



Taxonomy Research
& Information Network
building australian capacity

Accelerating discovery

the products, outcomes and protocols from the
Taxonomy Research & Information Network
to assist with identifying and conserving
Australia's biodiversity

ISSUE TWO





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The Commonwealth Environment Research Facilities (CERF) program is the Australian Government's \$100 million commitment to world-class, public good, environmental research.

CERF aims to improve Australia's capacity to understand and respond to current and emerging priorities for the conservation and use of the nation's environmental assets. These include Australia's flora and fauna in terrestrial, freshwater, coastal and marine ecosystems, and soils, water and air as home to Australia's biodiversity.

It is primarily providing funding for the creation of national, multidisciplinary, research hubs. Some funding is also being provided for separate significant projects and fellowships.

Accelerating discovery

the products, outcomes and protocols from the Taxonomy Research & Information Network to assist with identifying and conserving Australia's biodiversity



Taxonomy is the discovery, description, identification and classification of organisms.

Taxonomy provides the basis for identifying and monitoring Australia's biodiversity which in turn provides the knowledge needed for effective environmental management.

The Taxonomy Research & Information Network (TRIN) has been addressing critical gaps in taxonomic knowledge of key Australian animal and plant groups, as well as investigating ways of accelerating the taxonomic process.

TRIN's research projects included a range of taxonomic and systematic investigators using a diversity of approaches and methodologies.

This is the second issue of the online publication, 'Accelerating discovery', produced by TRIN to highlight its products, research outcomes and protocols.

Further information and links to the products and publications can be found on the TRIN website at: www.taxonomy.org.au

VISION

An accelerated rate of discovery, description, documentation, delivery and adoption of high quality information on Australia's biota.

MISSION

Through innovative approaches to taxonomic research and dissemination of relevant information TRIN will deliver high quality scientific knowledge critical to sound and responsive decision making in conservation, management and sustainable use of Australia's biota.

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Introduction



The TRIN research network brought together a critical mass of taxonomic research, with broad goals to:

- reinvigorate taxonomy in Australia
- evaluate and road test new methodologies for research and delivery of taxonomic information for a wide range of end users, and
- create and maintain a modern collaborative national electronic framework for taxonomic knowledge delivery.

TRIN applied these goals to a select number of projects covering small terrestrial vertebrates, aquatic invertebrates, ants and weeds of national significance, as well as two network-wide activities around biodiversity informatics and knowledge exchange. Research was directed at five specific objectives with the aim of realising TRIN's broader goals, namely:

1. Address the knowledge gaps in key Australian taxonomic groups
2. Accelerate rate of understanding of Australian biodiversity using an integrated approach for capturing, assembling, analysing and managing taxonomic information.
3. Provide seamless access to biodiversity data and taxonomic information by applying a best-practice information management and delivery framework.
4. Provide information in a form that meets end user needs and encourages uptake
5. Provide a legacy to drive accelerated taxonomic research and delivery.

Through its innovative approach to taxonomic research and the dissemination of information, TRIN was able to expand to other projects and initiatives. By focussing on the five objectives, TRIN delivered high quality scientific knowledge critical to sound and responsive decision making in conservation, management and sustainable use of Australia's biota.

Snapshots of these achievements, as they relate to the five objectives, are presented in this issue of 'Accelerating Discovery'.

Delivery against key messages

The application of new approaches often meets with some inertia and usually requires considerable time and effort to illustrate effectiveness and appropriateness for various situations. TRIN discovered that changing the way taxonomy is practised is not straight forward. This is largely related to cultural and social change rather than to any scientific issues. However, having early career researchers testing new methodologies proved successful and led to a high degree of adoption. Improved uptake and impact grew with increasing familiarity of TRIN products and tools, particularly in the biodiversity informatics arena.

TRIN delivered big wins in:

Creating Knowledge – *through addressing gaps in skills and knowledge of significant, iconic and diverse groups lacking expertise.*

Substantial outputs resulted from three ant projects, all groups of high diversity and poor taxonomic coverage; significant cryptic diversity is revealed in small terrestrial vertebrates; and attention to aquatic macroinvertebrates discovered 30% more species than previously recognised.

Accelerating Knowledge – *with innovative approaches in the taxonomic process to capturing, assembling, analysing and managing information.* Each of the taxonomic projects adopted integrated approaches to their research using morphological and molecular datasets together with novel means of gathering (e.g. PDA and microCT scanner technologies) and collating information (e.g. via the wiki) for analysis. Data is stored in and exposed via various on-line fit for purpose databases, and valuable products are published in shared space.

Delivering Knowledge – *by providing freely accessible, convenient, appropriate, reliable, ready to use biodiversity information suited to the needs of users.* The biodiversity informatics team in the development of the wiki, taxon profiles, linked lab book and the phylowidget, set standards and collaborated with others needing their service. The team assisted in the development of the remote microscopy capability and with infrastructure and content of the various identification tools, as well as providing LUCID training.

1. Filling crucial gaps



TRIN took on significant, iconic and biodiverse Australian groups which had not been tackled before taxonomically, either because of a lack of resources or because they required different investigative approaches with novel techniques and methodologies. Some of these groups lacked even basic documentation of species-level taxonomy, biology and distribution. The knowledge gained means these groups now have the capacity to assist with effective environmental management. The research led to the development of an ongoing information framework that can be applied to other flora and fauna.

HIGHLIGHTS

- The genus *Acrobates* (Feather-tail Gliders) was recognised to consist of 2 species – no one has previously suspected that this genus consisted of more than one species.
- The identity of more than 50 species of mayflies has been clarified. This has increased the number of described species of Australian mayflies by 30%, and greatly improved our knowledge of these invertebrates.
- Clarification of the identity of the cryptic *Melomys*-like rodents (mosaic-tailed rats) from the wet tropics, determined it to be a new genus and species.
- A species-level revision of the ant genus, *Iridomyrmex*, resulted in recognition of 79 species, 31 of them newly described.
- Approximately 40,000 specimens from throughout Australia, South-east Asia and the South Pacific were examined and databased as part of the revision of the ant genus, *Iridomyrmex*.
- The Australian Mangrove and Saltmarsh Ecosystem Resource includes a compilation of species lists, profiles and species interactions, helping to identify important knowledge gaps in the information available on this heavily impacted ecosystem.
- Work on fossorial reptiles (blind snakes and legless lizards) demonstrated their fine scale endemism and high local diversity. This emphasises their potential significance as indicators of environmental health.
- The insect family keys provide identification guides to the 650 families of Australian insects, including interactive keys to 50% of Australia's insects, and dichotomous keys to the remainder. These provide a readily accessible knowledge base for identifying Australia's terrestrial invertebrates, as well as information on their biology, ecology and economic importance.
- DNA barcoding is proving useful in rapid identification of invasives and contributing to meaningful analyses of plant diversity patterns.



Ants, ants, everywhere

The ant genus, *Iridomyrmex*, is the 'Eucalyptus' of the invertebrate world, occurring throughout Australia in exceptionally high densities and exhibiting rich diversity with nearly 100 species.

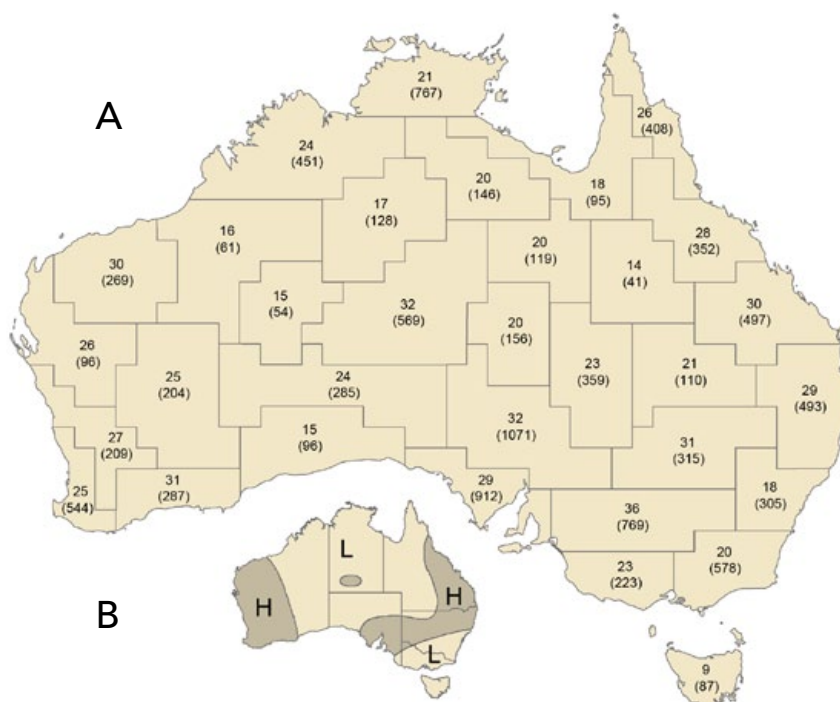
This ecologically important genus has been poorly understood as a lack of conspicuous morphological characters has hampered serious taxonomic work on the group – until now that is.

TRIN has produced a first-ever species-level taxonomic revision of the group using a combination of traditional morphological analyses and molecular techniques. The key to species of *Iridomyrmex*, together with maps and images for each species, fills an essential gap in utilising these common ants in a wide range of studies, including assisting with identification and natural resource management field monitoring.

Research encompassed examination and databasing of nearly 40,000 specimens from throughout

Australia and neighbouring countries, providing the ability to investigate patterns of diversity across Australia and in biogeographic regions.

At the continental scale, it is clear that *Iridomyrmex* is well adapted to Australian conditions with a dozen or more species present in most areas (with the exception of wet, cool Tasmania, where there is currently only nine species known). While regional variation in number of species is minimal, there are areas of greater diversity (i.e., with 25-30 species) as seen on map B. These higher diversity areas correspond to transitional habitats between the dry, arid areas of central Australia and the wet, cooler areas of the extreme south-east of the continent. It should be noted that many of the lower density areas are also the most poorly collected and it is likely that additional species will be found in these areas in the future. However, given the large amount of data presently available it is unlikely that the broad pattern outlined here will change significantly.



Species richness for the Australian *Iridomyrmex* fauna.

A. Number of species (upper number) and collecting events (lower number) clustered by Barlow (1985) botanical regions, based on material examined during this study.

B. Density plot based on A and distribution of individual species: H ('high' diversity) – areas with 25-30 species; L ('low' diversity) – areas with < c. 20 species.

[hover over image to enlarge]

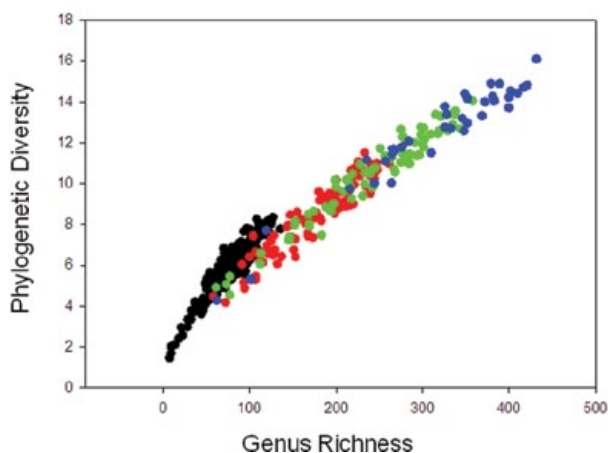


Barcoding life

DNA barcoding was undertaken on under-studied groups such as rare *Acacia* species, weedy invasive grasses, native hardwood tree species, potentially overfished marine biota and important pollinators and insects that provide significant ecosystem services. The barcoding work used high-throughput sequencing to accelerate development of barcode reference databases for Australian groups. Unknown specimens are sequenced and assigned a barcode. This DNA sequence is then compared to a known reference database of barcodes from which an identification can be made.

DNA barcoding invasive grasses helped identify an incursion of Mexican Feather Grass (*Nassella tenuissima*) in Australia. This species is a weed of national significance and the barcoding sequences led to its rapid identification and swift removal from Victoria. The barcoding sequence reference library will limit the incursion of future invasions.

TRIN used DNA barcode data to improve estimates of plant diversity patterns in Australian tropical rainforests. Until now, analysis of diversity across entire floras has been limited to calculating taxonomic (e.g. species) richness.



Approximately linear relationship between taxonomic richness (at genus level) and phylogenetic diversity in vascular plants demonstrated using data from nearly 200 plots across the Wet Tropics.

[hover over image to enlarge]

Water quality monitors

Taxonomic treatments of key aquatic macroinvertebrates provided baseline taxonomic data for effective environmental and ecological research in aquatic ecosystems.

The studies focused on Ephemeroptera (mayflies) to improve their capacity for applications in detection of environmental change in water systems. Phenotypic and molecular datasets were combined with different life history stages using contemporary DNA barcoding approaches to provide web-based interactive keys to species.

DNA barcoding techniques have greatly increased the speed and ease to identify and delimit species, discover cryptic species, and associate adult and larval stages for aquatic macroinvertebrates.

A greater knowledge of the mayfly groups and their identification keys will provide better scientifically informed water quality monitoring. Keys have been rolled out at various taxonomic workshops, to a range of users such as water quality experts and policy makers.

The barcode dataset allows phylogenetic diversity – measuring evolutionary distinctiveness – to be calculated for the first time. Results confirm that taxonomic richness is a good proxy for phylogenetic diversity for the vascular flora of the Wet Tropics, and will enable more sophisticated biodiversity conservation planning in the World Heritage area.

The barcodes have been compiled into Australian biodiversity DNA barcode libraries and lodged with GENBANK, with data generated for a range of organisms including trees, grasses, fish, flies, fungi, termites, ants, beetles and butterflies.



We thought the work was done

A collaborative team of morphologists, geneticists, and ancient DNA specialists has been extremely effective at identifying and resolving taxonomic problems among the Australian terrestrial vertebrate fauna. Phenotypic, morphometric, ecological, distribution and ancient DNA datasets were combined to provide robustly tested hypotheses of species boundaries, relationships, and past and present distributions. Some of the highlights of this work include:

- discovering significant taxonomic complexity across all groups and all habitats, which is rife in some particularly poorly known groups such as blind snakes
- revealing the taxonomic complexity in several reptile groups of key interest for environmental management and conservation (rock and tree dwelling skinks; fossorial reptiles)
- vouchering distributional data available for the first time for the original mammal fauna of the Southern Tablelands region, providing a solid scientific foundation for planned species reintroductions in this area
- recognising the genus *Acrobates* (Feather-tail Gliders) consists of more than one species
- clarifying the identity of the cryptic *Melomys*-like rodents (mosaic-tailed rats) from the Wet Tropics, now determined to be a new genus and species.

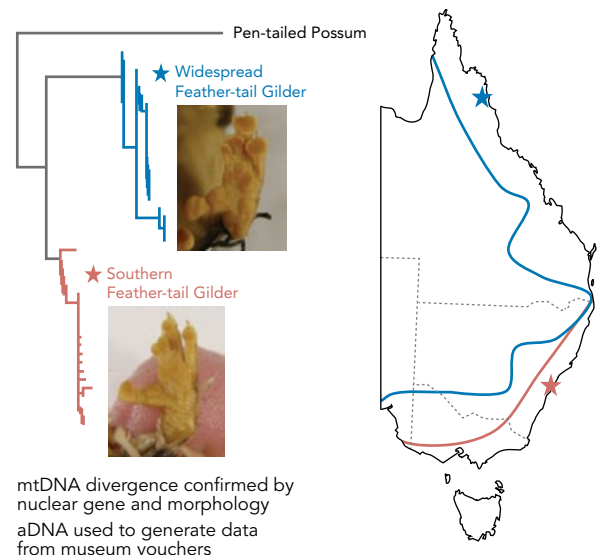
These findings highlight the need for further work to be conducted on small terrestrial vertebrates since they are not as taxonomically well known as previously thought.

Two Feather-tail Gliders?

The first inkling that there might be more than one species of Feather-tail Glider came from examination of jaws and teeth specimens collected in caves. Re-examination of museum specimens in the Australian National Wildlife Collection revealed two forms differing in details of skulls, feet and tails, but otherwise very similar in size, colouration and body form. DNA sequencing confirmed the two forms are distinct evolutionary lineages, and shows them to be surprisingly ancient. Specimens in state museum collections provided the basis for a broad-scale map – showing the two species have broadly overlapping ranges in south-eastern Australia, with one extending north to Cape York.



The original Feather-tail Glider specimens were collected at Sydney, during the first few years of European settlement. These specimens are still held in the Natural History Museum in London and were examined to link the scientific name *Acrobates pygmaeus* to one of the two species – the most southerly species. The other species also has a scientific name based on three pouch young specimens collected in north Queensland in the 1880s but which was erroneously described as a new species of pygmy possum.



2. Understanding biodiversity, now!



By using an integrated approach and innovative ideas to capture, assemble, analyse and manage taxonomic information, TRIN achieved impact in a comparatively short space of time. TRIN greatly improved the understanding of not only the targeted groups (ants, small terrestrial vertebrates, aquatic macroinvertebrates and weeds), but through the wiki as a collaborative platform, also enhanced accessible information on groups as diverse as mangrove and saltmarsh species, moths, sponges and bryophytes.

Building clusters and engaging the community has demonstrated the effectiveness of collaborative teams, integrating skills and knowledge, as well as practices and resources. The advantages of integrating modern genetic data, ancient DNA sequences and traditional anatomy and morphometrics are evident in outcomes of the small vertebrate research.

Application of some existing approaches and other novel advances illustrated ways to accelerate steps in the taxonomic process. For example, DNA barcoding provided a means of rapidly delimiting species of aquatic macroinvertebrates; gathering data using tailored PDA (Personal Digital Assistant) technology linked to specimen databases increased efficiency and decreased transcription errors; and the major analytical advances with microCT scanning datasets of both rodents and marsupials demonstrated the discriminatory power of the true 3D fine resolution morphometrics.

HIGHLIGHTS

- MicroCT scanning technology has revolutionised the way vertebrate taxonomy is conducted in Australia by greatly accelerating the rate of morphometric and anatomical data collection for mammals, reptiles and frogs.
- Work on Bitou bush and Boneseed demonstrated ongoing and widespread hybridisation between these two weeds in Australia and provided a scientific basis for actions by weed managers to eradicate Bitou bush from Victoria.
- DNA barcoding has enabled association of adults and larvae for nearly 60 species of aquatic macroinvertebrates. Molecular studies have also highlighted the presence of numerous cryptic species and areas of endemism such as Tasmania and the high altitude areas of the Alps.
- Online insect family keys provide a unique and critical resource in identifying and understanding Australia's terrestrial invertebrate fauna. For the first time numerous web-based interactive Lucid keys have been integrated with information stored in Biolink.
- TRIN's invasive species methodologies and protocols and DNA barcodings have been applied to the delimitation of species, enabling rapid assessment of genetic variation and taxonomy in an orchid group containing endangered species. Previously this research would have taken years to complete.
- The field PDA application has streamlined the capture of geo-data in vertebrate field work and is being adapted for use across a range of organisms, platforms, operating systems, and data collection environments. This enhances the data management and availability of information associated with many biological collecting processes.
- Results of ants research are available on the Australian Ants Online website, establishing the site as a web atlas for the group. Students, researchers, ecologists, land managers and environmentalists can access images and information including the geographic distribution of species.
- The dung beetle genus *Lepanus* was selected as a benchmark invertebrate group for biodiversity modelling: information on distribution, taxonomy and phylogenetic relationships provides comparable datasets to those available for plants and vertebrates.



Tackling invasive weeds

The weeds research focussed on selected species complexes that are considered Weeds of National Significance (WONS) (e.g. lantana, willows). Molecular taxonomic, genetic and ecological approaches were integrated to provide an improved scientific understanding of the life history strategies, invasiveness characteristics and patterns of gene flow within and between recognised species and ecological races. This revealed major findings such as:

- sequence analyses recognised a number of Lantana species and showed that a single species model is likely to be more appropriate for weedy *Lantana camara* than the current hybrid swarm model. This is a paradigm shift in our understanding of the source of diversity of Lantana: greater phenotypic diversity than previously revealed
- reproductive studies found the average female Grey Sallow (*Salix cinerea*) willow plant produced 560,000 seed; averaging to just over 5 million seed produced per 100 metres of infested stream, and has major implications for control in riverine systems.

By coupling the power of high throughput molecular techniques to traditional morphometric taxonomy there has been a rapid change in understanding weeds such as Lantana. This led to the development of a general strategy for approaching control of key environmental weeds, and the methodology being applied to other weeds with an accelerated impact:

- bitou bush and boneseed – both subspecies of *Chrysanthemoides monilifera*
- mesquite – *Prosopis* species.

The weeds project maintained close and regular contact with end user communities to ensure rapid uptake. Collaborative manuscripts being prepared for publication place our research results in the context of biocontrol efforts and weed practitioners, and is likely to change the way people think about tackling key environmental weeds.

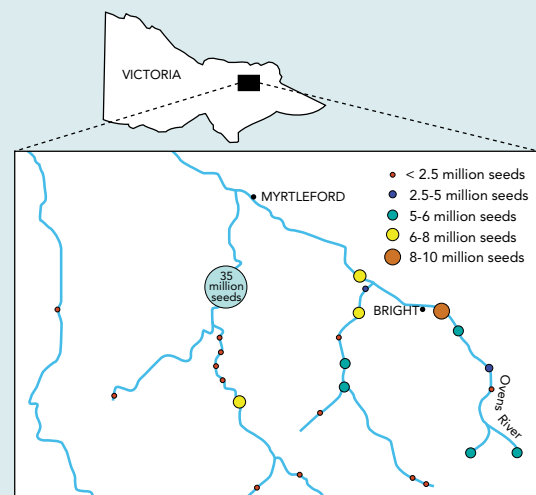
Wind in the Willows

Current control efforts for the highly invasive willow species, *Salix cinerea*, are extensive, costly and not always successful due to rapid post removal reinfestation. An improved knowledge of the reproductive and dispersal dynamics of this species will help to design control strategies that minimise future expansion and make current control efforts more effective.

To explicitly examine the reproductive ecology of this species in its invaded range field observations of population structure and reproductive output estimates were undertaken across the Ovens catchment in Victoria. Results found mean seed production is generally higher than 100,000 per tree and is highly variable with female reproductive fitness driven by tree size and flowering effort. Predictions of seed production at sites across the study catchment showed highly variable seed production across sites (see map) and found that management effort may be better spent removing the top 20% of seed producing sites which would result in a reduction in catchment seed set of over 50%.

Microsatellite-based paternity analysis of the invasive willow *Salix cinerea* was also undertaken at four sites to ascertain the variation of male reproductive fitness. Observed patterns of within-site mating dynamics have highlighted a highly skewed male fitness distribution with a small number of fathers being responsible for a large proportion of successful fertilisation events.

Taken together, these two sets of observations mean that future efforts to control invasive populations of *S. cinerea* should emphasise removal of large high fitness individuals within sites. This may be attained by first clearing high density sites that have the greatest reproductive output. Subsequently, targeting large trees at sparse and remote sites will have the greatest success in further reducing propagule pressure.



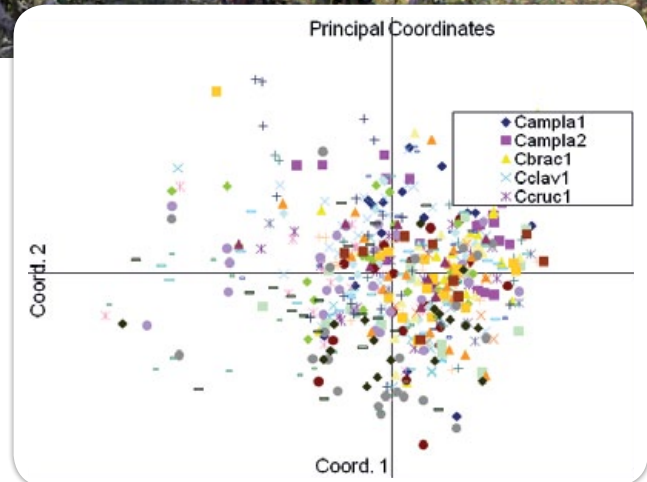


Rapid taxonomic assessment

Consideration of the conservation status of species requires information covering a range of variables relating to population status and biological characteristics, information that is often not available. Conservation agencies often request biologists and particularly taxonomists to comment on the taxonomic status of putatively threatened plant species, but in many cases there is little data to assess the claims. Thus, decisions are sometimes taken at both federal and state levels about the listing of endangered species with inadequate or no scientific data to support species definitions.

We used molecular methodologies and protocols developed in other TRIN projects to test applicability for rapid assessment of the species status of some closely related orchids that are potentially rare or threatened, in order to inform agencies responsible for legislative decisions.

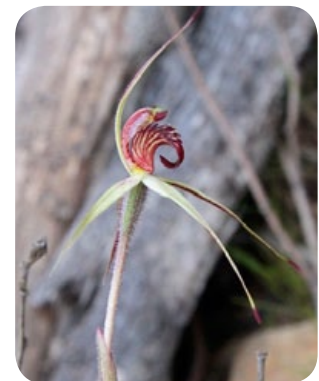
The population genetics research, sampling over 30 populations representing 14 putative Spider Orchid taxa from NSW, Victoria and SA, demonstrates high levels of genetic diversity within these populations and greater than that between populations; there is also evidence of historic gene flow between populations. Levels of population differentiation were lower than expected particularly among populations which are morphologically different and/or reproductively isolated through geography and flowering times. In addition, there is evidence of pollinator specialisation by male wasps in some species within the *Caladenia reticulata* complex. This means that some taxa within the complex have a different wasp species as a pollinator and that gene flow among these orchids is unlikely.



Principal Coordinates Analysis scatterplot of the genetic data of individual orchid plants. There are no clusters of plants from a single species or from a single population.

[hover over image to enlarge]

It is suggested that this species complex is currently undergoing speciation with plant pheromone mimicry driving the pollinator specialisation; genetic differences to accurately distinguish between putative taxa are yet to be detectable. Ambiguous species boundaries reflect the complex nature of plant evolution, yet remain difficult to translate into the conservation decision making process. Given the conservation status of each putative taxon, it is recommended that each population is conserved as a cautionary approach and pollinator specificity trials be undertaken to further address species delimitation hypotheses and complement the genetics data generated by this study



Spider Orchids from sampled populations:
Caladenia brachyscapa, *Caladenia fitzgeraldii* and *Caladenia reticulata*.



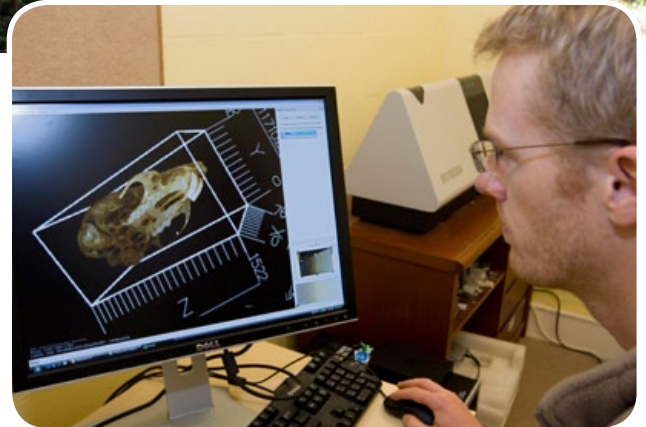
Digital repatriation

Acquisition of microCT scanner equipment revolutionised morphological research on small vertebrates. This technology was extended to the largest and most significant collection of small mammal type specimens from Australia, housed at the Natural History Museum in London.

The collection includes the only specimens in the world for several species that are now extinct. It is a major undertaking for Australian researchers to visit the collection, restricting capacity for our taxonomic work. Molecular taxonomy now drives a rapid process of taxonomic re-assessment. Linking type specimens into such studies remains a key, but problematic, step in the taxonomic process, and gaining DNA from type specimens remains problematic in both sampling a specimen and successfully sequencing it.

TRIN established a digital type collection to overcome the logistical constraints of physical access to type specimens. 3D 'specimens' will become increasingly important in taxonomic studies as they allow non-invasive access to internal characters and use of sophisticated and previously unviable analytical methods. They also form an important curatorial asset, minimising the handling of specimens, and providing security against future damage or loss of specimens.

The value of digital collections is particularly evident for type specimens. Many types are old and fragile, often representing extinct populations that can no longer be assayed for taxonomic purposes. The current state of type specimens can be preserved against inevitable degradation, while the need for future physical handling of the specimen is minimised, further reducing exposure to degrading processes.



3D digital image of the skull of a delicate mouse (*Pseudomys delicatulus*) generated by computed tomography of a microCT scan.



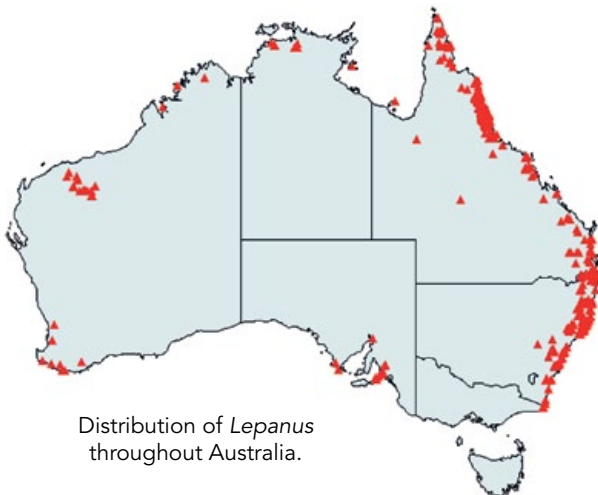
3D Micro-CT scan of hopping mouse skull from extinct *Pilliga* population.

Unlike physical specimens, digital type specimens can be loaned, providing easy global access to these important taxonomic references. MicroCT technology is currently the most comprehensive collection medium for bone elements, capturing the entire internal and external structure as x-ray attenuation values in 3D point space. This data is then convertible into surface meshes or rendered volumes for analysis or illustration and is extremely accurate.

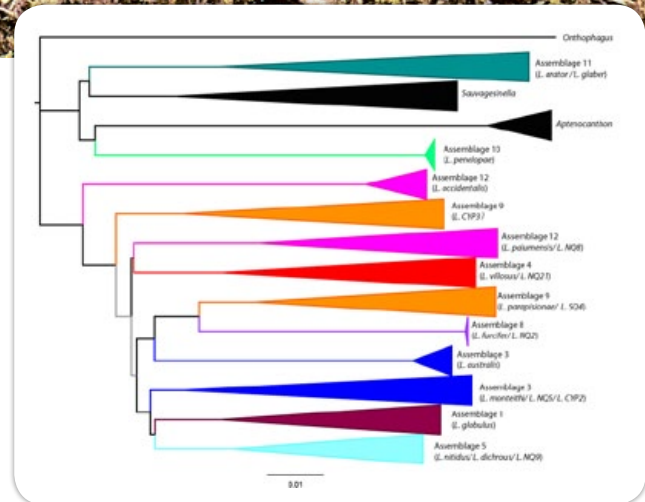


Benchmarking insects

Biodiversity modelling methods are increasingly incorporating phylogenetic as well as species distribution data to increase their effectiveness. The idea is that the evolutionary depth or 'phylogenetic diversity' of species present at a location is more meaningful than raw species counts which treat all species as equals in determining the diversity present at a site. Developing and testing methods for measuring phylogenetic diversity depend on the existence of benchmark groups for which the taxonomy, phylogenetic relationships and distributional databases are complete. Few groups of Australian organisms are so well known and at present no invertebrate examples are available. The dung beetle genus *Lepanus* (Coleoptera: Scarabaeidae) consists of 24 described species and many undescribed species divided into 12 species-groups on the basis of shared morphological features. Distributed throughout most of non-arid mainland Australia and with its highest species diversity in the montane Queensland wet tropics, *Lepanus* is an ideal benchmark group for biodiversity modelling.



Distribution of *Lepanus* throughout Australia.



Initial phylogenetic tree of *Lepanus* (based on genes: CO1, 16S and 28S).
[hover over image to enlarge]

TRIN increased the database records for *Lepanus* adding 4,760 specimens from ANIC, greatly expanding the geographic extent of our knowledge, and bringing the total number of database records available in all collections to 18,000. Taxonomic studies increased the number of putative species within the genus from 24 described species to 84 recognised (described and obviously distinct undescribed species) characterised largely on the basis of variability in the last abdominal segment and foretibia. The initial phylogeny of the group shows the species-group concepts are largely correct, 10 of 12 are monophyletic. Two of the assemblages, 10 and 11, proved not to be members of *Lepanus* and are more closely related to other dung-beetle genera *Aptenocanthon* and *Sauvagesinella*.

While the taxonomic and phylogenetic work is ongoing, each reinforces the other allowing for quicker progression of systematic knowledge within *Lepanus* than would be possible if either were conducted in isolation. Also while we have yet to integrate all the data collected in this study, comparing the geographic range of each species-assemblage against their phylogenetic relatedness shows that each assemblage is widely distributed and the beetles found at many localities include species from multiple assemblages. Thus the phylogenetic diversity at each site is higher than expected from raw species counts alone.

3. Novel tools for the taxonomy trade



TRIN's information and delivery framework builds on and links to existing national and international resources and databases in order to manage and distribute the knowledge using new, effective web-based platforms. The framework uses national and international biodiversity information standards and initiatives through an open architecture that ensures efficient exchange and sharing of data between systems.

By developing and employing the most up-to-date standards, protocols and conventions, biological data has been deposited in persistent data stores and is available through portals such as the Australian Biodiversity Information Facility, Australia's Virtual Herbarium, the On-line Zoological Collections of Australian Museums, GENBANK, the Consortium for the Barcode of Life, the Global Biodiversity Information Facility, the Australian Plant Pest Database. These ways of doing business improve taxonomic throughput, remove duplicated effort and ensure database interoperability and reusability of data and information.

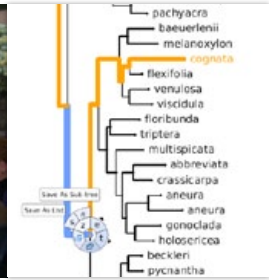
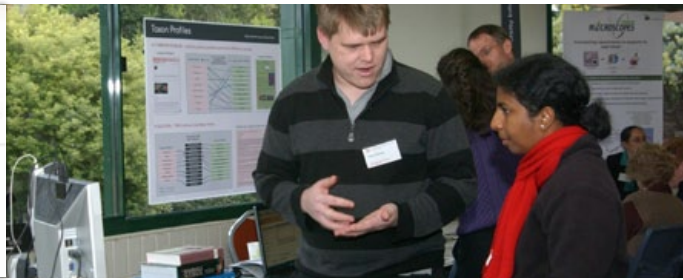
Work was also conducted to produce more comprehensive and flexible tools for data discovery, retrieval, reporting and display. This led to the development of the taxonomic framework in which researchers can deliver their research directly to the web, as well as electronic products such as online systems for biodiversity identification and discovery, including expediting access to existing taxonomic products, tools and information.

TRIN's biodiversity informatics team developed a close working relationship with the Atlas of Living Australia (ALA) - in some projects sharing tasks and expertise and in others undertaking complementary activities.

HIGHLIGHTS

- The *Taxon Profile Toolkit* presents new ways to deliver and compile taxonomic information using a streamlined system for semantically enabled structured documents.
- Information and images from aquatic macroinvertebrates and the insect family keys are exposed on the web through Biolink, making them accessible to other web-based biodiversity outreach projects, e.g. Atlas of Living Australia.
- A web-deliverable database for sub-fossil bone assemblages has been designed.
- The TRIN wiki provides a platform for the delivery and compilation of information from different sources at varying levels of protection, giving all users access to the tool's features and function.
- The integration of PDA field application data with collection management databases ensures accuracy and accelerates the rate of entry of taxonomic data into these databases, making it readily available to users.
- *TRINpin* – A patent application for very small light-activated transponders ('p-Chips') integrated into heads of entomological pins. This technology will facilitate innovation in curation practices.
- The *Linked Lab Book* is a research tool for taxonomy and systematics, for managing molecular as well as other descriptive data. It is streamlined, collaborative, structured yet flexible, online, integrated with other biodiversity data sources, and grounded in voucher specimens – ensuring retention of relevant results.
- The *Wiki-PhyloWidget* is a tool for exploring biodiversity information online from a phylogenetic point of view. Collaborative in nature, able to visualize alternative phylogenies, it can compile the characteristics of a clade from the linked lab book or other biodiversity data sources. Thus new keys can be built from old. Information collected in an earlier context can live once more.





What a Wiki did for taxonomy

Since its launch, the TRIN collaboration platform (<http://trin.org.au>) has been a compelling resource for accumulation of structured information as well as shared communication.

According to TRIN web-tools researcher and developer, Paul Harvey, the Wiki “has been shaped and built as scientists do their work. It is designed for collaboration”. This has led to a real strength in flexibility – individual taxonomists, research groups, and research societies have used the web tools and contributed to their design. Development has been in response to the specific needs identified for taxonomy and systematics. Researchers are able to ‘think aloud’ online, where information is structured as it is compiled.

Access to information on the Wiki may be finely controlled; i.e. as restricted or as open as required. The benefits of online collaboration include the ability to identify changes per-user (version control) and annotation.

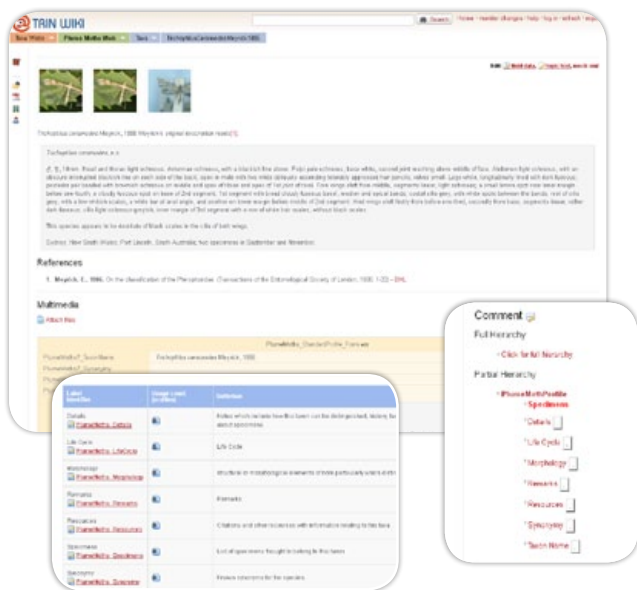
Additional capabilities have been added so that taxonomists and biodiversity researchers will be able to clearly and comprehensively document their taxa. Taxonomists may use their own terminology in structures that they define for themselves – but in a way that captures sufficient detail to later map everything against standard terms and structures which can then be exported to third-party databases, software packages and web services.

“The idea was that we didn’t want researchers to be exposed to daunting, rigid and bureaucratic database tools that took some wrangling to meet individual needs. We think we’re on the right track to making it easy enough for anybody to be able to build exactly what they want and start entering new taxa with minimal training”.

An example of this is the Plume Moths profiles at <http://trin.org.au/PlumeMoths/TaxonCreator>. The fields and their presentation are defined by taxonomists as they document their data. Current projects are drawn from entomology, marine invertebrates and vascular plants. As they progress, we will be able to take advantage of growing capabilities for search, commenting, linking and multimedia.

This rigorous online collaborative tool for taxonomy makes a disparate, fragmented discipline more effective. The TRIN web tools provide compelling solutions for taxonomists to be more productive, engage in online collaboration and produce richer information that can be re-used for many varied purposes.

Apart from the TRIN projects, a steady stream of taxonomic communities beyond the TRIN network are engaged with the site; as varied as Thysanoptera (thrips), Australian Herbarium Curators, Marine Invertebrates, Australian Systematic Botany Society, Xyloryctidae (moths) and Wattles.



Plume Moths profiles generated through the wiki.
[hover over images to enlarge]

4. Granting wishes – responding to the user



It was an early-held view by TRIN that taxonomy information must be provided to users in a way that can inform decision making. That is, taxonomy information needs to be translated from knowledge into practice. This meant that developers of taxonomy products had to assume responsibility for not only the scientific content but also the usability of their products.

As part of its information management activity and to ensure end user adoption, TRIN engaged a knowledge broker to facilitate promotion, awareness and adoption of the taxonomic results, outputs and products of the hub.

Knowledge exchange strategies designed to achieve greater engagement and end user penetration involved a number of universities across the country, and workshops with universities and community groups led to a higher adoption of TRIN's products and outcomes.

The Knowledge Exchange project actively engaged with the user community to elicit their needs and priorities, and to explore impediments to adoption of research results. Responding to user feedback and requirements helps to ensure accuracy of information and will usually enrich an identification key with higher success rate and enable more informed decision making.

Every effort has been made to publish and release information online, making it freely available. In addition, much of the research resulting from TRIN investigations is published in internationally recognised scientific journals, including electronic journals where appropriate.

HIGHLIGHTS

- The user community provided detailed feedback on the usability and effectiveness of the TRIN online identification tools through the product-testing workshops.
- For instance, users of the ant genus *Iridomyrmex* key identified the need for additional illustrations to clarify the meaning of selected characters used in the key. As a result, approximately 40 line drawings were prepared.
- The insect family keys website includes features that improve accessibility for non-standard browsers and assists disabled users who may be blind or visually impaired.
- Development of PDA technology for vertebrate field collecting data and incorporation into specimen databases generated interest from stakeholders for greater diversity of applications.
- In some cases accurate species lists are required by stakeholders – a full list of the previously almost unknown natural small mammal fauna of the ACT was provided to the Species Management Panel, Mulligan's Flat Woodlands Sanctuary to assist in reintroduction programs.
- Development of strategies to manage environmental weeds were generated through close collaboration between the TRIN weeds team and WONS liaison officers, so that outcomes from one study could be directly applied to other weeds issues.

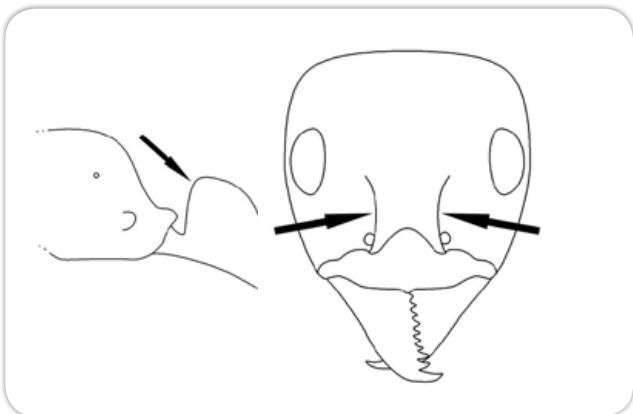


No stone left unturned

The translation of TRIN's taxonomy information and products into practice was facilitated through the expertise of a knowledge broker.

Research efforts focussed on gaining a superior understanding of the end users of taxonomy research by exploring what information end users utilise, how they apply it and what tasks they do. The factors that facilitate or impede the practical application of taxonomy knowledge were taken into account, and this information was used to try and better fulfil the needs of end users.

The knowledge broker facilitated a range of activities that brought together researchers and end users. These activities stimulated new connections, built relationships and networks, shared ideas and uncovered user needs. They encompassed a range of users and taxonomic groups (insects, plants, vertebrates, etc) and elicited an appreciation of the generic issues of what works, what doesn't work and why.



Line drawings prepared for the *Iridomyrmex* key as a result of user feedback from product-testing workshops.



Northern Australia product testing workshop for The Rodent Key.

The next step was a series of testing and feedback workshops that aimed to build the capacity of generators of taxonomy knowledge to communicate their science. The facilitation methods used in these workshops were evaluated from both the product developer and end user perspective to ensure that all participants were benefiting from the activity. The product developers were able to see first hand if their product worked for the user and was given different perspectives from the range of users participating in the workshops. The end users reported that working collaboratively with other users as well as with experts was valuable as was the hands-on experience with the particular product, and learning more about taxonomy generally.

The workshop method was well received by both product developers and product users with the approach being documented step by step. Practical guidelines and realistic examples are being encapsulated in an online toolkit for testing taxonomy products as a legacy of the knowledge brokering experience to taxonomy.

The lessons learned from knowledge brokering in TRIN are being developed as practical recommendations to aid generators of taxonomy knowledge in fulfilling users' information needs.



Tried and tested

The move to web-based taxonomy and information delivery is essential to achieve the goal of describing the living components of Australian biodiversity in a timely manner. Web access to comprehensive and authoritative information such as identification tools and information systems is now a universal expectation among users and stakeholders.

TRIN's development and compilation of extensively illustrated online identification keys was specifically conducted with the user in mind. Identification packages either generated directly by TRIN or served through its portals provide essential basic underpinning information for managing Australia's system of parks, reserves and other significant ecological assets. The provision of these freely accessible, convenient, appropriate, reliable and ready to use identification keys enables the broader adoption and application of scientific knowledge.

TRIN's testing and feedback workshops were well received by a variety of stakeholders and university undergraduate students. As a result, all identification keys developed by TRIN were assessed through a rigorous development and iteration process.



[hover over image to enlarge]

TRIN has developed a diversity of identification keys and tools:

Australian Ants Online

Provides details on their biology, identification and distribution, along with an introduction to the published literature.

Key to Mangrove Plant Species of Australia

Interactive key to obligate trees, shrubs, palms and terrestrial ferns.

What Bug Is That?

This site provides identification keys and information to the 600+ insect families of Australia. The keys to insect families are integrated on a single site greatly facilitating access to and use of identification keys to understand more about Australia's insect biodiversity.

Rodents of Australia

This interactive identification key includes 95 species (18 genera) of Australian rodents.

Larvae of the Australian Baetidae

An interactive identification key for 6 genera of Baetidae with sub-keys to species level.

Key to the Genera of Adult Mayflies of Australia

An interactive identification key for 45 genera.

Dichotomous identification keys:

Key to genera of larvae of Australian Chironomidae (Diptera) – 90 taxa

Key to the mature nymphs of *Coloburiscoides* (Lestage) (Ephemeroptera: Coloburiscidae) – 6 species

Tools for identifying selected Australian aquatic oligochaetes (Clitellata: Annelida) – 6 families (365 species)

Identification of the larvae of Australian Baetidae – 57 species

Draft identification key to Families of Diptera larvae of Australian inland waters – 29 families

A key to the Australian Genera of mayfly nymphs of the Family Leptophlebiidae (Ephemeroptera) – 23 genera

Identification guide to the brine shrimps (Crustacea: Anostraca: Artemiina) of Australia – 21 species

Preliminary key to the larvae of *Riekoperla* (Plecoptera: Gripopterygidae) – 24 species

TRIN has also assisted in the web delivery of existing keys:

Australian Tropical Rainforest Plants

Edition 6: Trees, shrubs, vines, herbs, grasses, sedges, palms, pandans and epiphytes, includes 2553 species in 175 families and has over 11,000 images.

Australian Tropical Rainforest Orchids

This key incorporates all species currently recognised (c. 224 species) in northern Australia, and is the orchid module of *Australian Tropical Rainforest Plants*.

The Pea Key

An interactive identification key for the 1500 species of Australian Pea-flowered Legumes.



Mobile data capture

PDA technology was initially tailored for field and lab application for vertebrate data collection in which information was transferred directly from field to the specimen collection database – a particularly useful enhancement. It has also been demonstrated to be effective for a variety of other scientific data management purposes.

Record type	# records
Bird observations	4,594
Bird Tracking	c. 7,721
Native plant surveys	1,908
Pasture plots	2,679
Pasture transects	11,470
Vegetation condition assessments	714
Total records	29,086

The data forms have proven easy to use and can be tailored to suit the preferences of users. Most importantly, they facilitate the particular functionality necessary for any mobile data system to be acceptable for effective electronic data capture, with crucial features to:

- minimise error
- secure the data in generic text format, and
- facilitate the delivery of data to databases.

However, the initial technology applications developed during TRIN are subject to some constraints, including being restricted to Windows Mobile platforms, the software used is not free or open source and it is rather clumsy and painful to use with text-rich information.

Next steps

In collaboration with the ALA and Gaia Resources we are now extending the mobile data capture PDA application to generalise the platforms on which it performs and the biological domains in which it can be applied. Providing a system that can perform on other mobile devices such as iPhones, iPads and android phones, and accommodating other organisms such as insects and plants, will greatly influence biological collecting processes well beyond TRIN and will enhance data management and availability of information.

The project involves adapting Gaia Resources HTML5 citizen science software to taxonomic collection data, with specific requirements:

- free and open source
- Darwin Core specimen data structure
- minimise entry error
- maximise data security
- facilitate delivery into collection databases
- able to operate on a diverse range of mobile platforms
- particularly those which are better adapted for text-rich input.

The system and HTML5 forms require:

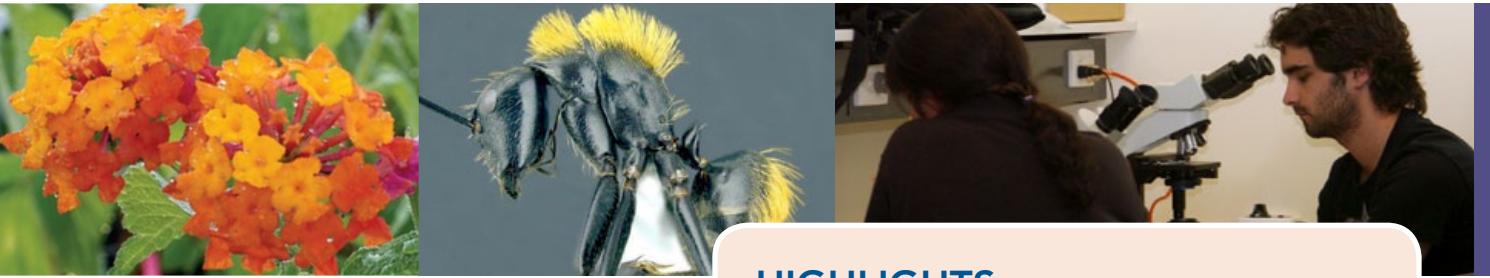
- data structure and entry constraints predefined via a web portal
- the resulting form can be downloaded to multiple mobile devices and used to record data – either
 - online – where there is mobile broadband access, records immediately synced to the server database
 - offline – records written to the device extendable memory (e.g. SD card) and synced up to the database when back online.
- data to be available in csv format for ease of import.

The project involves testing and adaptation of the system for

- ANWC – Parrot surveys
- ANIC – Insect light traps
- ANH – Living Collections in ANBG and alpine collecting surveys
- ABRS Bush Blitz – Various organisms and survey types.

iPad screen for data input.
[hover over image to enlarge]

5. Handing down a legacy



TRIN's enhanced knowledge and delivery framework provides a legacy of accelerated taxonomic research throughput and delivery into the future. TRIN also invested in the 'next generation' of Australia's taxonomists by providing PhD students and early career researchers with the technology, skills and capacity to increase the collective pool of biodiversity information required to meet Australia's mounting environmental and industry needs.

TRIN established multi-institutional, multidisciplinary national collaborations that strengthened the link between National, State and Territory institutions and reinforced strong collaborative arrangements with 8 Australian Universities, 5 State Museums, all State and Territory Herbaria, at least 10 additional State agencies and one international university. This brought a cross fertilisation of ideas and experiences, and the sharing of data, and analytical and delivery methods, helping to develop a national program of integrated research that will continue beyond TRIN's term.

Outcomes of the Knowledge Exchange project on community needs and priorities will inform the Australian taxonomic community for the future. The various tools developed, particularly through molecular systematics research and biodiversity informatics applications, are expected to provide universally applicable and efficient methods for taxonomy into the future.

HIGHLIGHTS

- TRIN has demonstrated real-world advantages of implementing best-practice in taxonomic research projects, and provided tangible evidence of the advantages of such practices.
- Tools developed through the weeds project provide universally applicable and rapid methods for genetic profiling of other weeds with complex introduction histories.
- The Australian Mangrove and Saltmarsh species project framework for data format and delivery provides an exemplar for other ecosystems.
- Globally applicable protocols for choosing appropriate species for small terrestrial mammal reintroductions are available.
- TRIN's collaboration with academic staff of several Australian universities ensures that new approaches will permeate effectively into the training of the next generation of molecular systematists and taxonomists.
- The TRIN wiki remains as a legacy product providing a sustainable collaborative networking framework beyond the life of TRIN.
- The 3D digital type collection of small vertebrates represents a significant legacy; a collection of Australian type material in Australia, forming a significant component of our biological heritage.
- The TRIN Genetic Diversity Summit recognised the importance of incorporating genetic diversity information into conservation planning and for the information to be available in a form interpretable by policy and decision-makers.
- The training of Early Career Researchers has improved Australia's capability in the field of taxonomy by broadening the base of researchers to disseminate and apply acquired skills in modern taxonomic methods nationally and internationally.
- The body of work conducted by the Knowledge Exchange project will inform the taxonomic community about user community needs and priorities and how to address these needs when developing taxonomic information products.
- The *TRINpin* patent has potential to greatly improve handling efficiency of entomological collections world-wide.



Spreading the word

In 2010, TRIN hosted two Interactive Field Days in Canberra and Cairns. The Field Days provided participants with the opportunity to interact with TRIN researchers and developers and to become familiar with a range of products and applications. A series of exhibits and small presentations included:

- identification keys for mangrove plants, insect families, mayflies, ants, rodents, eucalypts, rainforest plants and orchids
- management protocols for weeds and small vertebrates
- sub-fossil bones and microCT scanner technology
- remote microscopy demonstrations online to other laboratory locations
- a Wiki corner
- the PDA technology applications for field data collection
- other resources and applications that support biodiversity management, such as the Atlas of Living Australia, Australian Plant Name Index and Australian Plant Census.



Field Day participant navigating through *What Bug is That?* – an online resource for insects of Australia.



Field Day participants identifying live material using an identification key for eucalypts.

The Field Day in Canberra attracted a large contingent of participants from the policy and governance arena. They were impressed with the work achieved through the TRIN research program and appreciated the 'hands-on' experience with the various products.

More than 70 people attended the Field Day in Cairns representing a range of organisations and disciplines with a strong focus on practitioners from national parks, land management agencies and restoration groups to school and tertiary educators. The Cairns audience reported that the two-way communication format enabled increased awareness of available tools and where they can be found; and resulted in some researchers securing future collaboration and assistance for their work in Northern Australia.

Following both events, the booth holders and presenters expressed the importance of being able to show and discuss the products and research 'face to face' with enthusiastic participants.



Hot topic

The Genetic Diversity Summit brought together Australia's leading geneticists, biodiversity scientists and policy developers to explore the key elements for a more systematic approach to conserving Australia's genetic diversity. It also brought this issue more sharply into focus in the context of policy directions that are increasingly adopting whole of landscape and multiple species approaches to conservation.

The vision developed during the summit is to:

- improve the resilience of biodiversity through meaningful and explicit incorporation of evolutionary processes and genetic diversity into conservation policy and practice, and
- establish world leadership in science-based conservation policy by:
 - developing and incorporating explicit and verifiable targets pertaining to genetic diversity relevant to threatened species management and to ecosystem-scale and bioregional planning, and
 - utilising cutting-edge technologies in genomics, phenomics, phylogenetics, spatial modelling and information sciences.

Key outcomes identified are

- i. increased effectiveness of conservation actions, and
- ii. improved quality and accessibility of scientific knowledge for conservation practitioners and policy-makers.

A discussion paper summarising the outcomes of the summit and providing recommendations on how to incorporate genetic information into decision making and planning is being prepared and will be available for general comment mid-2011.

Capacity building

One of TRIN's key functions relates to capacity building through public awareness, training opportunities, growth of collaborative clusters and community engagement to enhance Australian taxonomic capacity and understanding of the Australian biota.

The reach of the network across the country and the range of tools and outcomes resulting from TRIN activities has alerted the taxonomic community of ways and opportunities to increase our taxonomic capacity. Taxonomy, systematics and diversity have a higher profile in government, both state and federal.

Collaborations have been productive with integrated research teams working across institutions and through close engagement with infrastructure initiatives such as the Atlas of Living Australia. Relationships have developed between taxonomy workers and policy makers in areas such as the reintroduction of mammals and weed biocontrol methods.

CERF resources enabled some projects to expand investigations by leveraging further support from other sources for research or equipment.

While this issue outlines many specific examples of scientific achievements from the teams supported by TRIN, there have also been an impressive array of intangible benefits arising from the various activities and collaborations.

TRIN benefited greatly from the extensive input over many years to the development of Australia's biological collections and their associated online, accessible databases. The sophisticated nature of the databases and high quality information of the collections meant ready access to not only taxonomic information, but also around geographic and ecological distribution and diversity patterns. Several projects involved databasing further specimens and enhancing the collections through taxonomic updating.

Equipped for the future

TRIN has played a significant role in the development of early career researchers and biodiversity informaticians.

For instance, two post graduates trained in ant taxonomy ensures increased capability for this diverse group of invertebrates. Research on the large world-wide ant genus *Camponotus* provides a clearer understanding of relationships and guidance for future work at species level.

When the Department of Environmental Management and Ecology group of La Trobe University's Albury-Wodonga Campus became involved with TRIN in 2007 no taxonomy researchers or graduate students were part of the group. In the 2011 academic year the aquatic macroinvertebrate group supports three post-graduate students and two honours students continuing taxonomic research directly as an outcome from the TRIN project.

While the CERF funded Taxonomy Research & Information Network (TRIN) hub has now formally ended, its many products and substantial outcomes continue to have an influence on taxonomy, and provide information for environmental benefit to Australia.

Throughout the term of TRIN, the Steering Committee was particularly insightful. The diversity and expertise of its members provided helpful direction and advice, contributing to the success of the network as a whole.

The Management Team were those responsible for the day to day function of the network and management of the program and its varied projects. They responded to many challenges along the way and helped keep the research activities on track.

Dr Judy West - TRIN Principal Researcher



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An Australian Government Initiative

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