity has intrinsic value and they recognise an obligation to protect and conserve this heritage for future generations. Taxonomic collections are a part of New Zealand's cultural heritage incorporating specimens from New Zealand's prehistoric past to the present day.

19 Such as New Zealand's national environmental reporting programme (www.mfe.govt.nz/more/environmental-reporting/about-environmental-reporting/our-environmental-reporting-programme).

Scientific credibility and quality assurance

Reproducible research in many areas of biological science and ecology depends on the ability to accurately identify the organisms being studied[20]. International convention recommends that name-bearing type specimens are to be deposited in permanent collections[21] (See Appendix 2). Furthermore, to validate primary data and to be able to test the conclusions of previous work, including the identity of organisms, examples of the specific organisms being researched should be lodged in national collections (voucher specimens) providing a critical research archive. The underpinning taxonomic research that documents and describes the New Zealand native and introduced biota is made available through publications on New Zealand Flora, Fauna and Mycota[22] and other research or revision publications.

Global relevance and international leverage

New Zealand is part of a global community of scientists. Knowledge of New Zealand's biota is pushing the frontiers of evolutionary biological science and is driving increasing interest in New Zealand's collections, resulting in visits from overseas experts. For example, the unique diversity and endemism of New Zealand's marine flora and fauna generates international interest. In 2013–14, the NIWA Marine Invertebrate Collection attracted 26 visiting researchers from 14 countries (See Appendix 4). Their work has resulted in increased authoritatively identified specimens in the collection, adding to local knowledge[23].

Historical value of collection material

A selection of the original specimens collected by Banks and Solander on Cook's first journey to New Zealand are today held in the collection of the Auckland War Memorial Museum, the Allan Herbarium at Landcare Research Manaaki Whenua, and at Te Papa. There is high scientific and cultural value in this collection, providing a reference to the flora growing in New Zealand before European colonisation. (See Appendix 8).

Resolving the identities of undescribed species for improved conservation management

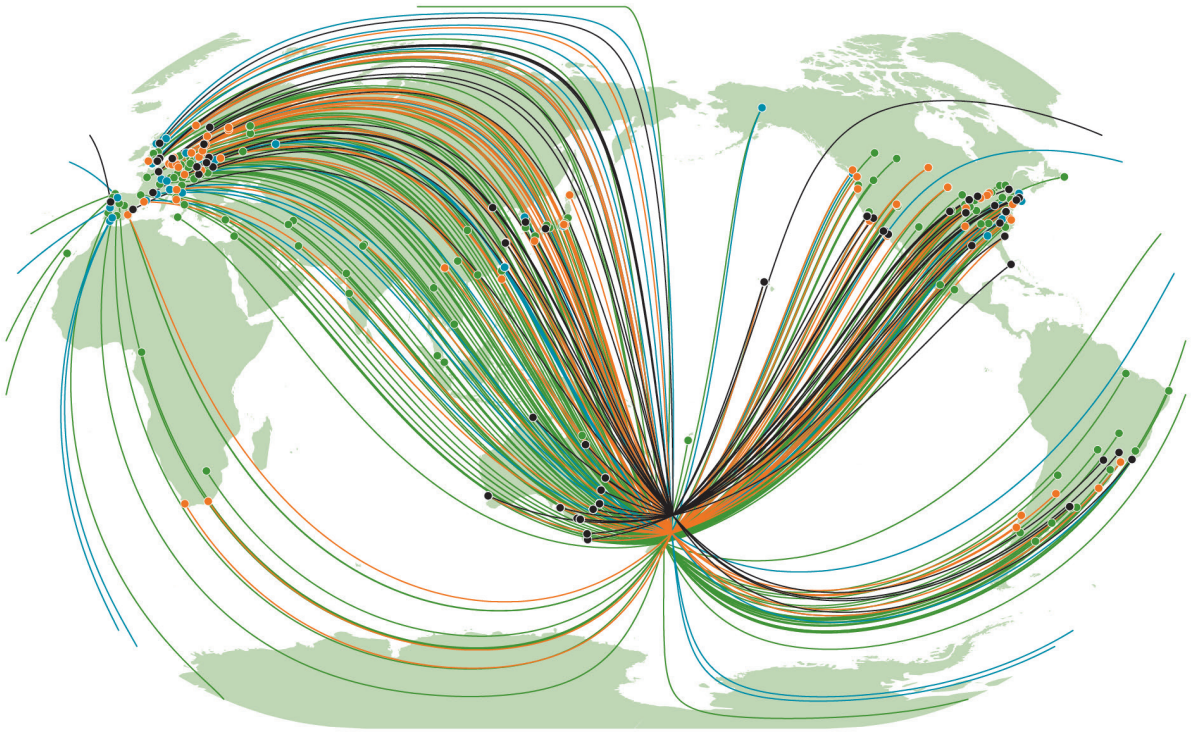
The New Zealand Arthropod Collection at Landcare Research has been assisting the Department of Conservation with threatened species management by resolving undescribed species identities found during surveys. Conservation management of species with uncertain status is hampered when the fundamental unit for conservation is not known. The implication is that environmental impact and biodiversity surveys are not robust when species cannot be identified. (See Appendix 8).

20 Schilthuizen *et. al.* (2015).

21 http://sciweb.nybg.org/science2/IndexHerbariorum.asp; www.iczn.org/iczn/index.jsp.

22 Fauna, Flora, and Mycota publications are a definitive list and description of the known animals, plants and micro-organisms within a specified geographical region, defined according to the International Code of Nomenclature for algae, fungi, and plants, the International Code of Zoological Nomenclature, and the International Code of Nomenclature of Bacteria.

23 Report on NIWA Marine Invertebrate Collection.



International loans of biological collections material from four institutions. The lines represent physical specimens sent/returned by each institution from 2010 to 2015. Each line represents one or more loans going to institutions overseas: black (Auckland Museum), green (Landcare Research collections), orange (Te Papa science collections), and blue (NIWA invertebrate collection). (See Appendix 4).

International collaborations

The three-volume Inventory of New Zealand Biodiversity[24] involved a team of 237 specialists from 17 countries. The entire living and fossil life of terrestrial, freshwater, and marine New Zealand was catalogued and reviewed amounting to a total of 56,200 living species and 14,700 fossil species (with an equivalent amount of predicted undiscovered species). No other nation has a similar inventory. This provides New Zealand with a unique benchmark against which indicators of biodiversity can be measured.

New Zealand's local capacity and credibility enables access to opportunities to participate in international fora, and thus leverage access to new developments and benefits through collaborations. Through participation in open access initiatives, such as the Global Biodiversity Information Facility (GBIF) and the Ocean Biogeographic Information System (OBIS)[25] (see p. 38), New Zealand researchers gain access to data on species and specimens that are held in overseas institutions, and share their own information globally[26].

The *Fishes of New Zealand*, the first comprehensive guide to be published since 1872, is a four-volume treatment to be published in November 2015. This project, led by the taxonomic experts of the Te Papa science team, has involved 44 authors, 33 of whom are international colleagues.

24 Gordon (2009, 2010 and 2012).

25 www.gbif.org/; http://iobis.org/mapper.

26 http://nzobisipt.elasticbeanstalk.com.

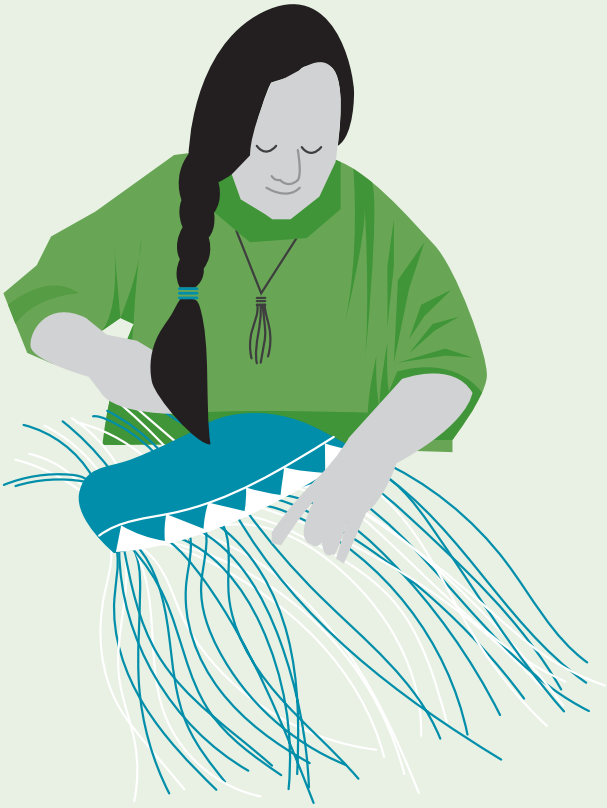
Māori interests

Collections and taxonomic research can provide key information about taonga species and assist with biodiversity and resource management. Settlements being negotiated by Māori through the Waitangi Tribunal processes involve the lands and other assets managed by the Department of Conservation. Conservation redress is an integral part of settlements, and a range of instruments have been developed to address Māori interests in areas of public conservation land. These instruments include transferring ownership of specific areas of high cultural significance, and mechanisms to involve and recognise Tangata Whenua in the management activities of these lands[27].

Mātauranga Māori practitioners offer important streams of knowledge and interpretation for collection custodians and research workers. There is potential to develop a broader Māori component to species taxonomy relating to their whakapapa, the role of traditional knowledge, precaution about uses (tapu procedures, karakia), expressions of tikanga and kawa (processes and protocols), and interpretation. The collections themselves provide an important repository for researchers and resource managers from iwi Māori to connect with the natural resources of their regions through the Rangatiratanga principle[28].

Sustaining traditional cultivars used by Māori weavers and enhancing understanding of their uses and origins

The National New Zealand Flax Collection is a collection of traditional weaving varieties of harakeke (New Zealand flax, Phormium spp.). In 1995, experimental plantings of traditional weaving varieties of harakeke were established at sites throughout New Zealand to find out what effect environmental conditions had on their growth and weaving qualities. The collection is now significant and well-researched, sustained by clones being distributed throughout Aotearoa, and enables local Māori weavers to access the traditional materials required for weaving culturally significant items. (See Appendix 8).



27 Department of Conservation General Policy (2005); Dodson (2014).

28 The Rangatiratanga principle – which flows from the Treaty principles and also through personal or collective mana of Māori – is the implication that Māori be the driver toward their own destiny for those decisions that affect the future.

Current status

Taxonomy and collections

There are specific features and activities that make up the biological collections' infrastructure that are needed to realise the benefits described in this document:

Storage requirements and standards: There are very specific requirements for the storage of biological specimens depending on the nature of the taxa being curated[29]. Such requirements include climate-controlled facilities (e.g. for humidity, temperature, light control; continuous operation of freezers or growth cabinets); specific health and safety considerations for material preserved and stored in alcohol or formalin; storage facilities for specimens that may range from micro-millimetre scales (microalgae, fungi) through to large and heavy objects (marine mammal skeletons, fossils); and specific maintenance requirements for living collections. Other important considerations include the management of toxins and hazardous materials associated with the preservation and storage of collections, as well as the requirements under biosecurity legislation for most New Zealand collections to be registered as containment facilities with the Ministry for Primary Industries.

29 www.nature.com/news/save-the-museums-1.16369.

The stages and processes involved in curation of specimens, as well as the various types of collection permits and permission required, from field sampling through to their incorporation within a collection, vary enormously depending on the organisms being studied. Frequently, in modern curatorial practice, specimens are sampled and preserved in a number of different ways in order to facilitate subsequent research (e.g. preserved for anatomical investigations, molecular analyses, isotope analyses). For example, in the New Zealand Cetacean Tissue Archive at the University of Auckland, tissue samples can be collected from stranded cetacean carcasses under the Marine Mammals Protection Act (1989) with permission of DOC and iwi.

Critical requirement for taxonomic research:
Taxonomy allows the correct identification and naming of species. Nevertheless, names are subject to change as new species are discovered, and existing species are reassessed in the light of new knowledge. Therefore, in order for the collections to maintain currency and impact, it is essential that they are associated with active taxonomic research programmes. The presence of highly trained and experienced taxonomists is also necessary for informed decision-making by end-users. Access to appropriate advice and information about new developments within the field, the updating of classifications, and the application of national and international standards are also needed by end-users.

Using herbarium specimens to track the ozone hole

Research workers have been able to use herbarium collections of mosses collected from Antarctica to examine flavonoid contents and estimate historical levels of Antarctic UVB radiation. Each year since ca. 1975 an ozone hole has developed over Antarctica from September to late November which means that during spring most of the region is subjected to abnormally high levels of UVB radiation. Using herbarium samples of the moss collected in Antarctica, research workers have been able to compare the levels of flavone aglycones in plants collected before and after the formation of the ozone hole, and thereby determined historical levels of UVB radiation. (Markham *et al.* (1990); Ryan *et al.* (2009)).

New Zealand's unique species – Albatrosses/ Toroa

Using museum specimens, molecular, and ecological information, the taxonomy of albatrosses was revised in 1996, increasing the degree of endemism for the group and New Zealand's role in managing the conservation of this highly threatened species group. The number of species recognised increased from 15 to 22, and New Zealand's endemic species increased from three to eight, with 12 species in total nesting in New Zealand. Two endemic New Zealand taxa remain to be revised, with a possible two new endemic species to be added to the total of 22[30].

30 Nunn *et al.* (1996), Robertson & Nunn (1998).

Although collection-holding organisations do not have specialists for all taxonomic groups represented in their collections, trained taxonomists facilitate access to national or international expertise and research activities. There remains a need, however, for New Zealand to have a critical mass of expertise with a deep knowledge of New Zealand's biota and its taxonomy. This is not something that can be imported from offshore. The view of at least one government agency reliant on taxonomic expertise is that it takes 10 to 15 years to develop in depth taxonomy expertise.

Species discovery in New Zealand: Species discovery, description, and classification are still a big part of taxonomic research in New Zealand, and field collecting programmes and specimen acquisition are important related activities. For example, even vascular plants, the most obvious features of our landscape, are not nearly as well-known as one would expect from a small first-world country, with about 15% of species yet to be described; 70% of New Zealand's arthropods remain undescribed; in the past 10 years, species as large and evident as whales and kiwi were discovered to be distinct and were described using museum-held specimens; and taxonomic work currently underway on lizards is likely to identify as many as 40 new taxa that are endemic to New Zealand, nearly doubling the number currently described[31].

Māori and Collections: Biological collections and taxonomic research provide an opportunity to grow Māori involvement in science, and there is potential also to develop an independent Māori interpretation of the collections which is based firstly on Māori taxonomy, moving away from the traditionally phylogeny-based classification drivers into the realm of whakapapa and the use of traditional knowledge to define and describe collections for use by multiple communities, including iwi Māori.

Within the collections considered in this report, there are examples (University of Auckland marine mammal tissue and DNA database, Ngā Tipu Whakaoranga Ethnobotany Database and New Zealand Flax and Living Plant Collections) where there are partnerships between the collection custodians and Māori, and where collections and associated activities are meeting both shared and specific scientific and cultural objectives. Te Papa has developed one of its core organisational philosophies around Mana Taonga, where researchers of the collections and museum staff recognise that taonga – objects, narratives,

31 Gordon (2009).

languages and all forms of cultural expression – have strong relationships with their source communities and connections to environment, people and places; and research should acknowledge the authority derived from these relationships and the innate spiritual values associated with them.

Some collection-holding organisations and some end-users have advisory panels involving Māori, e.g. the Characterising Land Biota portfolio (Landcare Research) Advisory Group seeks to identify opportunities for engagement with Māori around taxonomy and collections. There is a need for further work to understand how best to advance partnerships between collection holders and Māori; how to facilitate access and understanding; and to look to future opportunities. Museums routinely integrate Mātauranga Māori into their exhibition and outreach programmes, for example, in the Moana – My Ocean exhibition at Auckland Museum, and through cultural advisory groups involved in developing the exhibition renewal programme at Te Papa in 2014–15. NIWA engaged with Ngāi Tahu and Tainui to consider the issues involved in the use of Te Reo in the scientific naming of species, and this work was continued in studies carried out at the University of Waikato[32].

Databases and information systems: Most of New Zealand's collections have associated tools and databases, which are the means by which the collections and associated taxonomy are able to be used. These may be institutionally specific (e.g. Landcare Research) or proprietary systems (See Appendix 4). It is important to note that access to data and the quality of subsequent analyses depend on the quality of information available: many collections await identification and taxonomic investigation. Varying proportions of collections have been databased with many institutions having a considerable backlog of work yet to be completed, but with very limited sources of funds to do so. There is no common standard for collection databases although a bottom-up grouping of institutions has now formed a collaboration seeking to make data available[33].

A New Zealand initiative, the New Zealand Organisms Register (NZOR), uses data-federation technologies, developed within New Zealand, to assemble and deliver the (> 130,000) names. This is primarily a tool for standardising the naming and identification of the specific set of organisms known to occur in and around the New Zealand region and is a global first. NZOR data are increasingly embedded in stakeholder information systems to support improved and efficient data-management, for example by the Department of Conservation. The development of NZOR was supported by a collective of primary natural resource agencies in New Zealand (DOC, MPI, EPA, ERMA – now EPA) and representatives of local and regional government, and three major collection holders (Landcare Research, NIWA, and Te Papa) but no longer receives financial support. The New Zealand Virtual Herbarium (NZVH) collaboration links data from 11 herbaria, and serves as an example of collaboration between collections and data-federation. Ongoing participation in these initiatives has, however, been constrained by the very limited resourcing available for biodiversity informatics and technical developments, as well as for underpinning databasing or collections.

The Panel endorses the principles involved in these initiatives exemplified by the New Zealand Virtual Herbarium and New Zealand Organism Register but there is no strategic approach or support for this activity nationally.

Long term stewardship: The collections require ongoing long-term care and development, registration, and databasing, without which there is loss of value of previous investment, loss of access to material and data, reduction in quality of specimens as well as to the quantity and rate of taxonomic research, loss of training, and increasing obsolescence of the information stored.

32 Whaanga *et al.* (2013).

33 https://teamwork.niwa.co.nz/pages/viewpage.action?pageId=27983920.

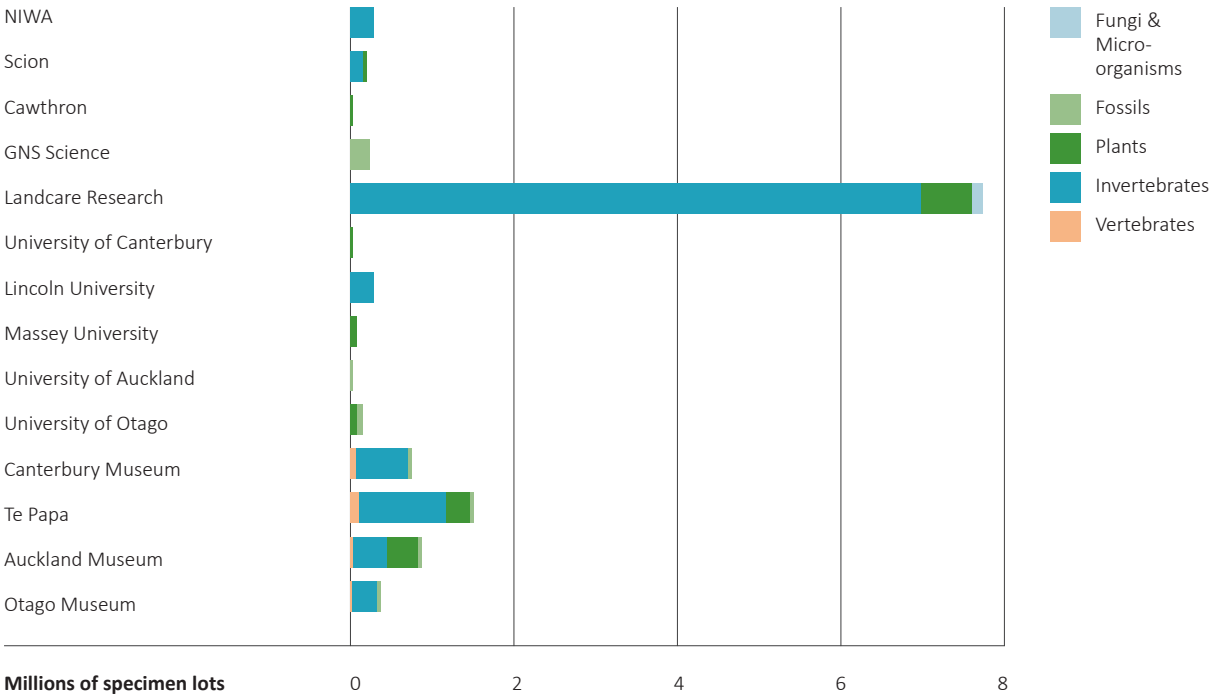
New Zealand's taxonomic collections

The Panel has identified 29 taxonomic collections housed in Crown Research Institutes, museums, tertiary education institutions, and the Cawthron Institute that represent the bulk of New Zealand's critical biological collections' infrastructure.

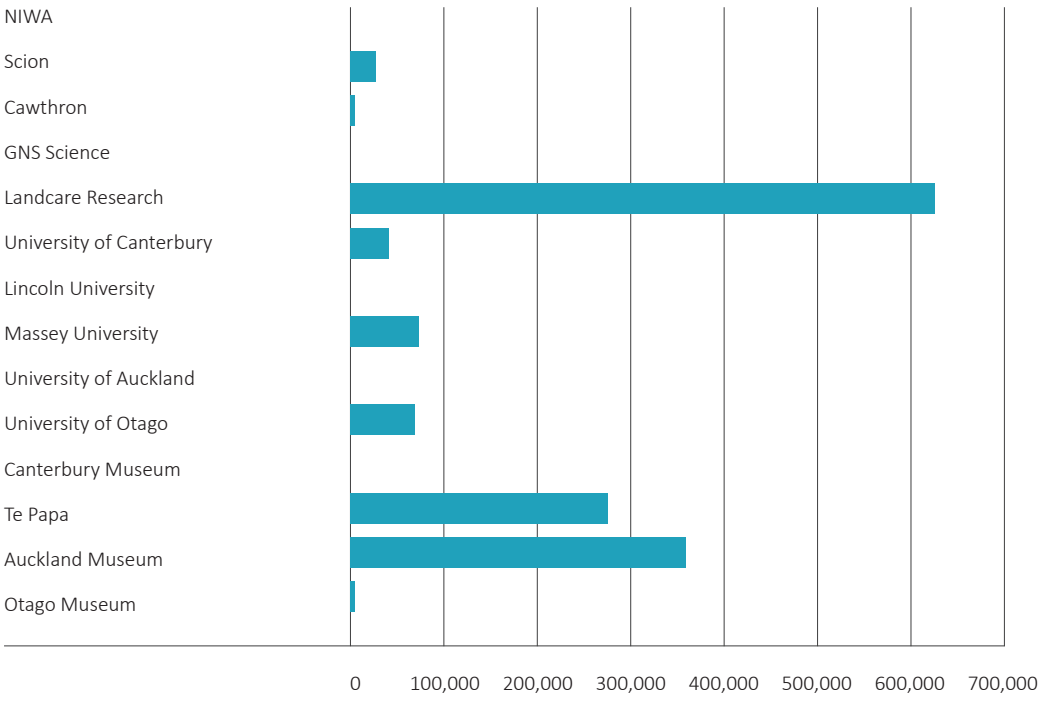
The Panel has gathered detail on 24 of these and identified five others of importance:

	Stewardship	Collection
Research institutes	GNS Science	National Paleontological Collection
	Landcare Research	Allan Herbarium
		International Collection of Micro-Organisms from Plants
		National New Zealand Flax Collection
		New Zealand Arthropod Collection
		New Zealand Fungal & Plant Disease Collection
	NIWA	Marine Invertebrate Collection
	SCION	National Forestry Herbarium
		National Forestry Insect Collection
		National Forestry Mycological Herbarium
		National Forestry Culture Collection
	Cawthron Institute	Cawthron Culture Collection of Microalgae
Museums	Museum of New Zealand Te Papa Tongarewa	Te Papa Science Collections
	Auckland Museum	Natural Science department of the Auckland Museum
	Canterbury Museum	Canterbury Museum natural history collections
	Otago Museum	Otago Museum Taxonomy collections
Tertiary education institutions	University of Auckland	New Zealand Cetacean Tissue Archive
		University of Auckland Paleontology Collection
	University of Canterbury	University of Canterbury Herbarium
	Lincoln University	Lincoln University Entomology Research Collection
	Massey University	Dame Ella Campbell Herbarium
	University of Otago	University of Otago Geology Museum
		Otago Regional Herbarium
	Unitec	Unitec Herbarium
Other (less information available)		New Zealand Reference Culture Collection (ESR)
		South Canterbury Museum
		University of Waikato Herbarium
		Waitomo Caves Discovery Centre
		Whanganui Museum animal collections

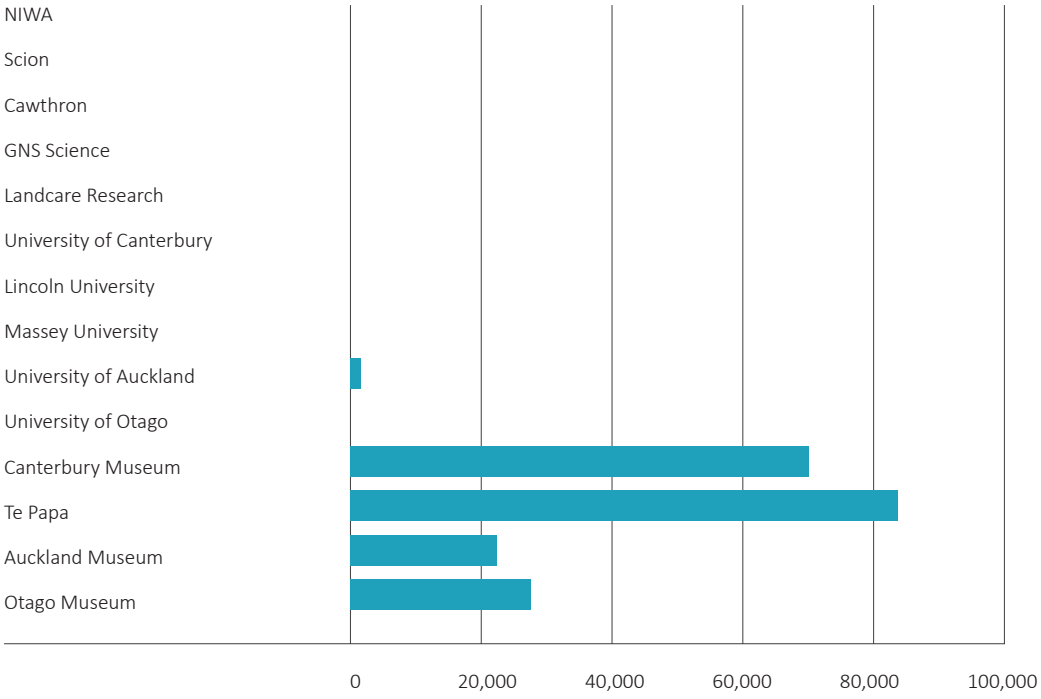
Holdings of New Zealand's main taxonomic research institutions by major taxon group



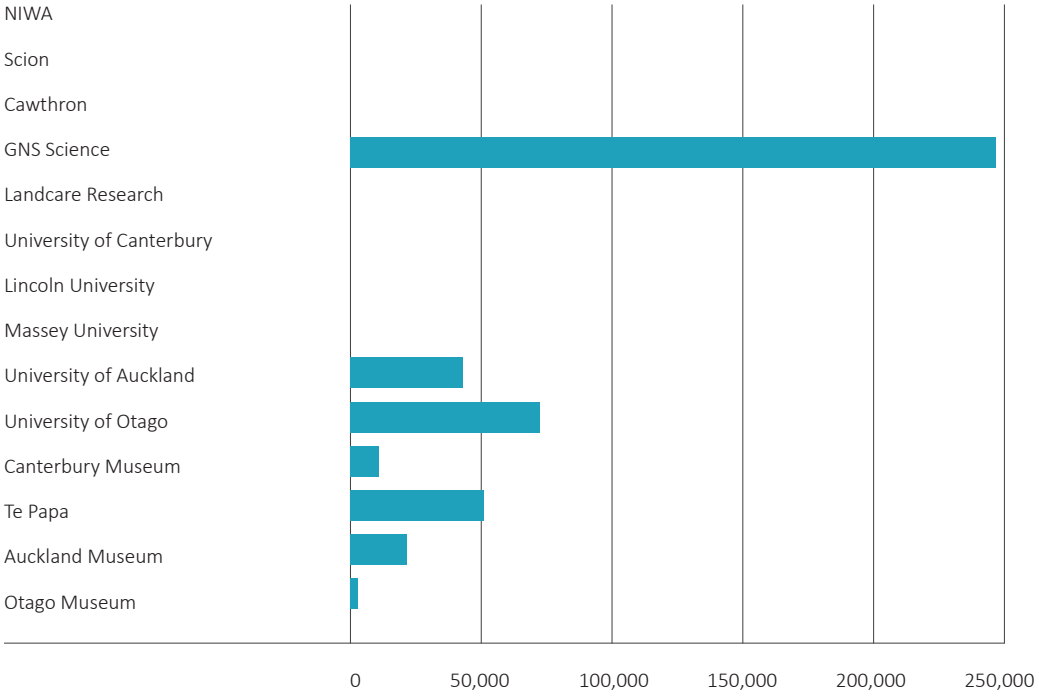
Plants



Vertebrates



Fossils

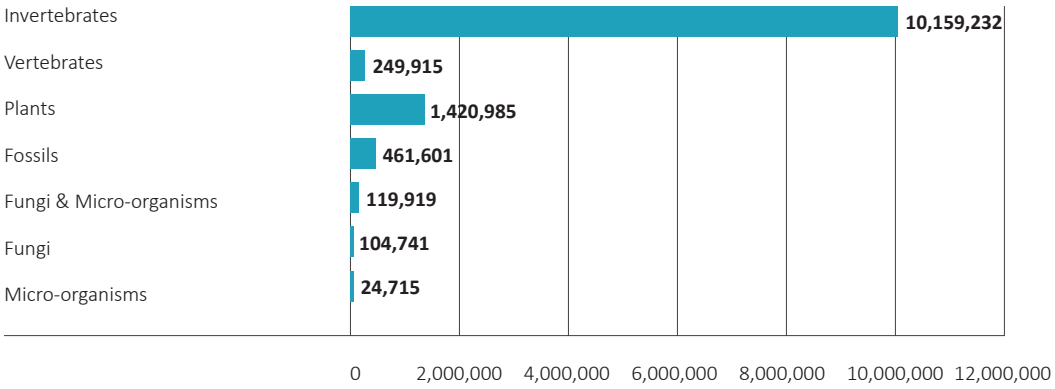


The taxonomic collections surveyed include approximately 12 million specimens/specimen lots of which 20 % have been electronically databased. Approximately 68% of these collections are housed within the CRIs (dominated numerically by the New Zealand Arthropod collection) and one quarter within the Museums (predominantly Te Papa and the three major metropolitan museums). The CRI collections include no vertebrate specimens, i.e. all fish, birds, marine mammals, lizards, etc. are housed in museum or university collections. All micro-organisms or fungi are housed in CRI or Cawthron collections.

Currently, major taxonomic collections are housed in all major metropolitan areas, with plant, fossil, and insect collections having the widest distribution with respect to collections holders (See Appendix 4).

Each collection has its own specialty of holdings, and when analysed at a fine scale by geographical spread of the collection items and by taxon, little duplication of expertise or collections is apparent among institutions. Museum collections are recognised for having a high proportion of specimens of historical or scientific importance, such as type specimens, whereas CRI collections are related to the core work of these institutions.

National taxonomic collection holdings by major taxa



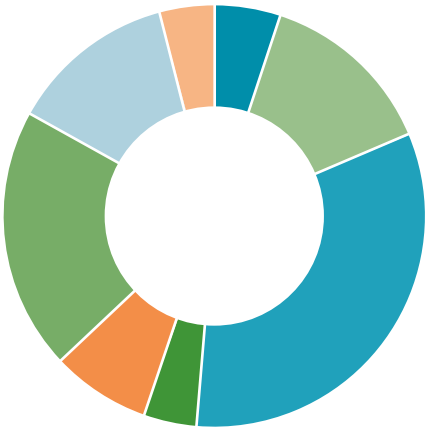
Type collections

Type specimens, the most critical biological specimens for taxonomic research in New Zealand, are distributed approximately equally between CRIs and Museums.

Landcare Research holds the greatest proportion of all type specimens but museums hold a greater proportion of types relative to their total holdings.

Holders of primary types

Primary types



Workforce

Number of Full Time Equivalents (FTEs) related to New Zealand's taxonomic collections

	Curation (research, taxonomy)	Collection management	Additional (projects/temporary funding)
CRIs + Cawthron	14.97	8.07	20.72
Museums	16.9	16.5	14.3
Tertiary Education Institutions	2.3	1.0	14.7
Total	**34.26**	**25.57**	**49.36**

Comparative data are available from surveys in 1995/96 and in 2001 that were conducted to establish baseline data for monitoring changes in CRIs and Universities. The 2001 survey was widened to include the Ministry of Agriculture and Fisheries and the museum sector. The survey included three aspects of taxonomic research (taxonomy, molecular analysis, phylogenetics) and three aspects of collection focused activities (collection management, databases/bioinformatics, information products).

There was a large drop in collection-focused activities in the five years between these two surveys. In 1995/96 in CRIs (excluding GNS) there were 25.6 FTE compared with 9.42 in 2001. In Universities these figures were 2.95 FTE in 1995/96 and 2.44 FTE in 2001. In the Museums sector in 2001 there were 21.44 FTE focused on these areas of collection management[34], which has reduced by 22% in the subsequent 14 years.

34 Penman (2002).

International biological collection initiatives

There have been a variety of approaches to the challenges associated with the long-term care of biological collections, as well as to improving infrastructure, access to specimens and associated data, and opportunities for new approaches to utilise these resources. Some examples are presented in Appendix 10. The international taxonomic and collections communities are well connected through a variety of professional organisations and societies, and these linkages have been greatly strengthened over the past decade with increasing use of the internet. The international Society for the Preservation of Natural History Collections (SPNHC) is "devoted to the preservation, conservation and management of natural history collections", providing a range of resources for practitioners, including developing best-practice guides and standards for natural history collections, and access to a range of online resources.

In 2014, the Natural Science Collections Alliance (based in the United States) partnered with the American Institute of Biological Sciences and the Society for the Preservation of Natural History Collections to launch a national initiative to build a biocollections community to implement and achieve the goals of the Network Integrated Biocollections Alliance (NIBA). This is a project supported by a five-year grant from the National Science Foundation. In addition, the White House Office of Science and Technology Policy issued a directive to federal agencies to develop policies to improve the management of and access to federal scientific collections. The strategic plan for the project describes the 10-year effort that will be directed to digitise and mobilise the scientific information associated with biological specimens held in U.S. research collections.

The primary objective of the initiative is "to create a national collections resource that will contribute critical information to U.S. scientific research and technology interests, and will aid in understanding the biodiversity dimensions and societal consequences of climate change, species invasions, natural disasters, the spread of disease vectors and agricultural pests and pollinators, and other environmental issues". NIBA resources such as databases, network portals, and analytical tools will "synthesise information contained in the nation's collections and place them into national service for stakeholders in government, academia, business, education, informal science education, and the public"[35].

35 https://digbiocol.files.wordpress.com/2010/08/niba_brochure.pdf.

NIBA's strategic plan recognises that digitising the collections in the USA represents "*a grand challenge that will require development of technical and human resources, such as automated workflows, a robust data publishing and error-checking infrastructure and professionals networked to support the creation of an enduring digital alliance of collections institutions*". The intention is to address these challenges through partnerships between federal agencies and other stakeholders.

Many reports, papers and discussion documents about the role and importance of systematics and natural history collections have been published over the past three decades, particularly in association with the Convention on Biological Diversity[36]. Associated with this, there are new approaches to analyses of data and combinations of data[37]. Within the past decade there has been increasing recognition of the value of collections in the analysis of biodiversity, with potential applications in conservation and ecology. Amongst other things, this allows threats to be inferred and may include considerations such as: anthropogenic change; responses of biota to climate change, including examination of apparent shifts in species ranges, distributions and patterns of species richness etc.; and detection of the presence of possible unwanted invasive species under future climate scenarios[38].

The Global Biodiversity Information Facility (GBIF) was formed as a multilateral, intergovernmental agreement to share the vast quantities of global biodiversity data freely and openly on the Internet[39].The New Zealand Government was a founding member signatory to GBIF in 2001. There are now over 60 countries involved and today GBIF provides access to over 500 million biodiversity data records from 14,000 datasets from 750 sources. GBIF is enabled through standards-based federated data-sharing. The New Zealand node[40] is managed by a staff member of Landcare Research, but while MBIE provides the annual membership fee and support for attendance at governance meetings, there is no government funding to manage the node and support the node for data entry and access. This is reflected in the very different contributions made by New Zealand and, for example, Australia, as revealed by GBIF analytics[41].

36 House of Lords (1992, 2002, 2008); www.cbd.int.

37 www.gbif.org.

38 Frey (2009),Graham *et al.* (2004); Johnson *et al.* (2011); McCarthy (1998); Newbold (2010); Ponder *et al.* (2001); Pyke & Ehrlich (2010); Shaffer *et al.* (1998); Tomizuka *et al.* (2012); Ward (2012).

39 www.gbif.org.

40 www.gbif.org/country/NZ/participation.

41 www.gbif.org/analytics/country/NZ/published showing NZ occurrence records flatlining since publication of (only plant) data in 2008, contrasted with www.gbif.org/analytics/country/AU/published.

A similar enterprise for the marine environment is the Ocean Biogeographic Information System (OBIS) which is a formal collaboration between GBIF and the Intergovernmental Oceanographic Commission of UNESCO, bringing further rationalisation to various initiatives to make data more widely available. NIWA operates and updates the Southwest Pacific Region node for OBIS and is currently funded by the Environmental Information Portfolio using Core Funding[42]. GBIF data contribute to biodiversity science in diverse areas such as invasive alien species, impacts of climate change, conservation, and human health, and supports policy implementation for achieving the Aichi Biodiversity Targets of the Convention on Biological Diversity (CBD), the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), and the Group on Earth Observations Biodiversity Observation Network (GEO-BON).

In Australia, the Atlas of Living Australia (ALA) was established with considerable government funding and has succeeded in linking diverse collections and research, providing information on all the known species in Australia aggregated from a wide range of data providers such as museums, herbaria, community groups, government departments, individuals, and universities (See Appendix 10). The ALA has been working to enable the software it developed to be reused by other countries and thematic nodes as a platform for implementing data portals. The GBIF Work Programme 2014–2016 includes activities to provide support for project coordination, documentation, training and helpdesk activities to facilitate this work. Four European nodes have decided to reuse the Atlas of Living Australia software for the development of their national biodiversity portals (Spain, France, Portugal, Scotland), and a number of other countries are exploring options.

Another series of related online initiatives is designed to give authoritative information about the validity of species names. These international initiatives have begun independently, sponsored by various communities of interested taxonomists. Currently, the Integrated Taxonomic Information Systems (ITIS) and Species 2000 are combined under the Catalogue of Life (CoL)[43]. The CoL is evolving to provide an effective partner to six global biodiversity programmes (through Indexing for Life, a European e-Infrastructure project, 2010–2013), creating in itself an ecosystem of services. The CoL is able to support partner programmes in establishing validated taxonomy, and also shares a variety of related services. For example, the World Register of Marine Species (WoRMS) is also collaborating with the Catalogue of Life team.

42 http://iobis.org/mapper (Kevin Mackay, NIWA, personal communication).

43 www.catalogueoflife.org.

New Zealand's taxonomic expertise

To help assess the current state of taxonomy in New Zealand, a survey of individuals undertaking taxonomy-related activities in New Zealand was initiated by the Panel (See Appendix 5).

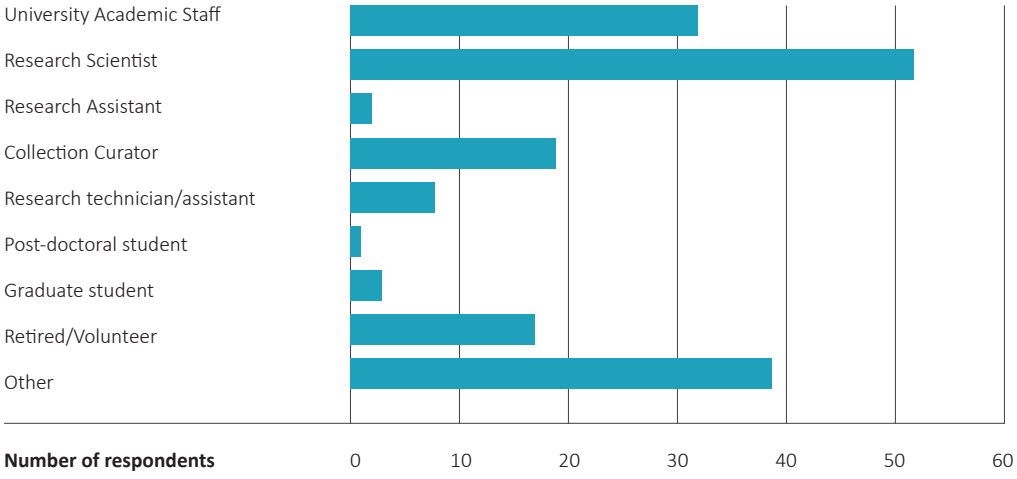
Attributes of the respondents

The majority of the 173 respondents (67%) have PhDs and 14% have an MSc. It is estimated that the total population may be about 366 ± 12.

In the total data set, the number of respondents reporting their position to be 'retired/volunteer' or 'other' is: 10% and 22%, respectively. The 'other' group contains positions in other occupations, working for government departments, self-employed or unemployed.

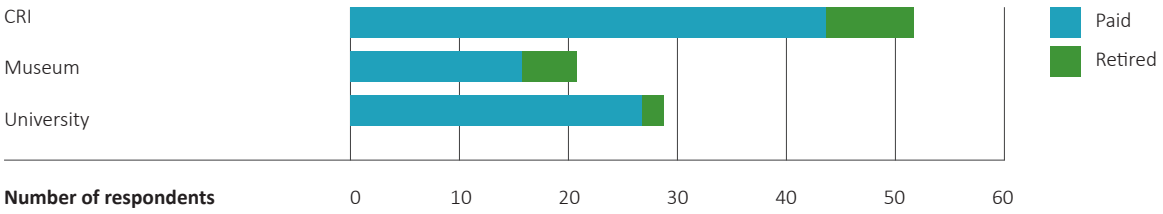
The level of taxonomic expertise of respondents ranged from an ability to recognise species using keys and reference material up to having written and published species descriptions and taxonomic revisions. That is, the sample population contains parataxonomists up to highly experienced taxonomy practitioners.

Numbers of total respondents in indicated positions



In order to identify taxonomy practitioners, respondents who indicated they have described species and/ or completed taxonomic revisions and have published taxonomic descriptions were separated from the total pool of respondents. In this practitioner group are those who are assumed to be in paid taxonomy-related employment although this group also contains retired practitioners and a few not in paid employment, but related to taxonomy (here grouped under retired/volunteer).

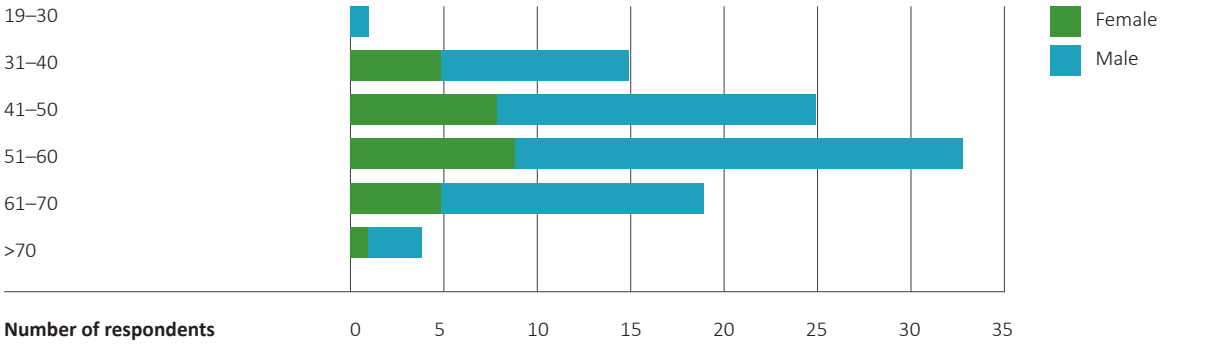
Proportion of retired/volunteers amongst practitioners



Taxonomy practitioners in paid employment are spread mostly amongst three types of institution: CRI + Cawthron Institute, museums, and academic institutions – mainly universities. The largest proportion of practitioners is at CRIs + Cawthron Institute (40%) followed by universities (22%) and museums (16%). These institutions are also host to retired practitioners at the rate of 15%, 24% and 7%, respectively.

When respondents who appear not to be in publicly funded employment are removed, it is estimated that the taxonomy practitioner workforce comprises 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 youngest age group. This lower number in the 19–30 age group may be the result of later diversion into other jobs once candidates have accumulated some post-doctoral experience.

Age and gender structure of employed publicly funded practitioners



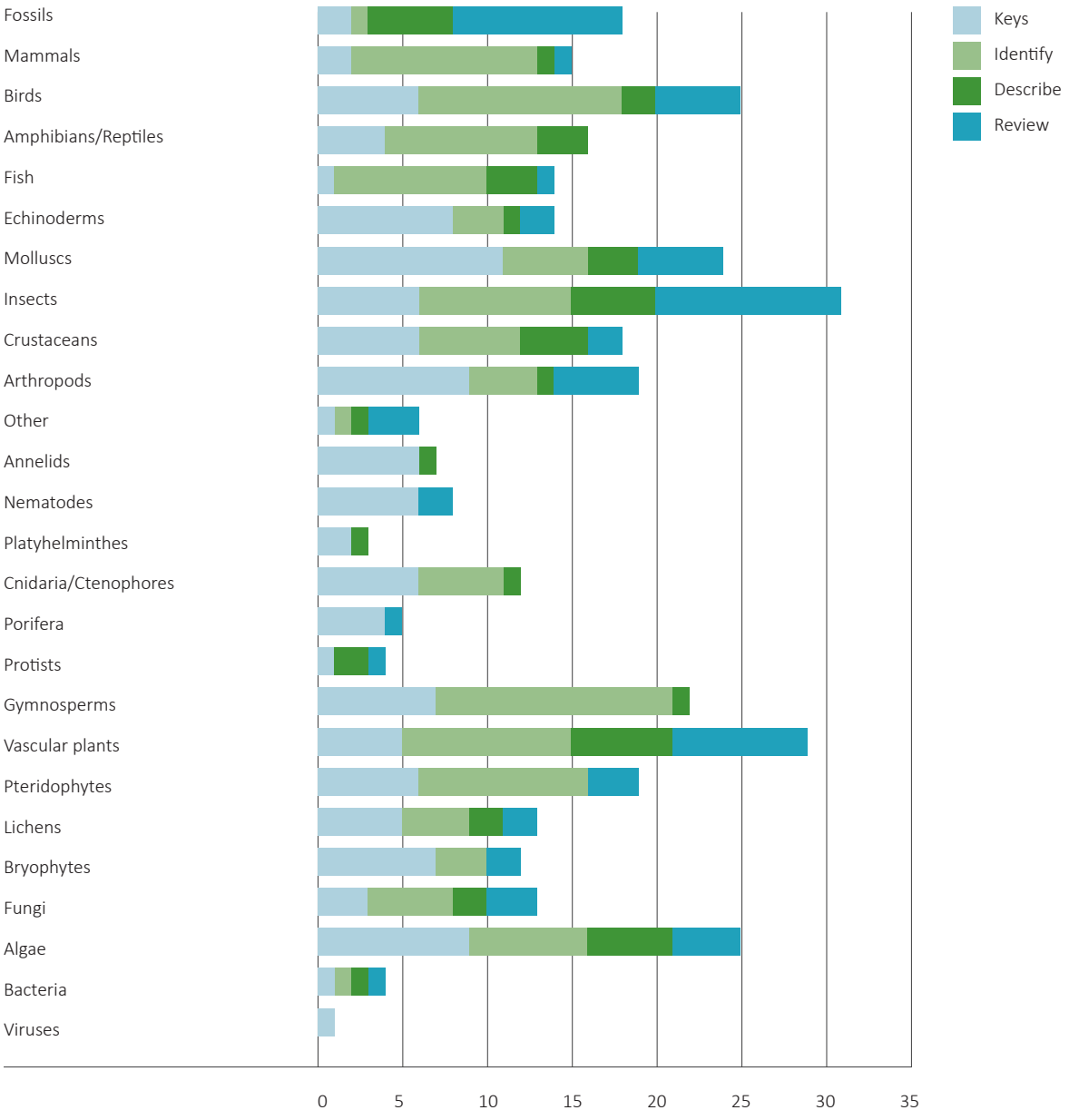
The expertise of these publicly funded taxonomy practitioners with high levels of skill and experience, is spread across a wide range of taxa although there is a focus on insects, vascular plants, and fossils; this is followed by algae, molluscs, and birds. Notably, a number of taxa have a small number or no experts associated with them. Note that some individuals have skills relating to several taxa so the numbers do not add up to the number of respondents.

To compare this expertise with collection holdings (Appendix 4) the panel aggregated taxa together into a smaller number of categories (vertebrates, invertebrates, plants, fossils, fungi, and micro-organisms). The pattern of total reported high level expertise approximately reflects collection holdings.

The highest level of expertise that 97 individual publicly funded practitioners reported in high level taxon groupings

	Taxon group					
Highest expertise	**Vertebrates**	**Invertebrates**	**Plants**	**Fossils**	**Fungi**	**Micro-organisms**
Describe	9	18	14	5	2	3
Revise	10	28	19	10	3	2
Total	**19**	**46**	**33**	**15**	**5**	**5**
New Zealand Collection specimen Holdings (lots)	249,915	10,159,232	1,420,985	461,601	14,741	24,715

Taxonomic expertise



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.

The type of work undertaken by the different institutions is reflected in the spread of tasks expected of their employees. That is, smaller proportions of time are spent teaching in museums and CRIs + Cawthron Institute than in universities. In museums, 67% of respondents report curation as an activity they spent more than 25% of their time on, whereas, in CRIs + Cawthron Institute, 26% spend this much time on this activity and only 6% in universities. In CRIs + Cawthron Institute, only 19% reported being able to spend 25% or more of their time on taxonomic research, in museums 23% and 17% in universities.

Among the 97 publicly funded practitioners, a relatively small proportion is able to spend a significant amount of their time on taxonomic research. Of particular significance is that 77% of all publicly funded taxonomic practitioners are funded to spend less than 25% of their time on taxonomic research and 59% are funded to spend less than 10% of their time on taxonomic research. This suggests that highly qualified researchers are underused in New Zealand and risk an erosion of their capability through the loss of currency. This state of affairs is probably reflected in the accumulated publication output of this population.

Number of publicly funded practitioners reporting being able to spend a range of their time on taxonomic research

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**

Numbers of publicly funded practitioners who have published varying quantities of papers, reviews and books/book chapters

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

Of the total number of publicly funded practitioners (97), the majority report zero to modest levels of publication output. This is probably related to either the youth of respondents, their low level of taxonomy funding, and/or the type of position they have. Thirty-nine experienced individuals report a total accumulated output of more than 20 journal articles and a small number have the highest output of taxonomic revisions.

Reports of current supervision of postgraduate students by publicly funded practitioners at each type of institution

Place of work	PhD students	MSc students
CRI or Publicly Funded Research Institution	16	11
Museum	2	2
University	16	10
Other	7	6
Grand total	**41**	**29**

Despite the inadequate level of financial support for taxonomic work, the reported current supervision of postgraduate students by publicly funded practitioners is surprisingly high. Forty one respondents report supervising PhD students and twenty nine report supervising MSc students. Given that only tertiary education institutions are degree-conferring institutions, and students usually have more than one supervisor, these data do not indicate the number of students training in taxonomy. It is interesting to note the 31 instances of non-university respondents supervising students largely from CRIs + Cawthron Institute. This reflects a high level of cooperation between institutions in the transfer of knowledge to students. It is clear that the majority of the supervised students were not represented among respondents to this survey.

Representation of Māori and Pasifika ethnicities in museum taxonomy staffing

In May 2015, questionnaires were sent to 15 museums nationally to assess their staffing and capability in natural history collection management and curation. Of a total of nine agencies that responded to the questionnaire and later interviews, four staff (Otago Museum, Te Papa, Otago University Geology Museum and Kauri Museum – one volunteer) identified as being of Māori ethnicity. There is room for improvement in the representation of tangata whenua and Pasifika ethnicities in the work of caring for and interpreting the biological collections of New Zealand and wider region.

Comparison with other countries

It is possible to compare some aspects of the taxonomic workforce of New Zealand with those surveyed in Canada in 2009[44] and Australia in 2003[45]. Both these surveys used a different methodology, had different objectives and were undertaken 6 and 12 years, respectively, before this New Zealand study. Therefore, there are a limited number of comparable characteristics. Thus, comparison is limited to age structure and the amount of time that taxonomists actually spend on taxonomy.

Given the limitation of the data available, proportional aspects are compared here. In essence, New Zealand appears to have the greatest imbalance in its taxonomic workforce with only 16% of the workforce in the 20–40 age bracket, compared with 36% in Canada and 23% in Australia. Also, compared with New Zealand, Canada and Australia have a more balanced distribution of staff over the age range 31–60 years and appear to be more regularly recruiting younger taxonomists.

Patterns of time spent on taxonomic research at selected types of institution indicate that there is a vastly larger proportion of New Zealand taxonomists who are underutilised in their speciality with e.g. 59% having 10% or less of their working time available for taxonomic research.

Some recent papers citing global expertise[46] have argued that there are more taxonomists describing species than ever before (See Appendix 11). These conclusions are hotly debated and may simply reflect the increasing trend towards multiple authorship. For New Zealand, the issue is the number of professional taxonomists who have enough funded research time to be regular contributors to new species discovery in New Zealand as well as to be contributors to knowledge of evolution and relationships of the New Zealand flora and fauna with that of the rest of the world.

Comparison of the proportional age structure of the taxonomy workforce of New Zealand, Australia (2003), and Canada (2009)

	Country		
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%	-

Proportion of employed research taxonomists who are funded to spend > 50% of their time on taxonomic research

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

44 www.scienceadvice.ca/en/assessments/completed/biodiversity.aspx.

45 www.environment.gov.au/node/13879.

46 Joppa *et al.* (2011), Costello *et al.* (2012), (2013).

Taxonomy training

New Zealand – current situation

Consultation with end-users and practitioners revealed profound concerns about New Zealand training in taxonomy. This extended to include questioning whether graduates in biology at all levels are equipped with an understanding of basic taxonomic principles and an appreciation of the importance of up-to-date taxonomy. This includes critical application of authoritative names, vouchering of specimens, and the role of collections and databases. Discussions with collection holders revealed severe problems in obtaining and retaining skilled capability.

End-users are acutely aware of the lead time required for an expert taxonomist to be trained (ca. 10–15 years) and expressed concern about the vulnerability of current capacity in New Zealand. They also recognised that importing expertise was not an immediate answer to skill shortages. Trained taxonomists recruited from outside New Zealand require training in New Zealand's flora and fauna, a significant issue given the high proportion of endemic species in the biota.

In discussion with the Universities New Zealand Research Committee, it was pointed out that the universities respond to market and student demands. If there is a decline in the teaching of taxonomy, then this was a response to demand. Further, in the absence of job opportunities students are unlikely to engage in this area of biological sciences. The Panel recognises that New Zealand is part of an international science labour market and that specialist career paths for a relatively small number of taxonomists and curators do not provide a strong basis for generic courses in universities or elsewhere.

The results of the survey conducted by Universities New Zealand for the Panel is provided in summary form in Appendix 6 for the seven universities that responded, with data on courses, postgraduate students and research programmes. As in other areas of university activity, the research focus of individual staff members has a strong influence on the focus of teaching and activities conducted within departments. The data from the survey are in some cases difficult to interpret; for example, some universities listed underpinning courses in biological sciences and paleontology. While exposure to plant and animal diversity is an important component of a biological sciences degree, entry level courses only very broadly support skill development related to taxonomy, systematics, or curation. This does not equate to training in taxonomic principles.

There are examples of collaborative approaches in New Zealand between the major institutions where taxonomic and collections expertise reside (CRIs, museums) and universities (e.g. Joint Graduate Schools between CRIs and universities; co-supervision of PhD students; summer scholarships arranged between museums or CRIs and universities for undergraduate or early stage graduate students). In addition, training has extended beyond tertiary institutions, such as the training schemes developed within CRIs, e.g. NIWA recognised the skill shortage within marine taxonomy and developed some technical parataxonomic training for staff (extending the expertise available in New Zealand across a wider range of phyla/taxonomic groups by connecting staff with mentors (usually overseas experts), and developing and expanding collaborative linkages); Landcare and the Department of Conservation have developed a training programme to develop DOC staff skills in identification of plants involving work on specimens in the herbarium under the guidance of expert taxonomists.

International examples of training

Internationally, it is recognised that there are insufficient human resources and tools available to describe undocumented biodiversity and to provide the robust information required for to meet the needs of end-users[47]. Thus, several countries have put in place interventions to address similar issues to those faced by New Zealand. A collaborative approach has been initiated by Scottish universities for postgraduate level study and research. This is an example of how a post-graduate student enrolling at one university has access to the relevant departments in the Scottish university system. This approach was developed by the universities and then supported by the funding body.

The Panel particularly endorses the course of action taken by the EU in forming the DEST (Distributed European School of Taxonomy) under the umbrella of the Consortium of European Taxonomic Facilities (CETAF)[48]. CETAF is the only European network that is devoted to promoting taxonomic research and collections-based activities and is funded by its member institutions (Appendix 10). The major aim of DEST is to transfer knowledge between current and future generations of taxonomists by providing high quality education, running a series of intensive postgraduate courses (involving ca. 100 providers from 60 institutions) that are available to students enrolled at tertiary institutions across Europe and also in other parts of the world.

47 www.cbd.int/gti/problem.shtml.

48 www.cetaf.org.

Imperial College London and the Natural History Museum have joined to deliver two distinct one-year courses: a MSc course in taxonomy and systematics[49], and a MRes Biosystematics[50] (Appendix 10). In both cases the university and the students get the benefit of access to taxonomic specialists at the museum, and access to unrivalled biological specimens, and the students gain an understanding of the strong scholarly traditions of natural history museums, while the Museum has the opportunity to engage with potential taxonomists, curators and collection managers.

Stewardship and funding of collections

(See Appendix 9 for purpose and primary function of collection holders).

Research institutes

Stewardship

Crown Research Institutes hold collections on behalf of the Crown with the expectation that they are made available to provide benefits to New Zealand. The Crown Research Institutes Act 1992 does not specifically mention their taxonomic collections, but in each relevant CRI's Statement of Core Purpose, its operating principles state that it will "maintain its databases, collections and infrastructure and manage the scientific and research data it generates in a sustainable manner, providing appropriate access and maximising the reusability of data sets".

In addition, under Open Government initiatives, Crown Research Institutes are expected to make the information from the collections and associated research available at the cost of delivery. Although there have been advances in delivery systems via the internet and Open Access protocols, these are making recovery of costs problematic. Also, significant parts of collections may not be subject to active research but still incur significant, and rising, costs in maintenance and storage without immediate or obvious outputs or outcomes.

The Cawthron Institute has similar stewardship responsibilities to Crown Research Institutes for its collection, as part of a specific non-contestable Crown contract.

Funding

Historically, the taxonomic collections, along with other databases in Crown Research Institutes and the Cawthron Institute, were funded as a component of separate contestable research contracts. These databases and collections were subsequently partially supported by a specific non-contestable infrastructure fund. This was used to increase taxonomic stability and visibility as well as better recognise long-term priority and needs. This was based on a clear understanding of the range of taxonomic activities required in the national interest.

More recently, the funding for these databases and collections became part of Crown Research Institute Core Funding mechanism (or in the case of Cawthron its specific Backbone contract). Such funding is ring-fenced to the extent that permission is required from the government funder to move significant amounts of designated Core funding to other activities in any one year. However, more broadly, Core funding allows CRI Boards and the Cawthron Institute to manage resources and priorities over a broad suite of activities and infrastructure. Through this, they may reprioritise activity, focusing on their own institutional requirements, without due regard to wider national needs. This problem for taxonomy has been greatly increased through the rising pressure on Core funding, in the absence of any mechanism to compensate for inflation, combined with the increased costs of physical collection, storage, and curation.

Museums

Stewardship

Museums have long been repositories for biological collections and there are specific legislative Acts protecting collections at Te Papa, Auckland, Canterbury and Otago Museums. The smaller regional museum collections have significant embedded information in terms of spatial and temporal data and some have collections representing the biodiversity of their localities. Te Papa and the three metropolitan museums differ from the research institute collections in that they hold a higher proportion of type specimens described early in New Zealand's biological discovery phase and they cover a broader range of species groups. The majority of vertebrate collections are held in these museums. These collections also support the development of resources for exhibitions and outreach. The researchers and curators employed within museums conduct taxonomic research as well as act in an interpretive role for natural history resources for the public.

49 www.nhm.ac.uk/our-science/courses-and-students/masters-science-taxonomy-biodiversity.html.

50 www.nhm.ac.uk/our-science/courses-and-students/masters-research-biosystematics.

Funding

Te Papa receives funding from the Ministry for Culture and Heritage to be distributed amongst its various activities and collections. However, there is limited funding allocated for core taxonomic research. Research funding from external sources is therefore important to Te Papa's research activities. Te Papa recently received additional funding for maintaining critical infrastructure – mainly the building infrastructure holding the collections – and there is also limited funding to address variable levels of collection conditions and care, variable levels of databasing, and digitising of data. Funding for collection development and acquisition of new specimens enables databasing of newly acquired specimens, but the backlog of undatabased specimens is not addressed from the government grant.

Regional and metropolitan museums are supported by local rate payers and local government, supplemented by grants, sponsors, donors and other revenue-generating commercial activities. There are very limited sources of external central government funding available to support taxonomic, collection based, or information systems research.

Universities

Stewardship

Universities have built up collections to support teaching and research interests. The Education Act 1989 does not specifically mention universities' collections or museums but university teaching must be research-informed and would therefore draw on collections infrastructure.

Previously, taxonomy and natural history featured more prominently in curricula, and biological collections were widely used to support teaching and research. Currently, greater attention is being given to other approaches to biological and geological sciences technologies, and the need for and costs of maintaining university-based collections are increasingly being questioned. Some universities have given their herbaria to the nearby taxonomic research institution (e.g. University of Auckland to the Auckland Museum and Victoria University of Wellington to Te Papa). However, the costs associated with a transfer of collections and the associated re-housing and databasing of the material have been borne largely by the receiving museum. Some university collections have particular importance because of the nature of the material they hold and/or their location (e.g. Lincoln University Entomological collection; University of Otago Regional Herbarium).

Funding

Collections in universities do not have a specific external funding stream. They are either departmental resources, often associated with teaching programmes, or research collections largely based on activities of one or two current staff members and/or associated with a particular historical research speciality of the university. These collections are vulnerable to disposal due to changes in departmental or university priorities.

Government agencies

Some government agencies have capability in collections to support their missions. For example, the Ministry for Primary Industry operates laboratories to support border protection activities and pest risk assessment and these have reference collections on which to base immediate decisions, while the Department of Conservation has a collection of *Powelliphanta* snail shells to help understand and describe snail diversity. Regional councils may also have collections to assist resource managers especially in plant pest control.

Māori (and/or Pasifika) aligned collections

The scope and existence of collections aligned to Māori and Pasifika entities has not been quantified within this report but there is no doubt about the existence of taonga collections within indigenous interests and their contribution to cultural practices such as the collection of rongoa (traditional medicine) materials from living collections held by iwi, hapū, or whānau by region or locality.

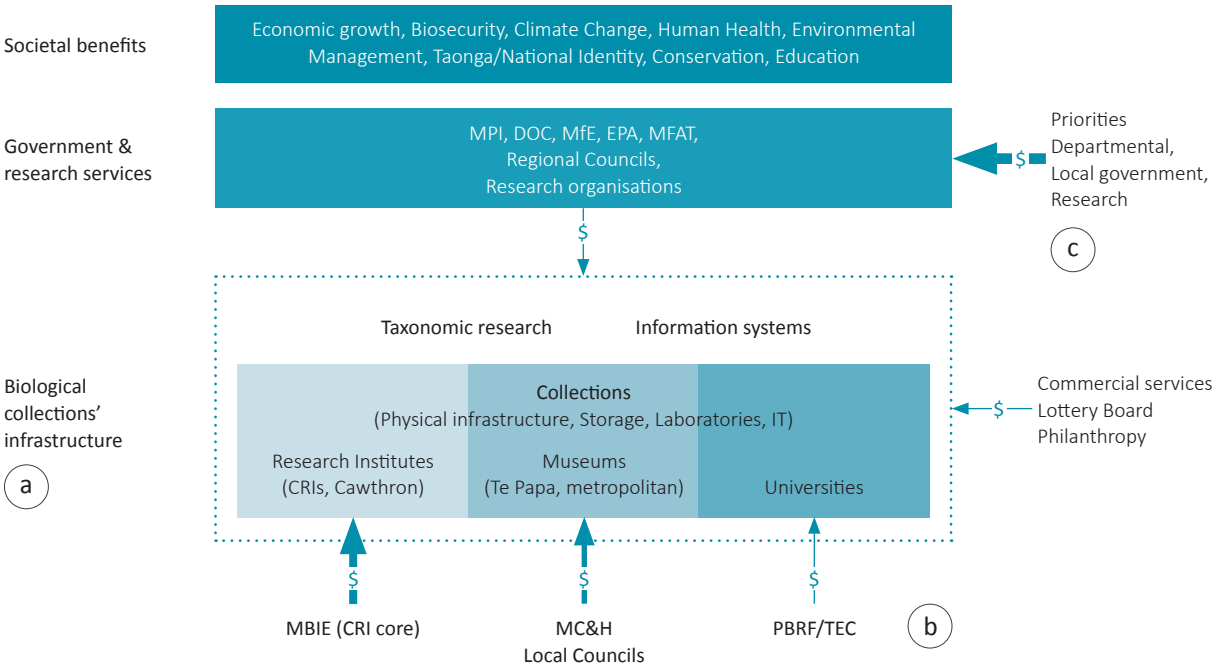
Private individuals

Private individuals may develop significant collections associated with personal natural history or research interests. These collections are often donated to museums or CRIs, but there are significant costs associated with the incorporation and re-housing of material and sometimes the funding and capabilities of the recipient organisations are not sufficient to fully accommodate these donations.

Strategic alignment

The Panel notes that there is a disconnect between the funding and delivery of services. There appears to be weak strategic alignment between the setting of output priorities of departments and agencies that are providing services and benefits, and the input priorities of those providing the main funding to the collections' infrastructure. There is also no obvious alignment between the input science funding to CRIs and research organisations and the other components of the New Zealand biological collections' infrastructure, despite the fact that New Zealand depends significantly on all of these science collections.

The biological collections' infrastructure is largely invisible to the many beneficiaries, as numerous services that rely on and access such 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.



Relationship of biological collections' infrastructure to Government and research services and funding. a: Biological collections infrastructure consists of the physical collections, their associated taxonomic research and species naming, and the information systems that allow access to this data. b: There is no strategic connection between collection funders. c: Lack of strategic connection between priorities set at departmental level and the investment by MBIE, Ministry for Culture & Heritage and other funders.

At an institution or collection level there are some specific initiatives to link with user communities. Landcare Research has worked closely through an Advisory Group with its end-users and stakeholders, devising prioritisation criteria that take into account such issues as end-user demands, science drivers, knowledge gaps, institutional capacity, and contractual elements. Landcare Research has actively engaged in a strategic refreshment process to prioritise investment and these criteria have been applied not only to the identification of research priorities but also priorities for specific capabilities, data, and services. This has resulted in significant change in research direction, and a much heavier investment in digitisation and imaging activities. Landcare commissioned an independent review of their taxonomic collections to benchmark their work against global good practice.

Scion engages the forestry industry and MPI, particularly in relation to biosecurity issues, to identify stakeholder needs and whether the National Forestry collections are meeting these. In the case of NIWA, within the Marine Biodiversity and Biosecurity Outcome Based Investment, the size of the funds to be prioritised was so limited that the Taxonomic Advisory Group for the OBI eventually concluded that there was so little room for movement, the work of the Advisory Group was not useful. They trusted the taxonomists were doing high priority work within the expertise and funds available.

Risks

In the course of gathering evidence, the Panel identified specific areas where the current policy environment presents risks to the delivery of services:

Delivery of government initiatives and legislative obligations: The Panel's view is that, currently, timely access to specimens and associated data at a national scale is not possible; collections are not easily searchable or accessible to those outside the collection's host organisation, even though some data are in digital format. The biological collections' infrastructure is required to meet both major legislative requirements and policy initiatives committed to by the government. For example, the recent establishment of the Extended Economic Zone and Continental Shelf, and the announcement of the Kermadec Ocean Sanctuary, will make additional demands on the biological collections' infrastructure (see also case studies in Appendix 10).

Examples of where there are specific requirements for specie- level information and authoritative names include:

- Biosecurity Act 1993 – "A chief technical officer may permit an organism seized under this section to be held in the custody of the Director-General for so long as is necessary for the importer to apply to the Authority for a determination under section 26 of the Hazardous Substances and New Organisms Act 1996 that the organism is, or is not, a new organism."
- Conservation Act 1987 – "Wildlife management areas – (1) Every wildlife management area shall be so managed—(a) that its wildlife and wildlife habitat values (including the capacity for the movement of wildlife, genetic material of indigenous plants, and genetic material of wildlife) are protected; and (b) that its indigenous natural resources and its historic resources are protected."
- Fisheries Act 1996 – "Environmental principles – All persons exercising or performing functions, duties, or powers under this Act, in relation to the utilisation of fisheries resources or ensuring sustainability, shall take into account the following environmental principles: (a) associated or dependent species should be maintained above a level that ensures their long-term viability: (b) biological diversity of the aquatic environment should be maintained."

Vulnerability of national scale interests to individual institutional decisions: The absence of national-scale oversight means that the current New Zealand collections' infrastructure is vulnerable to individual institutional policy changes and priorities. This can be seen in two recent examples:

Lincoln University Entomological Collection: In 2014, Lincoln University proposed to close the Entomology Museum and disestablish the role of Technical Officer. Following 92 submissions the university changed its view and acknowledged that *"the reference to Entomology no longer being a strategic focus for the University did not appropriately reflect the extent to which Entomology is undertaken by a variety of staff, postgraduates and undergraduates, particularly in the intersection with the Bio-Protection Research Centre and our Crown Research Institute colleagues. Further, we recognise and hereby acknowledge the significance of the Museum collection regionally and nationally."* It was also stated that, *"Based on the submissions and the new knowledge, the value and significance of the Entomology collection is accepted"*.

Te Papa: In 2013–14 Te Papa proposed to move some or all of its natural history collections from Te Papa in Wellington to off-site storage in south Auckland. Although the stated reasons for this mainly centred on risk factors associated with earthquakes, there was no consultation with users or other collection-holding organisations on how the current facilities could be strengthened or risks mitigated. If implemented, this plan would leave Wellington (and the lower North Island) and the associated research institutions (e.g. two universities, two CRIs, Te Papa scientists), and local and central government agencies (e.g. Greater Wellington Regional Council, DOC, MPI, MfE) without critical natural history specimens (reference material for identification purposes, research programmes, a repository for voucher material). The fact that this move was able to be proposed and pursued without recognition of the risks to other organisations which depend on access to the collections is indicative of the lack of formal recognition of the connections across the collection and research sectors.

Problems when the taxonomy is incomplete – *Didemnum*, aka Whangamata Sea Squirt

Didemnum vexillum is a sea squirt which often presents as a yellowish wax dripping over a structure such as a rope or mussel line. *Didemnum vexillum* poses a threat to the marine farming industry because of its ability to smother structures as well as growing on the hulls of vessels, aquaculture, and other marine equipment. The species was first described in 2002 by an Australian taxonomist from samples collected in New Zealand and regarded to be a native species. However, the behaviour of the species suggested that it could be introduced. Another sea squirt that was described in the USA at a similar time was causing similar problems. Recently, it has been established that both the New Zealand and USA populations of the sea squirt belong to the same species and its origin is probably Japan/North-western Pacific. This species has been recently reported to be spreading rapidly and aggressively in other parts of the world including the North Atlantic with severe detrimental economic and ecological impacts being predicted. The lack of clarity about whether this was a native or non-native species in New Zealand led to confusion and uncertainty about how to address its rapid spread and colonisation of marine farming equipment[51].

51 Stefaniak *et al.* (2012).

Coordination of national and stakeholder requirements: Although stakeholder advisory groups have been operating in some CRIs along with processes for the prioritisation of taxonomic research and collection development activities[52] (see p. 50) there is no national coordination, nor are there links with non-CRI collection holders. There is no process at present for assessing whether the current collections, research activities, and collection development policies of individual institutions meet national and stakeholder needs.

Funding and costs: CRI collections, funded through Core funding, are under pressure and without an explicit national scale regulatory framework, are at risk. The biological specimen collections formerly housed in Divisions of the DSIR, are now housed in CRIs, and along with the collections at the Cawthron Institute, are part of the set of collections termed Nationally Significant Collections and Databases[53] that have been supported by fixed funding since 2010. In the case of the CRIs, this is through Core funding, and for the Cawthron Institute through a contract with MBIE.

Visibility of the overall needs of the collections' infrastructure is low outside the stewards of the collections themselves as a consequence of the diversity of fragmented funding sources and distributed/imprecise ownership/stewardship of collections.

A survey of the annual running costs of the larger taxonomic collections identified that $12.5 million was currently being spent annually to cover their staffing, materials, housing and overheads[54]. In terms of the value of the collections themselves, Auckland Museum's replacement costing methodology would value Type specimens at $5,000, coastal specimens at $50/lot, offshore specimens at $120/lot and deep sea specimens at $425/lot. With this subsample of the review's surveyed collections holding over 24,000 type specimens, and 12 million collection lots, this would equate to a conservative value of over $680 million[55].

The annual running costs for the collections should be contrasted with the societal benefits that are being derived from them. A recent review of New Zealand's pest management[56] highlighted that weeds were a threat to one-third of all of New Zealand's threatened plant species and could potentially degrade 7% of the conservation estate within a decade, corresponding to a loss of native biodiversity equivalent to $1.3 billion[57]. Similarly, production losses to aquaculture from a single species of sea squirt *(Styela clava Herdman)* have been estimated to be $15 million p.a. in 2005[58]. More recent estimates suggest that if *S. clava* spreads to Marlborough, production losses over the next eight years could amount to $383 million[59]. If the taxonomic support from New Zealand's taxonomic collections were improved, more could be done to counter the $1.28 billion annual cost from pests, diseases and weeds to New Zealand's productive sector, which rises to $2.45 billion annually when the downstream effects are factored in[60].

52 For example, Landcare Research Characterising Land Biota Portfolio Advisory Group.

53 MBIE recognised Nationally Significant Collections and Databases: Allan Herbarium and Associated Databases; Cawthron Microalgae Collection; Crop Germplasm Resources Unit; International Collection of Micro-organisms from Plants and Associated Databases; Land Resource Information System; Margot Forde Germplasm Centre; National Climate Database; National Collections of Fruit Crop Germplasm; National Earthquake Information Database; National Forest Herbarium and Database; National Groundwater Monitoring Programme; National Petrology Reference Collection and PET Database; National Vegetation Survey Databank; New Zealand Arthropod Collection; New Zealand Nematode Collection and Specimen and Information Database; New Zealand Fossil Record File; New Zealand Freshwater Fish Database; New Zealand Fungal Herbarium and Associated Database; New Zealand Geomagnetic Database; New Zealand National Paleontological Collection and Database; New Zealand Volcano Database; Ngā Tipu Whakaoranga Ethnobotany Database and New Zealand Flax and Living Plant Collections; NIWA Marine Benthic Biology Collection; Regional Geological Map Archive and Database; Solar UV-B Radiation Database; Water Resources Archive.

54 For the Natural Science Department of the Auckland War Memorial Museum; Te Papa Natural History Collection; Canterbury Museum Natural History Collections; Otago Museum Natural History Collections; New Zealand Arthropod Collection and associated databases; New Zealand Fungal and Plant Disease Collection and associated databases; International Collection of Micro-organisms from Plants and associated databases; Allan Herbarium and associated databases; Ngā Tipu Whakaoranga Ethnobotany Database and New Zealand Flax and Living Plant Collections; National Forestry Herbarium; National Forestry Insect Collection, National Forestry Mycological Herbarium, National Forestry Culture Collection; Cawthron Culture Collection of Micro-algae; National Paleontological collection; Dame Ella Campbell Herbarium; University of Auckland Paleontology Collection; and NIWA Marine Invertebrate collections (including NIWA's marine invertebrate taxonomy, algal taxonomy (micro and macroalgae), and marine fish research).

55 Using $50 per lot.

56 Goldson *et al.* (2015).

57 Williams & Timmins (2002).

58 NZIER (2005).

59 Deloitte (2011).

60 Nimmo-Bell (2009).

Uncertainty in our knowledge of species constrains both protection and development: Protection of our biodiversity and development of new opportunities for sustainable use of biological resources requires understanding of the composition and state of our biota. Despite achievements in describing New Zealand's species[61], continued uncertainty in our knowledge of species and their interrelationships reduces our ability to provide certainty in resource use through the RMA and other legislative and international agreements (including an inability to report on progress under international agreements). This uncertainty opens prospects for more litigation. Also, iwi have insufficient information on which to base resource development and cultural renaissance in their rohe.

Cultural interests: Indigenous communities in both New Zealand and the wider Pacific region have long-standing interests and relationships with their biological heritage, especially since the contact period where Cook and others procured samples, named biota, and collected local knowledge. There is a significant opportunity to build the contribution of these communities to the unique and specific understanding of the region's natural world. The relationship of Māori to Aotearoa's unique natural world and also the wider Pacific region exists across a continuum through both whakapapa and spatial association. It is imperative for Māori that the opportunity to support Te Ao Turoa (the natural world) is captured and enhanced at all times.

Investment in the biological collections' infrastructure and workforce: The investment that has been made in the biological collections' infrastructure, and in the skills and training of the science workforce, is not being realised because of under-funding. With the current world shortage of skilled taxonomists and an acknowledged ageing workforce it is in the nation's interests to get the greatest value from remaining highly skilled taxonomists who are currently unable to make a full contribution to both New Zealand and international science. The reduction in national taxonomic expertise means that the quality of science and the delivery of timely information and services is placed at risk. For example, the large number of undescribed and unknown marine, freshwater, and terrestrial species in New Zealand's realm has implications for New Zealand State of the Environment reporting: species may be affected by a range of pressures before their presence is even known[62].

61 Gordon (2009, 2010, 2012). www.virtualherbarium.org.nz/home;jsessionid=3D6956D5301F87A47D726178FB2234D8; NIWA Memoir series http://crustacea.net/crustace/calanoida/index.htm.

62 MacDiarmid *et al.* (2012); Ministry for the Environment (2015).

Accidental, deliberate introduction of invasive species

An error in the taxonomy of cordgrass on the US west coast in the 1970s resulted in the accidental transplanting of an invasive species into the San Francisco Bay area. Thirty years later, the taxonomic mistake was recognised after the latent invasive ability of *Spartina densiflora* became apparent. Its original distribution range eventually expanded as it massively displaced native organisms and changed the entire physiognomy of regional landscapes along the US west coast. This mistake is difficult to remedy because the integrity of the ecological and physical aspects of the environment have been compromised[63].

New Zealand has an evolving issue concerning approved imports of mixed live inocula of mycorrhizal fungi where these products contain species new to New Zealand. These products are being marketed especially to restoration projects, and in so doing are introducing new organisms to native plantings. Regulation of the content of these mixed products currently relies on inadequate authentication of "present in New Zealand" status for species stated on the product label, and there has been no independent analysis of species composition in advance of, or subsequent to, the granting of approvals.

63 Bortolus (2008).

Legal protection: Despite their uniqueness and priceless value, legal protection for collections is limited to the Museum of New Zealand Te Papa Tongarewa Act 1992, the Auckland War Memorial Museum Act, and Trust Board Acts of some metropolitan museums. The Protected Objects Act 1975 is now dated and only provides protection for natural history specimens mainly in the area of sale and export outside of New Zealand. There is limited legal protection for these assets within New Zealand, despite a range of domestic and international needs and obligations relying on them.

Summary

The lack of visibility and understanding of the specific needs of New Zealand taxonomic collections is contributing to the erosion of capability and resources, through the limitations of existing funding and support mechanisms. The level of funding is a significant and increasingly critical factor, as is the disconnect between the departments and agencies delivering services and benefits, and the input priorities of those providing the main funding to the collections' infrastructure. In addition, 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. Also, despite a range of domestic and international needs and obligations that rely on them, there is limited legal protection for these assets.

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 meet their own budgetary needs, not necessarily in the country's long-term interests.

Examples of specific stress points in New Zealand's taxonomic collections

Institution	Stress point for collections
Landcare Research	Responsible for five of the biological collections identified as part of this review. Core funding and its predecessors have been static since 2008 – this equals ca. 20–25% decline in real funding. There have been staff redundancies in both 2013 and 2015, affecting taxonomic capability. Since the 2009 Backbone contract was signed, Landcare Research has lost around 12 FTE of taxonomy and collections staff through redundancies, reduced hours, and non-replacement of staff.
Cawthron Institute	Current funding only allows the successful care and maintenance of a fixed number of living microalgal species. Discovery of any new taxa and their retention requires other cultures to be shed. For example, recent prioritised research into likely toxicity threats under climate change models has forced Cawthron to be selective and cull some strains in order to take in new material to reflect the new research needs, while also continuing to underpin seafood safety research to ensure shellfish domestic and export consumption is not compromised.
NIWA	The NIWA Invertebrate collection has been closed in successive years for one month each year to conserve and manage funds. Retiring taxonomists have not been replaced as the proportion of individual scientists' time funded from taxonomic programmes is insufficient to make a case for staff recruitment.
Te Papa	Constraints on CRIs' funds have meant cuts to CRI/Te Papa joint research (land plants, marine fishes). Recent staff realignments have resulted in a reduction in numbers of staff working on the natural environment collections and their management, and a loss in capability.

The Panel's analysis of other countries' taxonomic infrastructure shows that New Zealand is not alone in the issues raised here, especially fragmentation (See Appendix 10). However, as a small and relatively well-connected country, New Zealand should be able to do much better than New Zealand is. The continued decline in support for the biological collections' infrastructure 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 New Zealand is limiting its opportunities to leverage technological advances.

If New Zealand's small size, its brand, its health and security needs, its economic advantages in agriculture, and its dependence on international trade are as important as government policy suggests, it seems to the Panel that New Zealand's biological collections' infrastructure cannot afford to be anything other than leading edge, best practice, and internationally connected.

Documentation of cultivated plants in New Zealand

There is no catalogue of exotic cultivated plants in New Zealand, that is, plants which have not naturalised but remain as garden plants. Although MPI curates the Plants Biosecurity Index (PBI), a list of exotic plants in New Zealand was developed as a working tool when the Hazardous Substances and New Organisms Act was under development to guide importation of plants under the Health Standards, but there are no vouchers associated with this list. It is therefore not possible to verify which cultivated plants are present in New Zealand. This is an issue for MPI and EPA who must determine if new incursions or proposed plant imports are already in the country. As no names on the PBI are verified by vouchers there is no evidence they are correctly identified. Thus permission to import a plant may be granted based on a plant being incorrectly on this list, or permission to import a plant may be denied even though the species has been in New Zealand for many decades, but is not on the PBI. (See Appendix 8).

Future requirements for New Zealand's taxonomic collections

Stakeholder needs

In addition to consultation with a wide range of end-users and stakeholders, the Panel considered two recent surveys of stakeholder views of the future:

Te Papa survey

In 2013, a wide range of user groups was asked by Te Papa to identify their needs for analyses that would be made possible through a national biodiversity data system[64]. This survey revealed a demand amongst current users of biological data for a range of 'national-scale' and 'big-picture' analyses. The types of data analyses required involve aggregation of data temporally, spatially and in response to management scenarios with modelling approaches. New Zealand's national biological collections network is a key resource to achieve this vision.

Looking out to 2035

In early 2015, the Panel invited collection holders, users, and policy makers to look out to 2035 and provide their views of what an effective system would look like for supporting, developing, and managing New Zealand's taxonomic collections, databases, information systems, and associated research. A total of 44 respondents participated in the survey. The need for long term, adequate and stable funding emerged as a central theme of critical importance. Given that the biological collections are recognised as national scientific and heritage assets, short term funding is fundamentally contradictory.

64 Waugh *et al.* (2013).

Respondents identified the need for taxonomic research, collections, and database priorities to be developed jointly with end-users, and outputs (accessible databases, identification tools, and scholarly research) to be tailored to meet nationally agreed targets. They noted that the prioritisation processes used by some CRIs with strong linkages to end-user communities are an effective model and should be implemented at a national scale.

Responses from the users of the collections and taxonomic research, such as the Department of Conservation, the Environmental Protection Authority, and Regional Councils, highlighted a list of future taxonomic needs. These included the following:

- collections to provide the basis for research on important species for New Zealand;
- a process for researchers to submit new biological systematic data on a regular basis to end-users;
- provision of searchable information on the distribution of weeds, such as the extent of infestations, site information, plant associations, alternative names (including non-scientific) or outdated names. This would include full GIS integration to see layers on maps;
- the provision of an indication of the invasive potential of species and/or biological traits, to assist in understanding future climate scenarios and the impact of climate variability on species (including pest) distributions.

Respondents also anticipated that innovative approaches to taxonomic research will be developed to accelerate taxonomic productivity and meet society's needs. For example, this may include greater automation in digital data gathering and analysis, high-throughput molecular analyses, and the integration of these activities with informatics infrastructures. The results of taxonomic research generally should be able to be made more accessible to end-users, enabled by new approaches to publication of data and results, identification tools and biodiversity data summaries, and tailored to meet specific community and end-user requirements.

For the collections themselves, respondents identified the following characteristics of a future-focused (2035) system:

- Collections should form part of a distributed national network to service practitioner and end-user needs as components of a national biodiversity collection, and be valued both scientifically and as heritage assets;
- Collections should be curated to international and well-documented standards, with national oversight of curatorial practice, record keeping, and collection-development policies;
- Collections should be able to provide services to users through facilities for on-site research on the specimens, and rapidly arrange and provide loans to bona fide researchers;

- Collections should be actively worked on, and adequately resourced to cope with new accessions and to catalogue and database any backlog of existing material;
- Collections should be linked by interoperable digital services and information systems, improving access to biodata for users, for example, biodiversity management planning, climate change research, ecotoxicology, biosecurity surveillance, and community science needs;
- Collection custodians should implement a workplan based on national priorities and link to international networks; (See Appendix 4)
- A national collections network should be used for training students and emerging professionals.

In addition, it was identified that future initiatives need to ensure highly integrative taxonomists are available in New Zealand who can conduct research across biodiversity discovery, organismal biology, taxonomy, phylogenetics, and evolution.

A new approach for New Zealand

The Panel has concluded that that there needs to be a new approach to biological collections and taxonomic research in New Zealand that addresses national coordination, investment, stewardship, protection, and training.

There is a strong desire within the biological collections community to put this in place, with the necessary support of Government, to achieve much better outcomes for New Zealand.

Principles for investment and stewardship

The Panel has identified seven principles that should drive changes to the current system and which would support the future vision of the biological collections' infrastructure.

1. *The timeframe of investment certainty should reflect the timeframe of the activity being supported*

   The activities to be supported are

   - a mix of permanent curation and storage linked to programmes of taxonomic research, which need to be informed by national priorities and tied to the relevant collections;
   - biodiversity information systems, tools, and database development, which require medium term programmes;
   - shorter-term projects responsive to various user needs.

   The current system does not reflect this diversity of needs at all well.

2. *Investment should recognise the critical interdependencies between taxonomic research, national biological collections, and their associated data and information systems*

   All three of these activities need to be effective to get the intended impact. If any one of these layers of activity is compromised then the impact of the collections will be significantly limited.

3. *Inflation in the costs of operating collection infrastructure over time needs to be explicitly recognised. This pertains especially to physical storage and curation*

   The need for safe, secure, permanent physical storage and curation of collection specimens and taxonomic research do not lend themselves to significant efficiency gains through technological substitution. The basic infrastructural requirements need to be accommodated in a way that avoids trading-off taxonomic expertise. The adoption of new technologies, such as digitisation and online access, can definitely enhance the impact and service the collections can provide, but they are no substitute for taxonomic skills.

4. *Stewardship of collections should sit with the Research Institute or organisation most appropriate to its main area of taxonomic research and end-user communities*

   The physical location of the collections has evolved over time, consistent with this principle, and the Panel does not see any need to make significant changes to the current location and stewardship of collections. National coordination will provide a mechanism to further evolve the collections in line with collection holders' needs and priorities informed by a national strategy.

5. *Investment should continue to reflect the mix of national, local government, educational, and business uses of the collections (including by government agencies such as MPI, DOC, and MfE)*

   Biological taxonomic collections underpin a wide range of economic, environmental, health, educational, and cultural services that benefit New Zealand. The collections and related activities should be aligned with the priorities of national and regional stakeholders. Public benefit activities should be supported by central government, and regional interest supported by local government funding. Museums have evolved with a regional role and funding support largely from local government. The Panel sees no need to change this where there continues to be local educational opportunities as well as national benefits.

6. *Investment and stewardship should recognise the criticality of open access, common standards and interoperability between collections, both nationally and internationally*

   Biodiversity and taxonomic data from biological collections should be easily shared in common, open ways, and shared needs for biodiversity information systems and tools should be identified. New investment will go further if priorities are coordinated as part of a national strategy and collections will be used and accessed more if access is easier, systems are interoperable, and if they have common standards and protocols.

7. *End-user charging should be sought where this does not limit the public benefit*

   The main users of the collections are government agencies on behalf of taxpayers, and the public for educational use. There may be scope to use co-funding arrangements to encourage alignment of government user priorities and collection holders' priorities. However, this must be done carefully and recognise the shorter-term focus of the government agencies that have only sporadic requirements in any particular area. Commercial income-generating opportunities should be limited, e.g. charges for cost of access, publication of information, and sponsorship, where the public benefit is enhanced rather than reduced.

Improving system performance

National coordination

In order to maximise the impact of existing investment, gain greater efficiencies, and reverse the lack of visibility of collections' infrastructure, biodiversity information systems, and taxonomic research, there is a need for national coordination, prioritisation, oversight, and stewardship.

Central government has a critical role in preventing coordination failure. There is a many-to-many relationship between the collections and the broad range of benefits they support, and the collections themselves are geographically distributed. There is a diverse range of funding sources and individual organisation missions and priorities. Currently there is no clear point of stewardship within or outside government; with this there is no national collections' development strategy. As a result, individual collection-holders are making decisions and allocating scarce resources with only a partial view of the overall infrastructure and needs. The efficiency and effectiveness of the collections' infrastructure must therefore be improved. The value of past investments must be better protected, through stronger coordination around priority setting, standards, resource allocation, access to specialised expertise, and development of tools and information systems.

The Panel sees a need for the establishment of a national coordination mechanism to:

- Develop and maintain a national register of biological collections;
- Develop processes for identifying priority taxonomic research needs and provide guidance to funders;
- Provide national oversight and coordination around standards, database and information; systems development, and the adoption of new technologies and techniques;
- Coordinate national and international access to, and interoperability of, the collections' databases and information systems in order to enhance access and usefulness of the collections;
- Facilitate strengthened collaborations between collection holders and universities to ensure the provision of appropriate taxonomic training and access to expertise;
- Provide a point of contact and advice for government on matters relating to the biological collections' infrastructure, including the development of a national collections' policy;
- Work with iwi to ensure communities engage with national biological collections and derive meaning from them. Enable full participation in the interpretation, care, and development of collections thereby fulfilling the role of kaitiaki.

National coordination would be able to support the delivery of new and exciting integrated and interoperable biodiversity information services. Recent developments in bioinformatics and cyberinfrastructure are transforming taxonomy and collections-based research, revolutionising the way biodiversity data are being discovered, described and documented, made accessible, analysed, and disseminated (See Appendix 12).

The Panel's view is that the major potential of technological advances for taxonomy and collections' infrastructure is to increase knowledge creation, enable timely access to data, and to future-proof collections, taxonomic research, and related data. Examples of initiatives that would be able to be facilitated through the national coordination mechanisms, and would bring immediate benefit, include:

- Full participation in the Global Biodiversity Information Facility (GBIF);
- Adoption of a fully operational New Zealand Organisms Register;
- Extending the electronic Biota of New Zealand;
- Developing an Atlas of living Aotearoa;
- Citizen Science portal initiatives are strengthened and broadened;
- Electronic capture of collections data;
- Genetic characterisation of collection specimens;
- Development of innovative diagnostic tools.

A stronger representation of indigenous interests, through staffing and scholarship about the collections and their care, is an example of one opportunity that could be facilitated through the national coordination mechanism, as well as enabling research into the collections aligned to traditional knowledge systems, such as Mātauranga Māori. This should be seen as complementing scientific study.

The national coordination mechanism would be in a position to, for example, evaluate the status and condition of biological collections, whether there are opportunities for rationalisation, and for more effective use of resources. The Panel has considered potential criteria that would be required to designate taxonomic collections of national importance. For example, the collections should provide the following:

- a trusted scientific baseline for New Zealand to properly manage its major economic, environmental, or social priorities and related risks; and/or
- a collection of records that protects a unique aspect of New Zealand's culture and heritage for reference and education; and/or
- a collection required to service New Zealand's legal obligations; and/or
- a collection required to service New Zealand's international obligations;

and

- the contained physical specimens require specialised storage facilities;
- taxonomic research is a necessary part of the collection;
- the loss of a physical specimen or collection would be irreversible or costly;
- the collection is largely publicly funded and accessible to users.

In addition, the Panel considers that the establishment of a single point of responsibility in government would enable a coherent approach to policy in the resourcing of the biological collections' infrastructure, and collection-based research. Such an initiative would provide the main channel for interaction and information exchange between the government and the biological collections' coordinating mechanism. This would involve departmental service providers and users (both science and culture and heritage related), public outreach and education, and domestic and international obligations.

Legal protection

The current situation where the biological collections have only partial protection, alongside the lack of overall strategy and policy, is continuing to undermine the stability of the long-term work programmes essential to ensuring that New Zealand has a high-quality, fit-for-purpose biological collections' infrastructure.

The Measurements Standards Laboratory (MSL) is an example of infrastructure in a different context that addresses the need for scientific references to support industry and trade, and which has legislation to protect and guide it. The biological collections' infrastructure shares similar attributes by providing critical scientific references to an even wider range of services as part of New Zealand's own and global obligations. The MSL legislation has provided stability for the physical measurement infrastructure, aided by the legislative requirement to designate a Chief Metrologist with overall stewardship responsibility. An equivalent framework for the biological collections, recognising the distributed nature of collections, and the need to protect the critical collections for the long term, has the potential to aid long-term stability in support and remove some of the risk identified in this report.

Training initiatives

The Panel considers that there are opportunities to put in place incentives to address training issues in relation to the future supply of trained researchers placed in a context of an optimally sized workforce. The general aim would be to ensure there are enough well-trained graduates to meet current and future needs, possibly through the development of relevant course modules, coordinated at a national level and delivered through a consortium of tertiary providers in conjunction with lead taxonomic research teams (i.e. based in universities, CRIs, and Museums). In the Panel's view such interventions would be able to overcome the lack of a coherent approach among universities and other research institutions to educate skilled taxonomists and systematists. A proposal to develop a consortium for training in taxonomy/systematics in New Zealand was proposed in 1995 and recommended the development of strong linkages with international centres of excellence[65].

65 Penman (1995).

Initiatives to enable increased involvement of practitioners of Mātauranga Māori and other indigenous knowledge systems should be established, and informed by an appropriate advisory mechanism. Improved representation of tangata whenua and Pasifika communities in caring for and interpreting the collections should be a goal of training systems, and implemented nationally.

As indicated earlier in this report there are examples of international approaches to the issue of insufficient experts residing in any single tertiary institution and also enabling the advantages of multi-agency approaches to training (e.g. Scottish universities; DEST in Europe; Masters degrees offered by Imperial College and Natural History Museum London) (Appendix 10). In addition there are already some examples of strong collaborative approaches in New Zealand (e.g. Joint Graduate Schools between CRIs and universities; co-supervision of PhD students).

Such interventions are more likely to work well if there is a small amount of additional funding to incentivise collaboration (other initiatives that have been successful in New Zealand received around $500K per annum). Success is also much more likely if universities are provided with incentives for collaboration that also include the relevant potential employers, such as collection holders, and other interest groups (in particular CRIs, museums, and relevant government departments). Examples of previous successful initiatives in New Zealand are those to build capacity in the social sciences, and following the first PBRF in nursing and IT studies.

Investment

Maximising the benefits for New Zealanders from its biological collections in future requires addressing the current shortfall and continuing decline in funding, and dealing with the inefficiencies inherent in the currently fragmented system of funding and stewardship.

The National Statement of Science Investment recognises the role of Government as the main investor in environmental research, “particularly where the public is the primary beneficiary, such as understanding the environment, its inherent processes, and threats and mitigations.” The NSSI further states that “effective environmental management can underpin economic goals, and that a significant opportunity for improving New Zealand’s environmental management is to improve our information and evidence base, and our understanding of environmental opportunities and limits”.[66] It also recognises that high-impact research cannot always be valued in economic terms alone and that environmental (role in the ecosystem), and cultural or social (as taonga or public amenity) values also need to be considered.

There are strong and diverse public benefits to the collections, for example, accumulated knowledge of New Zealand’s natural history, the preservation of taonga of particular significance to historical events such as the kōwhai collected on James Cook’s first visit, or the records of early whale migrations of significance to Māori. The collections also inform New Zealand’s biodiversity and environmental values that are part of New Zealand’s “brand or heritage” that helps to sell our goods to the world and attracts tourism.

Individual businesses, government users and members of society are not in a position to fund and manage the required infrastructure for their specific purposes. The high uncertainty about timing of their future needs and the very long time periods required for collecting and managing the collections means that it essential for central government (and local government to some extent), acting on behalf of taxpayers and rate payers, to provide the necessary investment in infrastructure needed to serve the wide-ranging national needs.

66 Ministry of Business, Innovation and Employment (2015).

Immediate investment

Government urgently needs to address the immediate investment needs of the national biological collections and research staff so that critical taxonomic expertise is restored, and that services and quality are not put at further risk.

Long term investment

An initiatives package should be developed that:

- Provides for a national coordinating mechanism;
- Adopts a strategic and tailored approach to investment that addresses the long term needs of the sector and also provides opportunity for shorter-term prioritised projects;
- Enables the development and implementation of new digital and scientific technologies and related services to enhance access and value to the existing collections, including key integrating and aggregating tools at both national and international level;
- Allows new skills initiatives targeted specifically at taxonomy and collections needs;
- Enhances public understanding about taxonomy and biological collections, and the use of and access to collections.

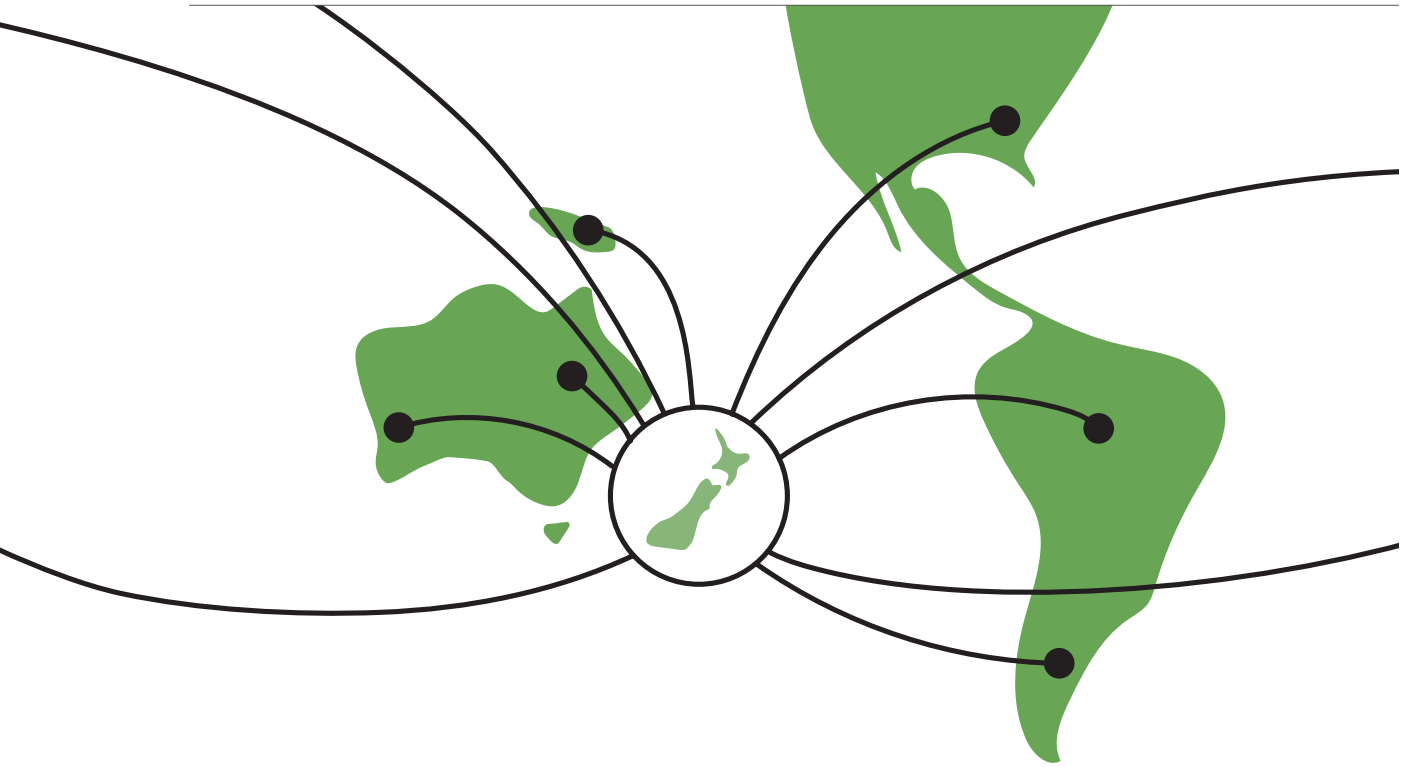
Recommendations

New Zealand should strive to have deep and comprehensive knowledge of its biota across its lands, fresh waters, and surrounding seas that: defines New Zealand's evolution, uniqueness and cultural icons; allows New Zealand to sustainably manage its natural resources and economic opportunities; protects New Zealanders' health and well-being; and allows New Zealand to stand tall in the international community in meeting its global obligations.

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.

In order to realise such a vision, 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 heritage assets.

The Panel is convinced that a whole-of-systems approach must be taken to interconnect providers, custodians, practitioners, stakeholders, and end-users across the taxonomic and collections sector. 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 investment, coordination, protection, stewardship, and training.



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, including 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 addresses 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 adopts 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.

For further information

Please contact info@royalsociety.org.nz

or go to the Royal Society of New Zealand web page:
www.royalsociety.org.nz/taxonomy

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