USES OF PRIMARY SPECIES-OCCURRENCE DATA

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Abstract:

This paper examines uses for primary species-occurrence data in research, education and in other areas of human endeavour, and provides examples from the literature of many of these uses. The paper examines not only data from labels, or from observational notes, but the data inherent in museum and herbarium collections themselves, which are long-term storage receptacles of information and data that are still largely untouched. Projects include the study of the species and their distributions through both time and space, their use for education, both formal and public, for conservation and scientific research, use in medicine and forensic studies, in natural resource management and climate change, in art, history and recreation, and for social and political use. Uses are many and varied and may well form the basis of much of what we do as people every day.

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This paper was commissioned from Arthur Chapman in 2004 by the GBIF DIGIT programme to highlight the importance of data quality as it relates to primary species occurrence data. Our understanding of these issues and the tools available for facilitating error checking and cleaning is rapidly evolving. As a result we see this paper as an interim discussion of the topics as they stood in 2004. Therefore, we expect there will be future versions of this document and would appreciate the data provider and user communities' input.

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Introduction

Plant and animal specimen data held in museums and herbaria, survey data and species observational data provide a vast information resource, providing not only present day information on the locations of these entities, but also historic information going back several hundred years (Chapman and Busby 1994). It is estimated that there are approximately 2.5-3 billion collections worldwide in museums, herbaria and other collection institutions (Duckworth *et al.* 1993, OECD 1999). In addition there are untold numbers of observational data records. Projects to digitise this information are underway in many institutions, with others at either the discussion or planning stage.

A key purpose of digital information in the biological sciences is to provide users of information with a cost-effective method of querying and analysing that information. The biological world is infinitely complex and must be generalised, approximated and abstracted in order to be represented and understood (Goodchild *et al.* 1991). Ways of presenting biodiversity information to users is through the use of geographic information systems, environmental modelling tools, decision support systems, books, cds, images and on-line databases, specimens and their parts, DNA reports, etc. Within these tools, however, it is essential that variation be sampled and measured, and error and uncertainty be described and visualised. It is in this area that we still have a long way to go (Goodchild *et al.* 1991).

The uses of primary species-occurrence data are wide and varied and encompase virtually every aspect of human endeavour – food, shelter and recreation; art and history, society, science and politics. The examples shown in this paper emphasizes the importance of having museum specimen data digitized and made available to the wider user community. In this way, the collections will be made even more valuable than they already are, and provide new opportunities for funding and collaboration through their increased relevance and value to a much larger audience. With dwindling resources being made available for the biological sciences, funding bodies are beginning to ask the relevance of many natural history collections, and it is becoming increasingly more difficult to obtain funds for collection maintenance. By making information available to the broader scientific community for use in conservation and the many other areas of study covered in this paper, institutions will have a much more robust and sustainable argument for continued funding. In addition, it will rapidly add to the world's knowledge of biodiversity and ecological systems and aid in its future conservation and sustainable use and management.

The increased availability of data on species is opening up new and improved methods of dealing with these issues. The information in museums is a storehouse going back hundreds of years, and the new availability of that storehouse in on-line databases is improving science, reducing costs by providing for more efficient and effective biological survey, freeing up scientists to spend more time on research, and leading to a more rapid build-up of knowledge of our environments leading to its improved conservation and sustainable use.

Taxonomic research is benefiting through the availability of images of specimens, including types, data on the location of specimens in other museums, etc. But perhaps the greatest benefit of the availability of distributed data is the study of the biogeography of species – their location in time and space. "By reducing the costs of studying vectors of human disease, biological invasions, and global climate change, biological collections provide direct financial and social benefits to society" (Suarez and Tsutsui 2004).

One of the things that will come out of a study of uses of species-occurrence data is the opening up new requirements for recording information as part of future collecting events (Chapman 2005b). This may even include a greater use of digital images (Basset *et al.* 2000), and video. But along with all the positives of electronic data exchange, there is a tendency to divorce the data from the objects, and it is important that those outside the museum community recognise that the objects themselves remain important long-term repositories and sources of data that have yet be captured and developed (Winker 2004). Ultimately, maintaining and developing the infrastructure of biodiversity collections will produce unforeseen benefits (Suarez and Tsutsui 2004). Those benefits to society will be multiplied through the ready availability of the information to those that need to use them.

But primary species-occurrence data are not just the data held in museums and herbaria. There is a massive amount of observational and survey data held in universities, by non-governmental organisations and by private individuals and these data add valuable additional knowledge on our environment. They are not competing data resources but complementary and each have their strengths and weaknesses in supplying the information the world needs.

Some question the value of digitised museum specimen data for use in biogeographic and other studies because much of the data are “outdated and unreliable”, with many records misidentified or badly geo-referenced (Wheeler *et al.* 2004). That may be true for many records, but, as shown in this paper, there are many other records that are not so unreliable, and that are being used by researchers and others with great success. The museum community is aware of the problems inherent in their data and are making concerted attempts to improve the quality of those data (Chapman 2005a), and as stated by Edwards (2004), “one of the best ways to expose those errors is to make the data visible, so that qualified researchers can compare and correct them”. All data have errors, but that should not be a reason not to use the data, but to ensure that the error is documented and that users are made aware of the errors so that they may determine the fitness for use of the data (Chapman 2005b).

There are many uses for primary species data. Traditionally, collections in museums and herbaria were only made with one main purpose in mind – that of taxonomic study. Their long-term mission, however, is to document biodiversity and its distribution through time and space for research and education (Winker 2004) and to serve the public. The introduction of computer processing and computer databases have opened up this vast data store to many new uses (Chapman 1999). These uses include biogeographic studies (Longmore 1986, Peterson *et al.* 1998), conservation planning (Faith *et al.* 2001), reserve selection (Margules and Pressey 2000), development of environmental regionalisations (Thackway and Cresswell 1995), climate change studies (Chapman and Milne 1998, Pouliquen and Newman 1999, Peterson *et al.* 2002a), agriculture, forestry and fishery production (Booth 1996, Nicholls 1997, Cunningham *et al.* 2001), species translocation studies (Panetta and Mitchell 1991, Soberón *et al.* 2000, Peterson and Veiglas 2001), etc., etc. These and other uses will be elaborated further in this document. Many of these studies have used environmental modelling using software such as BIOCLIM (Nix 1986, Busby 1991), GARP (Stockwell and Peters 1999, Pereira 2002) or methods such as Generalised Linear Models (GLM) (Austin 2002). Most of these species distribution models rely on specimen or observation records, generally of a presence-only nature (usually including records from herbaria or museums as well as observation data) or occasionally presence-absence data from systematic surveys.

Much of the data (both museum and observational) have been collected opportunistically rather than systematically (Chapman 1999, Williams *et al.* 2002) and this can result in large spatial biases – for example, collections that are highly correlated with road or river networks (Margules and Redhead 1995, Chapman 1999, Peterson *et al.* 2002, Lampe and Riede 2002). Museum and herbarium data and most observational data, generally only supply information on the presence of the entity at a particular time and says nothing about absences in any other place or time (Peterson *et al.* 1998). This restricts their use in some environmental models, but they remain the largest and most complete database of biological information over the last 200+ years we are ever likely to have. The cost of replacing these data with new surveys would be prohibitive. It is not unusual for a single survey to exceed $1 million to conduct (Burbidge 1991). Further, because of their collection over time, they provide irreplaceable baseline data about biological diversity during a time when humans have had tremendous impact on such diversity. They are an essential resource in any effort to conserve the environment, as they provide the only fully documented record of the occurrence of species in areas that may have undergone habitat change due to clearing for agriculture, urbanization, climate change, or been modified in some other way (Chapman 1999).

But primary species data do not stop with just the information on the label, as there is information contained within the collections themselves and this may be used for tissue sampling, chemical analysis of contaminants, forensic information held in the DNA of individual specimens, etc. Living culture collections of micro-organisms that cannot otherwise be preserved, images and even video of individual birds and animals in the field, of preserved specimens in museums, or micrographs of parts, and even drawn illustrations – some done before photography was invented – must also be regarded as an integral part of the species-occurrence data record.

Data interchange and distributed data

As early as 1974, discussions on developing standards for electronic exchange of primary specimen data between museums and herbaria were taking place. Although the Internet was restricted to users in a limited research community and not generally available to biodiversity institutions (Kristula 2001), and exchange via media such as floppy disks, and magnetic tape was occurring around the world, no standards for doing so existed. As a result of these discussions, a standard for the interchange of biotaxonomic information was developed in Australia in 1979 (Busby 1979). Later, the Australian herbaria got together and extended this standard for use by botanical institutions and the HISPID (Herbarium Information Standards for the Interchange of Data) standard was developed (Croft 1989, Conn 1996, 2000). Although very few institutions used these standards for interchange, many used them as a template for designing their databases. The HISPID standard was later adopted as a TDWG (Taxonomic Databases Working Group) standard.

The development of the Internet, and especially the World Wide Web (Berners-Lee 1999), allowed new opportunities for the interchange of data. Although the Environmental Resources Information Network (ERIN) used distributed data for modelling on the Internet as early as 1994 (Boston and Stockwell 1995), there were few other successful electronic data interchange projects that utilised the internet until the Species Analyst (Vieglas 1999, 2003a) project began the late 1990s.

Since then, a number of distributed projects have begun, including the Red Mundial de Información sobre Biodiversidad (REMIB) –The World Network on Biodiversity (CONABIO 2002), Australian Virtual Herbarium (CHAH 2002), *species*Link (CRIA 2002), European Natural History Specimen Information Network (ENHSIN) (Güntsch 2004), Biological Collection Access Service for Europe (BioCASE 2003), the Mammal Networked Information System (MaNIS 2001), and the GBIF Portal (GBIF 2004). These systems use on-line information retrieval to search databases maintained in the home institutions, extracting data in a way similar to what Google does for web resources. Early versions of these relied on the information retrieval standard developed primarily for library use – Z39.50 (NISO 2002), but more recently the museums community have combined to develop new standards, the Darwin Core Schema (Vieglais 2003b) along with the DiGIR protocol (SourceForge 2004) and the combined BioCASE protocol (BioCASE 2003) and ABCD (Access to Biological Collections Data) schema (TDWG 2004) that are more fitted for interchange of primary species information. More recently the Taxonomic Databases Working Group and others have begun working to develop a combined protocol (TAPIR - http://ww3.bgbm.org/tapir) treading a middle path between the simplicity of DiGIR and the complexity of BioCASE.

Multiple uses

Most projects that use species-occurrence data incorporate more than just one type of use. As evident from this paper, there is considerable overlap in uses within any one project. A project might include mapped primary records, some taxonomic study (possibly involving the use of character databases), environmental modelling and predictive distributional studies which may involve endangered or migratory species, climate change impact studies as well as population viability analysis and studies of species associations, ecology and evolutionary history. The project may then involve species recovery studies and monitoring, as well as development of environment protection legislation, reserve and conservation assessment, links to border and custom controls to prevent illegal smuggling, and finally education and social links. It is sometimes difficult to identify where one use stops and another begins, and I hope readers will excuse the inevitable overlap that is evident throughout this paper.

The ability to search databases all around the world for spatially-referenced primary species-occurrence data has opened up the information to a range of uses, many of which have previously not been possible. This paper will elaborate on some of those uses and present examples. It should be noted that it is beyond the scope of a paper such as this to cover every example of use – examples given are just that – samples to illustrate the types of uses mentioned.

Some of this overlap in uses can be seen from the first GBIF Demonstration Project in 2003. (UTU-Biota 2004).

GBIF Demonstration Project 2003

The first GBIF Demonstration Project (http://gbifdemo.utu.fi/) provided a number of user-friendly examples of how primary biodiversity data can effectively be used, managed, exchanged and disseminated via the Internet. It was prepared for GBIF by the University of Turku in association with the Institute of Amazonian Research (IIAP). The project was divided into four sections or "tours". Tour 1 dealt with Neotropical species distributions, Tour 2 with multi-authored rainforest trees inventories, Tour 3 with sub-arctic plant observations and Tour 4 on planning and management of biodiversity.

In 2004, GBIF funded two more Demonstration projects (http://www.gbif.org). The first of these is an Australian-based project to develop an internet-based tool for biogeographic analysis of endemism and taxonomic distinctness. The second project is based in Mexico, and will demonstrate the feasibility of estimating the rate of disappearance of species populations by estimating distribution areas of species associated with primary vegetation on the basis of primary biodiversity data. Both will use data extracted via the GBIF Portal.

Benefits of making species-occurrence data available

Many of the uses of species-occurrence data elaborated in this paper have required the user to visit the collections institution – the museum or herbarium, etc. to seek access to the information, or to obtain identifications. Staff of the musem then has to spend time and resources in identifying the material for the user (which may be from hundreds to thousands a year for some collectors (Suarez and Tsutsui 2004) or readying the data for the user. Huge resources are spent each year as scientists travel to museums to use the collections, or as museums loan specimens to researchers. Between

1976 and 1986, the Smithsonian's entomological collection loaned, on average, over 100,000 specimens each year (Miller 1991) and it, like most of the world's larger museums, annually hosts hundred of visiting researchers. Collections institutions are now beginning to realise that they can save valuable time and resources by making available electronically as much of that data as is possible. An example is with the Botanischer Garten und Botanisches Museum Berlin-Dahlem where their herbarium loan system has been completely replaced with a digital loan system[1] (http://ww2.bgbm.org/Herbarium/AccessLoanNew.cfm). Not only does it free up resources, more often than not, those resources are the taxonomists and researchers that can then spend more time on basic research and curation and less on administration and on helping others. The digitisation of the hundreds of millions of collections held in natural history museums, however, is no small taksk and will take many years, or even decades to complete.

The increased use of species data through distributed systems will provide a climate that will allow, among others:

- Consolidation of collections infrastructure and holdings within museums, herbariums, botanical gardens, zoological gardens, germplasm banks, etc.;
- A reassignment of resources toward increased research and curation;
- Improvements in the standardization, quality, maintenance and organization of important biodiversity collections;
- Reduce physical handling of specimens, ensuring their longevity;
- Reduce costs of shipping, insurance, etc. of transferring loans and specimens between institutions;
- The sharing of information between institutions and researchers, including with countries of origin;
- A more rapid advancement of the biodiversity knowledge-base as researchers build on the information in a more timely manner;
- Establishment of international biodiversity information networks between institutions involved with biodiversity research, conservation, genetics, production, resource management, tourism, etc.;
- Improvements in the management and availability of image, cartographic, genetic, and other databases that will subsidize biodiversity research;
- Improvements in the management of conservation units as knowledge about biodiversity becomes more readily available;
- Improved evaluation of the representativeness of existing conservation units and reserves, and the identification of priority areas for the establishment of new ones;
- Development of projects to study problems that affect conservation, such as the effects and consequences of habitat fragmentation and climate change on biodiversity;
- Improvements in border controls for managing and monitoring movements in endangered species, pests and diseases as identification tools and knowledge about the distributions of taxa are improved;
- Production and dissemination of checklists of all known biota of conservation areas, regions, States, and countries, etc.;
- Increased and more efficient production of identification tools, keys, catalogues and monographs (electronic and/or paper publications);
- More and improved inventories and studies for identifying biodiversity information gaps (both taxonomic and geographic);
- Development of research projects that aim at understanding the temporal and spatial distribution of biological diversity processes and functions;

[1] Pers. comm.. Anton Güntsch, BGBM 2005.

- Comparative and retrospective studies for estimating biodiversity loss within regions, habitats, ecosystems, and across political and geographic boundaries;
- Comparative studies on environmental impact, such as climate change, urbanization, agriculture, fisheries, etc. and establishment of reference patterns for evaluation and monitoring of environmental impact with respect to biological diversity;
- Increased opportunities for bioprospecting, and the linking of programs with related and similar interests;
- Improvements in capacity building in biodiversity and biodiversity-related subjects;
- The development of professionals in new fields of knowledge and in new interfaces, such as biodiverty informatics, image services, and geographic information systems;
- Production of improved teaching material, such as field guides, identification keys, image databases, and on-line information for students and educators;
- Improved guides and information resources for use in ecotourism;
- Improved rates of publishing in taxonomy as researchers spend less time on identifications and on making data available on an individual basis;
- Improved linkages with local people for collecting, ecological research and preliminary identification using parataxonomists;
- transfer of some of the burden of sorting and preliminary identification of field samples from the extremely small number of highly-skilled taxonomists to technically-skilled parataxonomists;
- Development of new sources of funding for supporting collections.
- Etc.

Taxonomy

For hundreds of years, primary species-occurrence data have been used for taxonomic and biogeographic studies. Data in museums and herbaria have primarily been used for the determination and description of new taxa. Collections were also used, however, for such things as studying pollination biology, evolutionary relationships, and phylogenetics. These uses continue, and with users now having access to data from a greater geographic range, they are able to expand on these studies

Taxonomic Research

There are thousands of published examples of uses of primary species-occurrence data in taxonomy and in the elucidation of new taxa and phylogenetic relationships. Species data in museums are core to the study of basic taxonomy – the elucidation of new taxa and their descriptions. The world has about 1.4 million taxa already described (World Resources 1992) – nearly all based on collections in museums and herbaria. Many more still need to be described and thus one of the basic uses of species-occurrence data is the description and classification of plants, animals, algae, fungi, viruses, etc. Without these data, these processes could not continue.

Taxonomic projects are carried out at virtually every natural history museum and herbarium in the world with outputs in journals, monographs and electronically.

Examples:

- Biodiversity and Management and Utilization of West African Fishes is a project of ICLARM examing the taxonomy and phylogeny of fishes in Ghana and other West African states. <http://www.worldfishcenter.org/Pubs/ghana-proceedings/ghana-proceedings.htm>;
- Cicadas of South-East Asia and the West Pacific – research from the Institute for Biodiversity Research and Ecosystem Dynamics of the Zoological Museum of Amsterdam (Duffels 2003). <http://www.science.uva.nl/ZMA/entomology/CicadasSE.html>
- The taxonomy of Vietnam's exploited seahorses (Syngnathidae) (Lourie, *et al.* 1999). <http://seahorse.fisheries.ubc.ca/pubs/Lourie_etal_vietnam.pdf>.
- HymAToL – a project aimed at constructing a large-scale phylogenetic analysis of the Hymenoptera of the world as part of the Tree of Life project. <http://www.hymatol.org/about.html>.
- Phylogeny. A project from the University of Alberta in Canada. <http://www.deer.rr.ualberta.ca/library/phylogeny/Phylogeny.html>.

Name and Taxonomic Indices

Primary species-occurrence data has been used to develop lists of names and taxa which are used in one way or another by most of the projects throughout this paper. In much the same way as dictionaries and thesauri are used in the spoken and written languages of the word, indexes of names and taxa are used for the language of biodiversity. Collections institutions use them as authority files for their databases, taxonomists use them to help determine the correct spelling and the place of original publication, and scientists and amateurs use them to find the correct spelling of a name of a species, its synonyms and other information. These indexes can vary from being just a list of names, to detailed lists that include taxonomic information, synonyms, place of publication, type specimen information, references to different uses of the names (taxonomic concepts), etc.

Examples:

- Species2000 <http://www.species2000.org>;
- Integrated Taxonomic Information System (ITIS) <http://www.itis.usda.gov/>;
- International Plant Name Index (IPNI) <http://www.ipni.org/index.html>;
- Electronic Catalogue of Names of Known Organisms (ECat) program of GBIF <http://www.gbif.org/prog/ecat>;
- Universal Biodiversity Indexer and Organizer (UBio) <http://www.ubio.org/>;
- Index Fungorum <http://www.indexfungorum.org/>;
- Index of Viruses <http://www.ncbi.nlm.nih.gov/ICTVdb/Ictv/index.htm>;
- Taxonomic Search Engine (TSE) <http://darwin.zoology.gla.ac.uk/~rpage/portal/>;
- Nomenclator Zoologicus <http://uio.mbl.edu/NomenclatorZoologicus/>;
- Global Lepidoptera Names Index <http://www.nhm.ac.uk/entomology/lepindex/>;
- Tropicos <http://mobot.mobot.org/W3T/Search/vast.html>;
- Gray Card Index of Harvard University <http://www.huh.harvard.edu/databases/>.

Floras and Faunas

The publication of floras and faunas is one of the first outputs from the results of taxonomic research and their development is being greatly enhanced through access to species-occurrence data on-line. Most published floras and faunas include location information, and more often than not a simple mapped distribution. Traditionally, these maps were drawn by hand, and were invariable created without access to the totality of collections available. With distributed systems such as the GBIF Portal, and using a simple GIS, these maps can now be produced quickly and easily, and by having access to many more collections, are more likely to cover the totality of the distribution.

Examples:

- Flora of Australia online (ABRS, Canberra) <http://www.deh.gov.au/biodiversity/abrs/online-resources/abif/flora/main/>;
- Fauna of New Zealand (Manaaki Whenua Landcare Research) <http://www.landcareresearch.co.nz/research/biodiversity/invertebratesprog/faunaofnz/>;
- FaunaItalia <http://faunaitalia.it/index.htm> ;
- Phanerogamic Flora of the State of São Paulo (Brazil) <http://www.cria.org.br/flora/>.

Taxonomy and Ecological Biogeography

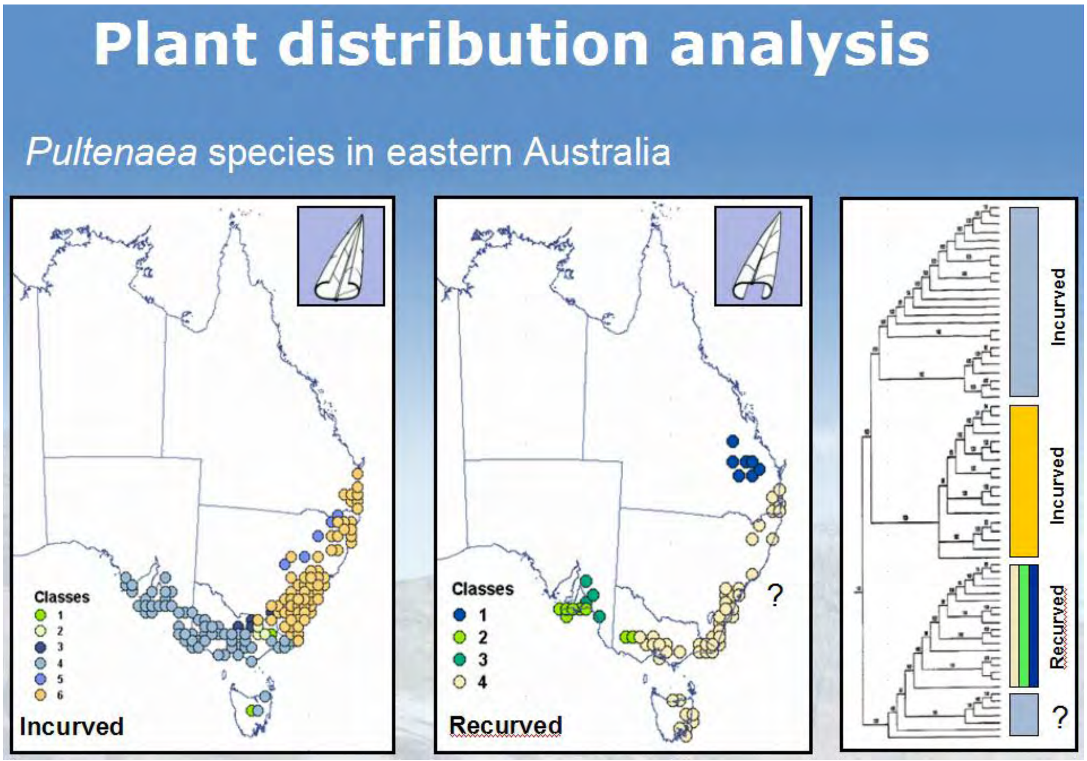

Fig. 1. *Phylogenetic information from Pultenaea species in Australia showing geographic patterns related to leaf morphology. Phylogenetic groups were determined using cluster analysis from herbarium records with affinities hypothesized using leaf morphology and the phylogenetic cladogram derived from molecular data (right). Data were collated through the Australian Virtual Herbarium (AVH) (CHAH 2002). Image from West and Whitbread (2004) with permission of the authors.*

The availability of distributed data points from many collections agencies, now allows for quicker and more detailed studies, for example by looking at provenance differences, locations of collections with different characteristics (plotting location against leaf length for example), and the mapping of different taxonomic concepts. Many of the products mentioned below (Floras, Faunas, field guides, etc.) are the visible output from the basic taxonomic research.

Examples:

- A project at the Centre for Plant Biodiversity Research in Australia, maps patterns related to leaf morphology in phylogenetic groups of the genus *Pultenaea* (figure 1). Groups were identified on the basis of leaf morphology and a phylogenetic cladogram based on molecular data (Bickford *et al.* 2004, West and Whitbread 2004).
- Another project at the Centre for Plant Biodiversity Research, uses data obtained from 8 Australian herbaria accessed through the Australian Virtual Herbarium (CHAH 2002) to plot geographic patterns related to different taxonomic concepts (West and Whitbread 2004).

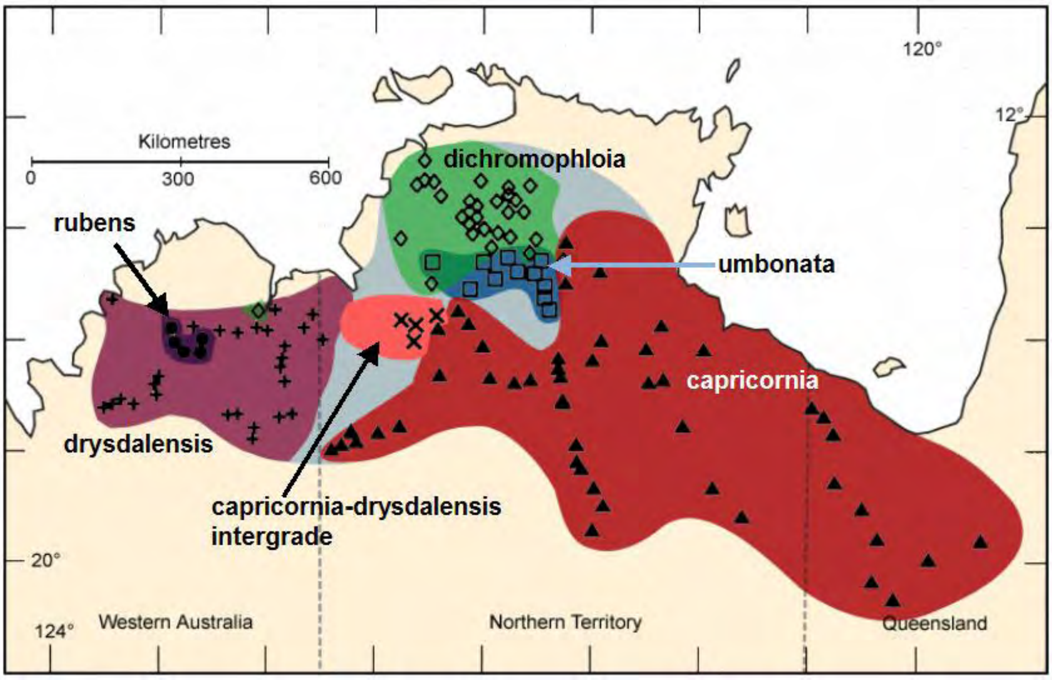

Fig. 2. *Map showing different interpretations of a group of species in the genus* Corymbia *(previously part of* Eucalyptus*). Different taxonomic concepts of experts propose* C. umbonata *and* C. dichromophloia *encompassing the total distribution of the group as shown, as compared to another concept which interprets* C. dichromophloia *in a more narrow sense and recognises a number of other species as mapped here. Image from West and Whitbread (2004) with permission of the authors.*

Field Guides

Most field guides incorporate a mapped distribution of the species under consideration. Again, like Floras and Faunas, they have traditionally included hand-drawn maps derived from the author's knowledge of the species. The availability of distributed species data now makes the production of maps and the inclusion of distributional information, that much easier and far more accurate.

Examples:

- Birds of Argentina and Uruguay. A Field Guide (Narotsky and Yzurieta 2003).
- Dragonfly Recording Network <http://www.searchnbn.net/organisation/organisation.jsp?orgKey=6>;
- Catalogue of the species of the Annelid Polychaetes of the Brazilian Coast (Amaral and Nallin 2004);
- Butterflies of North America <http://www.npwrc.usgs.gov/resource/distr/lepid/bflyusa/bflyusa.htm>;
- Butterflies of Australia (Braby 2000);
- Tour 2 from GBIF Demonstration Project 2003: Access to multi-author rainforest inventories <http://gbifdemo.utu.fi/>.
- BumblebeeID – find British species by colour pattern. <http://www.nhm.ac.uk/entomology/bombus/_key_colour_british/ck_widespread.html>

Integrated electronic resources

The development of character-based databases, interactive keys, and digital imaging, along with the arrival of CD-ROMs and DVDs has led to the development of a number of integrated electronic resources.

Examples:

- PoliKey (an interactive key and information system for polychaete families and higher taxa) (Glasby and Fauchald 2003)
- Publications from the Expert Centre for Taxonomic Identification (ETI) produced using the Linnaeus II software (Shalk and Heijman 1996).
    - Searchable and Browsable Index to CD products produced using the Linnaeus software <http://www.eti.uva.nl/Products/Search.html>. Some examples include:
        - Catalogue of the Chalcicoidea of the World,
        - Birds of Europe,
        - Crabs of Japan,
        - Davalliaceae,
        - Fauna Malesiana, and
        - Fishes of the North-Eastern Atlantic and Mediterranean.
        - Arthropods of Economic Importance
        - Bats of the Indian Subcontinent
        - Key to Cotton Insects
- Publications using the Lucid Software (University of Queensland 2004):
    - Searchable Index to published products using the Lucid software. Searches can be conducted taxonomically, geographically and in a number of other ways <http://www.lucidcentral.com/keys/keysearch.aspx>. Examples include:
        - Key to Common Chilocorus species of India (J. Poorani). an economically important genus of lady beetles,
        - Key to the World Genera of Eulophidae Parasitoids (Hymenoptera) of Leafmining Agromyzidae (Diptera),
        - Key to Insect Orders,
        - Pest Thrips of the World.
- Publications using DELTA and IntKey (Dalwitz and Paine (1986).
    - Index to publications using DELTA and IntKey <http://biodiversity.bio.uno.edu/delta/www/data.htm>. Some examples:,
        - Beetle – Elateroformia (Coleoptera) – families – (adults and larvae separate). Downloadable characters and descriptions for use in the Intkey program.
        - Braconidae (Hymenoptera) of the New World – subfamilies, genera and species >,
        - Downloadable characters and descriptions for use in the Intkey program - in English and Spanish.
        - Commercial timbers (in English, German, French, and Spanish)
        - Polychaete families and higher taxa
- Publications using XID Authoring System <http://www.exetersoftware.com/cat/xid.html>
        - Weeds of North America. A comprehensive weed identification reference for North America on CD, it contains 140 grass-like and 860 broadleaf weeds.
- CD-ROM Publications from the Australian Biological Resources Study (ABRS) and the Centre for Plant Biodiversity Research in Australia produced largely through use of Lucid Software (University of Queensland 2004)
  Examples include
  (<http://www.deh.gov.au/biodiversity/abrs/publications/cds/index.html>):

- Acacias of Australia,
- Mites in Soil,
- AusGrass,
- Spiders of Australia,
- Australian Tropical Rainforest Trees and Shrubs <http://www.anbg.gov.au/cpbr/cd-keys/rainforest-key/home_page.html>, and
- Eucalypts of Southern Australia <http://www.anbg.gov.au/cpbr/cd-keys/Euclid/>.

Check lists and inventories

Species checklists for regions, national parks, etc. can now be produced almost automatically, and maintained through the use of distributed information systems. This is probably one of the least used, but most powerful use of a distributed system.

Examples:

- Checklist of Amphibian Species and Identification Guide. An online Guide for the Identification of Amphibians in North America north of Mexico. <http://www.npwrc.usgs.gov/narcam/idguide/>;
- A Checklist of the Ants of Michigan <http://insects.ummz.lsa.umich.edu/fauna/MICHANTS.html>;
- Checklist of the Amphibians and Reptiles of Rara Avis, Costa Rica <http://www.rara-avis.com/herplist.htm>;
- Checklist and distribution of the liverworts and hornworts of sub-Saharan Africa, including the East African Islands <http://www.oshea.demon.co.uk/tbr/tbrr3.htm>;
- The Australian Mammal Audit (McKenzie and Burbidge 2002) was part of biodiversity audit for Australia <http://audit.ea.gov.au/ANRA/vegetation/docs/national/FINAL_MAMMAL_REPORT.doc>.

Image Databases

The use of Image databases, especially of type specimens is reducing damage to natural history collections as taxonomists use images of the specimens, or of the labels, rather than borrowing specimens.

Examples:

- New York Botanical Garden Vascular Plant Type Catalog <http://www.nybg.org/bsci/hcol/vasc/Acanthaceae.html>;
- Parasite Image Library <http://www.dpd.cdc.gov/dpdx/HTML/Image_Library.htm>;
- Natural History Museum (London) Specimen label images <http://atiniui.nhm.org/gallery/album33>.

Phylogenies

The study of phylogenies, or evolutionary trees is enhanced by the use of primary species-occurrence data.

Examples:

- Tree of Life – a collaborative Internet project containing information about phylogeny and biodiversity <http://tolweb.org/tree/phylogeny.html>;
- The study of phylogenetic patterns in groups of *Pultenaea* (figure 1) (Bickford *et al.* 2004).

Parataxonomy

Parataxonomists are used in a number of developing countries to do preliminary sorting of collections. These parataxonomists rely on good species-occurrence data and products to be able to carry out their work efficiently and effectively.

Examples:

- Parataxonomists have been extensively used in the Guanacaste Conservation Area in Costa Rica (Janzen *et al.* 1993) <http://www.unep-wcmc.org/forest/restoration/docs/CostaRica.pdf>;
- Parataxonomists are being used to conduct biological surveys by the New Guinea Binatang Research Centre <http://www.entu.cas.cz/png/parataxonomists.htm>.

Automated Identification Tools

Automated identification tools that use pattern recognition followed by clustering, ordination or use of artificial neural network are being tested for use with insects, birds and frogs.

Examples:

- In Germany bees can be identified using pattern recognition with the Automatic Bee Identification Software (ABIS) <http://www.informatik.uni-bonn.de/projects/ABIS/ABIS_Contact.html>;
- In Japan, cicadas and grasshoppers are being identified using hand-held recorders to recognise calls using the Intelligent Bioacoustic Identification System (IBIS) <http://www.elec.york.ac.uk/intsys/users/ijf101/research/acoustics/grasshoppers.shtml>;
- In Britain, the Intelligent Bioacoustic Identification System (IBIS) is being used to identify bats <http://www.elec.york.ac.uk/intsys/users/ijf101/research/acoustics/bats.shtml>; as well as to identify sett occupancy in badgers underground <http://www.elec.york.ac.uk/intsys/users/ijf101/research/acoustics/badgers.shtml>;
- In Finland, sinusoidal modelling of birdcalls allows for the development of automated identification of birds (Härmä 2003).

Biogeographic Studies

Natural history collections contain a unique and irreplaceable record of the natural and cultural history of our world. Many of the specimens and ancillary data in collections were obtained prior to the major modifications of the landscape and they are irreplaceable (Chapman 1999, Page *et al.* 2004). Indeed, the collections are the fundamental database on the changing landscapes and patterns of species distributions (Page *et al.* 2004).

There are hundreds, if not thousands of biogeographic studies using species-occurrence data. Some use simple distributions within a grid, others link to environmental data layers such as climate and geology through environmental modelling tools, others look at various combinations to develop indices of diversity and endemism, relative abundance, etc. All such projects benefit from being able to access distributed data from multiple institutions. Examples will be included under individual headings below.

The use of environmental modelling software such as BIOCLIM (Nix 1986, Busby 1991) GARP (Stockwell and Peters 1999, Pereira 2002), and methods such as GLM (Austin 2002), GAM (Hastie and Tibshirani 1990), Decision Trees (Breiman 1984), and Artificial Neural Networks (Fitzgerald and Lees 1992), etc. to link individual locations of plants and animals to environmental criteria such as climate to produce maps of potential distribution have been around for more than 20 years. Because of the scale of environmental layers available at the time, some of the earlier studies looked at broad-scale distributions of groups of plants or animals, such as used with the Elapid Snakes (Longmore 1986), or more intensely on one species such as with *Nothofagus cunninghamii* (Busby 1984). Because of the nature of the software available at the time, and the paucity of good environmental layers, these studies were slow and took months to produce a model for just one species, and were often carried out at a scale that allowed for only broad conclusions to be drawn. The development of new software and vastly improved environmental layers (Hijmans *et al.* 2004) has meant that models can now be produced in limited time, allowing for more intensive studies of individual species, or studies on much larger numbers of species. Care, however, needs to be taken in using any of these modelling methods, and it is best to seek advice from experts before using them to ensure that the right model is being used for the right data etc. (Chapman *et al.* 2005).

Distribution Atlases

Traditional uses for geo-referenced primary species data have been for developing maps of species distributions and the development of distribution atlases. In the past, these have often been as a presence or absence within a geographic grid, from 5 km to 2.5-degree grids, or in a biogeographic region. Many of these have not been made available electronically.

Examples of mapping by grid or region include:

- Fife Bird Atlas (2 km grid squares) <http://www.the-soc.fsnet.co.uk/fife_bird_atlas.htm>;
- Atlas of the British Flora (Perring and Walters 1962) (10 km grid squares);
- Millenium Atlas of Butterflies in Britain and Ireland (Asher *et al.* 2001) (10 km grid squares);
- Ontario Herpetofaunal Summary Atlas (10 km grid squares) <http://www.mnr.gov.on.ca/MNR/nhic/herps/about.html>;
- The Introduction and spread of the Asian Long-horned Beetle in the north America is being studied using biogeographic analysis <http://www.uvm.edu/albeetle/> and Peterson et al. (2004)

<http://www.specifysoftware.org/Informatics/bios/biostownpeterson/PSH_AMN_2004.pdf>.

- Atlas of Australian Birds (1st edition) (Blakers *et al.* 1984) (10-minute grid squares);
- Atlas Florae Europaeae (50 km grid squares) <http://www.biologie.uni-hamburg.de/b-online/ibc99/IDB/afe.html>;
- Census of Australian Vascular Plants (Hnatiuk 1990) (97 biogeographic regions covering all of Australia);
- Moths of North America (Counties or States) <http://www.npwrc.usgs.gov/resource/distr/lepid/moths/mothsusa.htm>.

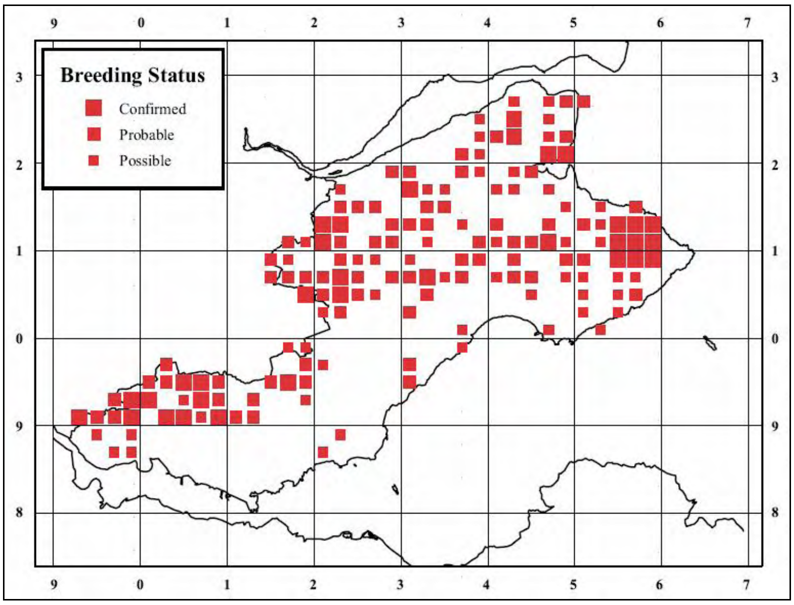

Fig. 3. *Distribution of the* Eurasian Curlew (Numenius arquata) *in Fife, Scotland from the Fife Bird Atlas (Elkins et al. 2003) using 2 km grid squares. Map reproduced with permission of the authors.*

Many of the early species distribution atlases were done by hand, and often without carrying out full geo-referencing. Mapping distributions in a grid could be carried out without a GIS and were easy to record merely as present or absent within each grid cell. The use of distributed database searches and Geographic Information Systems (GIS) now allows species distribution mapping and atlases to be produced much more accurately and with better presentation, and has allowed easier mapping of individual specimen records.

Examples of mapping individual records include:

- Atlas of Elapid Snakes of Australia (Longmore 1986);
- Protea Atlas Project (South Africa) <http://protea.worldonline.co.za/default.htm>;
- The New Atlas of Australian Birds <http://www.birdsaustralia.com.au/atlas/>;
- Tour 1 from GBIF Demonstration Project 2003: Reliability and consistency of Neotropical species distributions <http://gbifdemo.utu.fi/>;
- Atlas of the Birds of Mexico (Navarro *et al.* 2003).

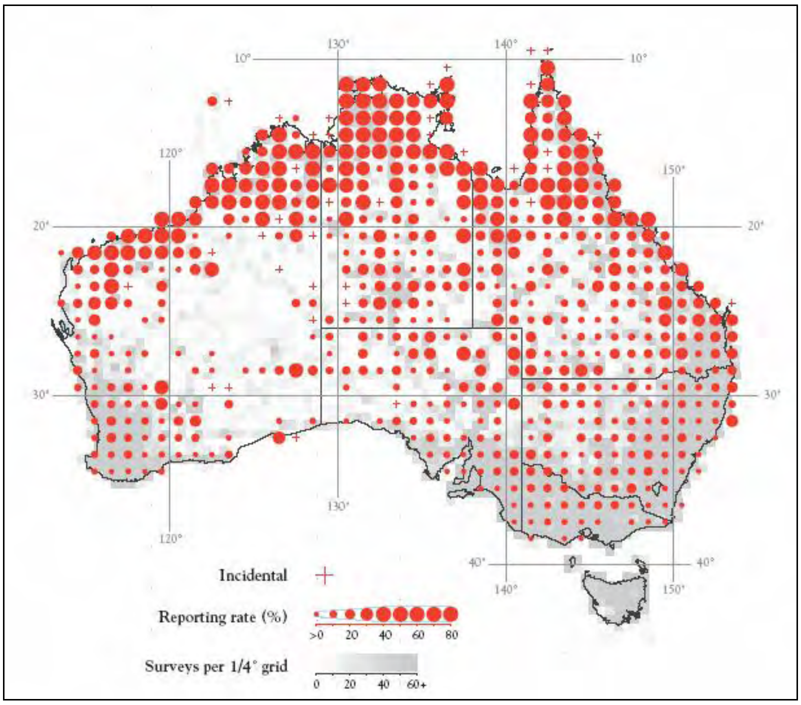

Fig. 4. *Distribution of the Rainbow Bee-eater from The New Atlas of Australian Birds (Barrett et al. 2003). Records are recorded as point records and mapped as a summary in 1-degree grid squares (red) and on 0.25-degree grid squares (grey).*

Species Distribution Modelling

In the mid 1980s, the concept of environmental species distribution modelling using environmental data such as climate, started to become possible with the development of computer software such as BIOCLIM (Nix 1986, Busby 1991). Since then, many new modelling methodologies and programs have been developed, including Generalised Linear Models (GLM) (Austin 2002), Generalised Additive Models (GAM) (Hastie and Tibshirani 1990), Genetic Algorithm for Rule-set Production (GARP) (Stockwell and Peters 1999, Pereira 2002), DOMAIN (Carpenter *et al.* 1993) and many, many others. These programs were stand-alone programs, but the availability of World Wide Web in 1994, saw the development of modelling on the Internet – firstly with BIOCLIM and GARP (Boston and Stockwell 1995), and later with modifications of these and other programs.

The development of these modelling techniques opened up primary species-occurrence data to many more uses. One of the main drawbacks of these data are their lack of comprehensiveness and completeness, and the use of models allows for gaps in the distributional knowledge of species to be filled. There are now many projects using modelling techniques for determining the potential distributions of species under present-day climatic conditions given various constraints, under altered climatic conditions following climate change, and under past climatic conditions in earlier epochs. Some of these uses will be covered under more specific topics below, but

Examples:

- Atlas of Elapid Snakes of Australia (BIOCLIM) (Longmore 1986);
- Atlas of Vertebrates Endemic to Australia's Wet Tropics (BIOCLIM) (Nix and Switzer 1991);
- Use of Environmental Gradients in Vegetation and Fauna Modelling (GLM) (Austin 2002);
- Potential distribution of *Anoplophora glabripennis* (Asian Long-horned Beetle) in North America (GARP) (Peterson *et al.* 2004);

- Predicting distributions of Mexican birds (GARP) (Peterson *et al*. 2002b);
- In Africa, tsetse fly habitats were modelled using species data and remotely-sensed vegetation data (Robinson *et al.* 1997).

Atlas of Elapid Snakes of Australia

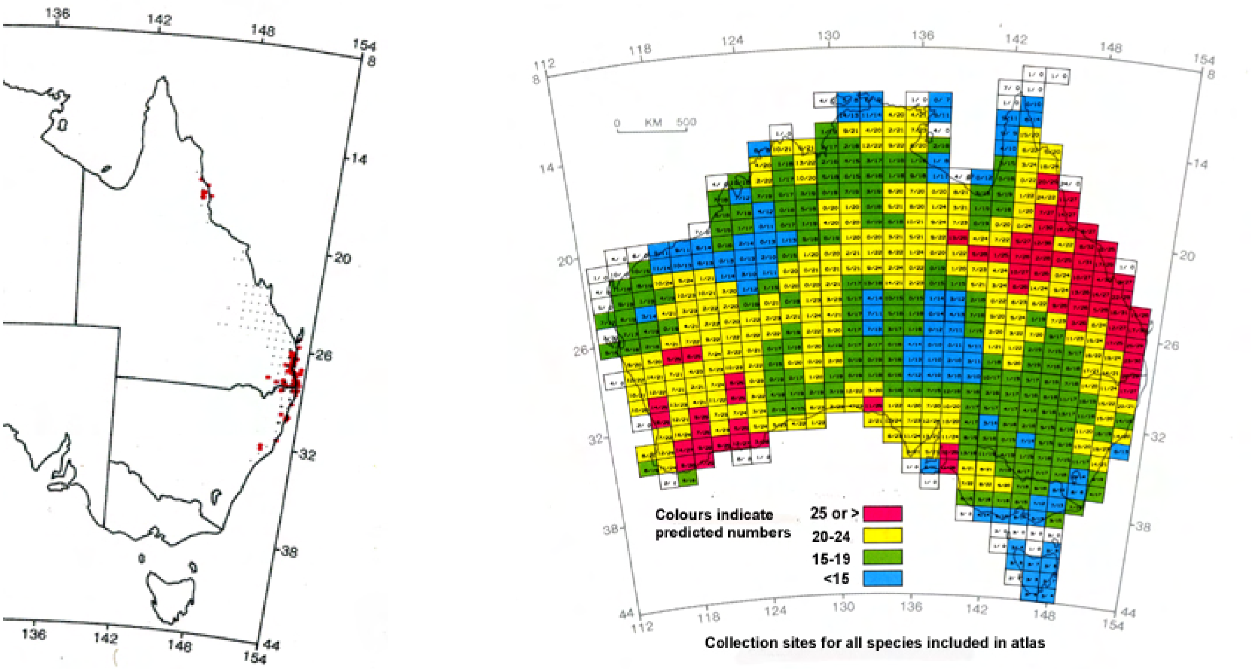

Fig. 5. *Left-hand image - Potential distribution for* Tropidechis carinatis *in Australia. Red stars indicate known collections, dots show modelled distribution. Right-hand image shows predicted numbers of species in each 1° x 1.5° cell. From Longmore (1986) with permission of Australian Biological Resources Study.*

The Atlas of Elapid Snakes (Longmore 1986) was a result of a pilot project conducted with the Australian Museum in 1982 to examine uses for geo-referenced primary species data. In 1983, the Australian Bureau of Flora and Fauna (now the Australian Biological Resources Study), decided that it was wasting resources by funding the collection of new species records without first utilising data already held by museums. Data for 17,000 records were then collected from all the major Australian museums, integrated and modelled using the bioclimatic modelling software, BIOCLIM (Nix 1986, Busby 1991). Many of the data were in a poor state of curation and required extensive data validation and cleaning prior to use. The Atlas contained maps for all 77 species of front-fanged, venomous terrestrial snakes (the family Elapidae) in Australia and was one of the first attempts to collate, geo-reference, and document all records of an animal group for purposes of biogeographic study. The project also saw the first detailed publication of the software program, BIOCLIM (Nix 1986).

Environmental data layers for use in bioclimatic modelling were still quite primitive. Twelve climate parameters were used at a scale of 0.5-degree resolution. Species data were geo-referenced as accurately as possible, and altitude determined to the nearest 50 m. The species were modelled using the 5-95 and 100 percentile ranges and mapped at a continental scale (figure 5).

Predicting new species distributions

By using species-occurrence data in conjunction with species modelling tools, it is possible for additional locations of species to be identified. In other cases, species modelling has identified disjunctions in climate profiles that have indicated that two species are present where only one was previously known.

Examples:

- Museum collections as well as new survey data were used to predict reptile diversity in Madagascar and were successful in predicting locations of new chameleon species (Raxworthy *et al.* 2003);
- In Australia, new locations of a rare *Leptospermum* species (Myrtaceae) were identified using species modelling (Lyne 1993) <http://www.anbg.gov.au/projects/leptospermum/leptospermum-namadgiensis.html>.

Studying species decline

By using locality information and collection information such as date of collection, primary species data can help in the understanding of species declines over time.

Examples:

- AmphibiaWeb (Wake 2004) <http://amphibiaweb.org/>; Species Decline: Contaminants as a Contributing Factor. Patuxent Wildlife Research Center Database <http://www.pwrc.usgs.gov/pattee/select.htm>;
- The Red List Index has developed a tool for measuring global trends in the status of biodiversity (Butchart *et al.* 2004). <http://www.birdlife.org/print.html?url=%2Fnews%2Fpr%2F2004%2F10%2Fred_list_indices.html>;
- Australian Terrestrial Biodiversity Assessment is part of the Australian Natural Resources Atlas v. 2.0 <http://audit.ea.gov.au/ANRA/vegetation/vegetation_frame.cfm?region_type=AUS&region_code=AUS&info=bio_asses>.

Species Diversity and Populations

The study of species diversity, species density and richness is a discipline that is being aided enormously by the increasing availability of species-occurrence data. In the past, these types of studies required months, if not years of data collection and preparation, and usually concentrated on the data available from just a few museums or herbaria and thus seldom covered the totality of the data. This new availability of data through distributed systems has meant that new tools are being developed to cater for the increases in data availability and to allow for more rapid analysis and assessment. As a result, the data can be used more effectively in biodiversity assessment projects, in conservation assessment and for regional planning and management.

The increased availability of data is allowing for improved modelling and distribution of associations and populations leading to improved understandings of species and how they interact with their environments. This is allowing for better management of populations, and understandings of threatened species and communities. This improved understanding, for example, is now allowing Australia to list threatened ecological communities as well as species (DEH 2000, 2004).

Species Diversity, Richness and Density

The study of species richness, density and abundance and the identification of centres of endemism have been key areas of research in biodiversity over the past 20 years. More recently, they have been integrated into conservation assessment and planning and species protection. In many cases, species diversity, and richness are used as surrogates for measuring biodiversity.

Species Richness Tools

New tools are being developed to assist in assessment of species richness and endemism and for use as planning tools for conservation assessment.

Examples:

- WorldMap uses species distribution data to produce species richness maps, which can then be used to carry out further analyses. (Williams *et al.* 1996) <http://www.nhm.ac.uk/science/projects/worldmap/index.html>;
- Australian Heritage Assessment Tool, under development at the Australian Department of the Environment and Heritage, can quickly generate maps of richness and endemism for a broad range of Australian plant, vertebrate and invertebrate taxa through an easy to use interface (figure 4);
- Pattern Analysis tools such as PATN (Belbin 1994) can be used to identify patterns in species diversity and endemism <http://www.patn.com.au/>;
- EstimateS is another software package for estimating species richness. (Colwell 2000) <http://viceroy.eeb.uconn.edu/estimates>;
- Species Richness bibliography <http://www.okstate.edu/artsci/botany/ecology/richness.htm>.

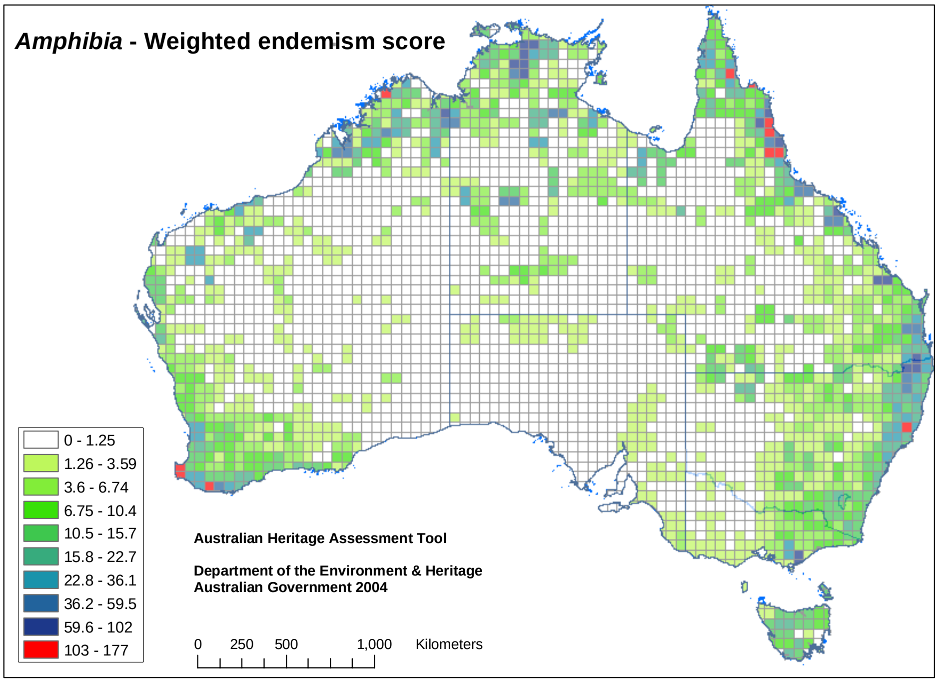

Fig. 6. *Endemism in Australian frogs showing peak areas for frog endemism highlighted in red. Image from the Australian Heritage Assessment Tool; published with permission of Cameron Slatyer and Dan Rosauer, Australian Department of the Environment and Heritage, 2004.*

Biodiversity Hotspots

Biodiversity hotspots or centres of endemism are regarded as the world's biologically richest and most important areas for conservation (Mittermeier *et al.* 2000). Conservation International has been conducting a program to assess those areas of the world regarded as the most "species rich".

Examples:

- Conservation International identifies the 25 most threatened biodiversity rich areas of the world (Myers *et al.* 2000) <http://www.biodiversityhotspots.org/xp/Hotspots>;
- Birdlife International's Endemic Bird Areas of the world (Stattesfield *et al.* 1998) <http://www.birdlife.net/action/science/endemic_bird_areas/>;
- Biodiversity hotspots in Australia <http://www.deh.gov.au/biodiversity/hotspots/index.html>;
- The Millenium Atlas of Butterflies is mapping the species richness of butterflies across the United Kingdom <http://www.butterfly-conservation.org/index.html?/bnm/atlas/index.html>.

Patterns of Species Richness

Species richness studies are conducted from the size of one vegetation community to a global scale. Most species richness studies have implications for conservation, the identification of hot spots as mentioned above and the identification of priority areas for conservation.

Examples:

- A study in central Brazil looked at the richness and abundance of caterpillars of one genus of plant in the cerrado (savannah-like) vegetation (Andrade *et al.* 1999) <http://www.scielo.sa.cr/scielo.php?pid=S0034-77441999000400005&script=sci_arttext&tlng=en>;
- A study in Africa is looking at species richness and endemism of insects in sub-Saharan Africa (Miller and Rogo 2001);

- Species richness and endemism in South American bird species was used to plan a network of reserves (Fjeldsa and Rahbek 1997);
- The geographic relationships and constraints on species richness were studied using mid-domain effects (Colwell and Lees 2000);
- Examining spatial patterns at the community level (Ferrier *et al.* 2002).

Studying Individual species

Species richness studies of single species – knowing where it occurs, and where it moves, and the densities of individual populations, can aid in the conservation of that species. By using historical data, changes in patterns of movement can be examined.

Examples

- The density of Elephants in the forests of central Africa is being studied using Geographic Information Systems (Michelmore 1994).

Evolutionary patterns

One of the aspects of species richness studies is the detection of patterns of endemism and richness. By looking at the patterns of species concentrations and endemism, historical evolutionary patterns can be determined.

Examples:

- In a study of conservation in Africa, Brooks (2001) examined four groups of animals – mammals, birds, snakes and amphibians and modelled species richness against environmental conditions such as primary productivity potential evapotranspiration, solar radiation, temperature, and rainfall.

Population Modelling — Population Viability Analysis

The modelling of populations can help track the dynamics of the population, and assist in determining a minimum area for conservation, and examine interactions with predators and prey, etc. Species observational data and data from intensive survey is an essential tool for these studies. Population Viability Analysis (PVA) was originally used to determine how large a population must be to have a reasonable chance of survival for a reasonable length of time.

Examples:

- At the Centre for Resource and Environmental Studies in Canberra, detailed studies have been conducted on populations of a small threatened marsupial – Leadbeater's Possum (*Gymnobelideus leadbeateri*) in the forests of northern Victoria. (Lindenmeyer and Possingham 1995, 2001. Lindenmeyer and Taylor 2001) <http://incres.anu.edu.au/possum/possum.html>;
- Applied Biomathematics® is using the RAMAS software package to model extinction risk in birds through use of Population Viability Analysis <http://www.ramas.com/birds.htm>;
- Many studies in China have used Population Viability Analysis to examine minimum reserve size for maintenance of viable populations of the Giant Panda (*Ailuropoda melanoleuca*) (Zhou and Pan 1997);
- An annual census of Southern Elephant Seals is conducted on sub-Antarctic Macquarie Island on the 15th October every year, and annual populations' estimates made (Burton 2001). It is estimated that around one-seventh of the world's populations of Elephant Seals live on the island, and that they forage over vast areas of the southern ocean from Heard Island in the west to the Ross Sea in the east <http://www.aad.gov.au/default.asp?casid=3802>.

Species Inter-relations

The study of species interactions is another area where species-occurrence data is essential. Such inter-relationships can include parasitic relationships, symbiotic relationships between species of animals, species of plants or between animals and plants; predator-prey relationships, competition, etc.

Examples:

- A project is being conducted in the Guanacaste Conservation Area in Costa Rica to make an inventory of Eukaryotic parasites of vertebrates (Brooks 2002) <http://brooksweb.zoo.utoronto.ca/FMPro?-DB=CONTENT.fp5&-Format=intro.html&-Lay=Layout_1&-Error=err.html&content_id=1&-Find>;
- A project at Madang, in Papua New Guinea looked at host specificity of insect herbivores on 60 species of rainforest trees. The project needed to cross-reference data on habitats, hosts, insect species, patterns of host use, and sampling events (Basset *et al.* 2000);
- The Parasite Database at the University of Toronto maintains information on parasite-host relationships <http://brooksweb.zoo.utoronto.ca/index.html>;
- A project at the European Network for Biodiversity Information (ENBI) in collaboration with African countries, is studying Afrotropical Ceratitidine Fruit Flies using a queryable web site on species distribution of insects and host plants. <http://projects.bebif.be/enbi/fruitfly/>
- Another study in Costa Rica is looking at the parasites of freshwater turtles (Platt 2000) <http://brooksweb.zoo.utoronto.ca/pdf/Neopolystoma%20fentoni.pdf>;
- In Canada, the predator-prey relationship between the nemertean (*Crebatulus lacteaus*) and the soft-shell clam (*Mya arenaria*) is being studied (Bourque *et al.* 2002) <http://pubs.nrc-cnrc.gc.ca/cgi-bin/rp/rp2_abst_e?cjz_z02-095_80_ns_nf_cjz>;
- The World Federation of Culture Collections (WFCC) is supplying data via GBIF on interactions between parasites and hosts for many species <http://wdcm.nig.ac.jp/hpcc.html> as is the Belgian Co-ordinated Collections of Micro-organisms (BCCM) <http://wdcm.nig.ac.jp/hpcc.html>.

Protecting Communities

In Australia, new environmental protection legislation (DEH 2000) now allows for the listing of threatened communities in a similar way to the listing of threatened species. Communities can be listed as: critically endangered, conservation dependant or extinct in the wild and there are severe penalties for any significant impact on them. Primary species-occurrence data are used to determine boundaries and definitions prior to listing (Chapman *et al.* 2001).

Examples:

- Riverine aquatic protected areas: protecting species, communities or ecosystem processes? (Koehn 2003).

Life Histories and Phenologies

The study of life histories of both plants and animals is benefiting from the availability of species-occurrence data. The use if primary species data also aids the study of phenologies – being able to relate collections and records to the date and time of occurrence.

Life History Studies

Museum collections are a logical resource for life history studies. As stated by Pettit in 1991

> "*Using existing collections for such studies often enables large amounts of data to be accumulated in a short time on such things as fecundity/mortality patterns, host-parasite relationships, estimates of breeding seasons, micro-growth increments (many organisms show growth layers when sectioned, such as the 'rings' of a tree, and these can be used to study past environmental conditions), food pests, life-cycle duration, larval growth pattern, migration (museum collections have been used to locate locust outbreak sites and to track traditional migration patterns), species that mimic other animals, and other polymorphisms, plant fecundity, flowering and fruiting dates, periods of dormancy, and correlations of plant growing sites with rainfall or altitude*." (Pettitt 1991).

Many animals and plants have completely different life stages, and species-occurrence data can supply a wealth of information on the relationship between different stages in the life cycle, and geographic locations or times of the year.

Examples:

- In the study of the North American Wood Stork (*Mycteria americana*) in Florida, museum collections were used to show that clutch sizes had not significantly declined since 1875 (Rogers 1990). Herons and egrets have also been studied <http://web8.si.edu/sms/irlspec/Cl_Aves3.htm>;
- Wingpad development in Plecoptera was studied in Italy using museum collections (Zwick 2003) <http://www.unipg.it/maystone/PDF%202001%20proc/ZWICK2%20IJM%20proceedings.pdf>.

Phenology

Phenology is the study of the timing of naturally occurring events and their relationship of biotic and abiotic variables. Examples include the flowering of plants, arrival and departure times of birds, the outbreak of plagues of locusts, the time of egg laying by monotremes and birds, etc. Primary species data are a major resource of information that can be used in phenological studies.

Examples:

- The study of the time of egg-laying of the codling moth (*Cydia pomonella*) an important pest of apples and pears, is important in determining times of spraying, etc. <http://www.ipm.ucdavis.edu/PHENOLOGY/ma-codling_moth.html>;
- In Kansas, a database of the times of flowering of wildflowers and grasses has been compiled <http://www.lib.ksu.edu/wildflower/season.html>;
- In the United States, the flight speed and rate of migration of birds is being studied <http://www.npwrc.usgs.gov/resource/othrdata/migratio/speed.htm>;
- Species data are being used in phenological studies of turtle nesting and migration <http://www.natureserve.org/explorer/servlet/NatureServe?searchName=Chelonia+mydas>.

Endangered, Migratory and Invasive Species

Endangered, migratory and invasive species are three groups of species regarded as key groups in biodiversity management. Indeed, in Australia, they are legislated as “nationally significant” (DEH 2000). Species-occurrence data are essential for the understanding and management of these groups of species in the environment.

Endangered Species

Endangered species provide many challenges to biogeographers, modellers and conservation biologists. There are usually so few records that environmental modelling techniques seldom work well. However, threatened species are essential components of any conservation program and species-occurrence records often provide the only available information. Primary species-occurrence databases are important for the identification of endangered species, identifying the reasons why they are endangered, for identifying external factors affecting the species, and for assisting in the development of species recovery plans.

Examples:

- IUCN Red List of Threatened Species http://www.redlist.org/.
- Endangered Species Program of the U.S.A. – U.S. Fish and Wildlife Service <http://endangered.fws.gov/>;
- Threatened Species Program – Australian Department of the Environment and Heritage <http://www.deh.gov.au/biodiversity/threatened/index.html>.

Species Recovery Plans

Species Recovery Plans are becoming an integral part of threatened species management in many countries.

Examples:

- Recovery Plan for the Angle-stemmed Myrtle (*Austromyrtus gonoclada*) Queensland Parks and Wildlife Service <http://www.deh.gov.au/biodiversity/threatened/publications/recovery/a-gonoclada/index.html>
- Threatened Species Recovery Plans Australian Department of the Environment and Heritage <http://www.deh.gov.au/biodiversity/threatened/recovery/list-common.html>;
- Threatened Species Recovery Plans New Zealand Department of Conservation <http://www.doc.govt.nz/Publications/004~Science-and-Research/Biodiversity-Recovery-Unit/Recovery-plans.asp> ;
- Recovery Plan Summaries from Environment Canada <http://www.speciesatrisk.gc.ca/publications/plans/default_e.cfm>.

Threats

The study of threats to endangered species can also be enhanced through the use of primary species data – especially when those threats are other species such as predators or competitors. In Australia, key threatening processes are listed under legislation, and include such things as feral goats, the root-rot fungus (*Phyophthora cinnamomi*), the Fire Ant (*Solenopsis invicta*), etc.

Examples:

- Threat Abatement Plans – Australian Department of the Environment and Heritage <http://www.deh.gov.au/biodiversity/threatened/tap/index.html> ;

- Threats to Albatrosses and Giant-petrels <http://www.deh.gov.au/biodiversity/threatened/publications/recovery/albatross/index.html>;
- The introduction of the red imported fire ant, *Solenopsis invicta*, has caused a reduction in biodiversity of Australian native flora and fauna <http://www.deh.gov.au/biodiversity/threatened/ktp/fireant.html>.

Species Decline

The study of the decline in species numbers and distributions is an important step in preventing future endangerment and extinction in species and species habitats. Species-occurrence databases are an important information source for the study of both past declines and for monitoring current species numbers for prevention of future declines.

Examples:

- AmphibiaWeb <http://www.amphibiaweb.org/declines/declines.html>;
- FrogLog – Newsletter of the Declining Amphibian Populations Taskforce <http://www.open.ac.uk/daptf/froglog/>;
- At Cornell University in the United States, the status of birds are monitored to identify declining species <http://www.scsc.k12.ar.us/2000backeast/ENatHist/Members/BryanM/page%202.htm>;
- Predicting risk of extinction in declining species (Purvis *et al.* 2000) <http://www.bio.ic.ac.uk/evolve/docs/pdfs/Purvis%202000%20PRSLB.PDF>.

Invasive species and translocation studies

The spread of invasive alien and translocated species is one of the biggest environmental problems faced by most countries today. It is regarded by the Convention on Biological Diversity as the second most important threat to biodiversity after habitat change (CBD 2004). It is estimated that there are as many as 120,000 introduced species in the six countries made up of the United States, United Kingdom, Australia, India, South Africa and Brazil, alone (Pimentel 2002). Of these, perhaps 20-30% is now regarded as a pest species. The cost in economic loss of the 30,000 non-indigenous species in the United States has been estimated at close to $123 billion a year (Pimentel *et al*. 1999, 2000).

Not all introduced species become invasive. In the history of the United States it is estimated that approximately 50,000 non-indigenous species have been introduced (Pimental *et al.* 1999). Many of these of these have been used as food crops, livestock and farmed animals such as cattle and poultry, pets, biological control agents, landscape restoration, etc. However, those that have become pests cost the world a lot of resources every year in lost production, control and disease.

Preventing future invasions and predicting the impact of already introduced species requires accurate identifications and information on the natural distributions and ecological requirements of those species as well as associated species that may have positive or negative impacts with them (Page *et al.* 2004). The availability of species-occurrence data from different countries through projects such as GBIF, allows researchers to identify the native locations of invasive species, determine the niche characteristics in the form of climatic and environmental requirements, and then use this information to predict likely spread in the country of introduction.

It also allows researchers to look at the distribution of possible biological control species, and to use this information to examine the possible spread and environmental limitations of these before introduction.

The availability of this information now makes possible, studies into invasive species and biological control agents that has not been previously possible, and this alone more than justifies the costs of projects such as GBIF.

There are many studies already using such information, and links to over 80 case studies can be seen on the web site of the Convention on Biological Diversity at <http://www.biodiv.org/programmes/cross-cutting/alien/cs.aspx>.

Example:

- The Global Invasive Species Program (GISP) in an On-line toolkit that "provides advice, references, and contacts to aid in preventing invasions by harmful species and eradicating or managing those invaders that establish populations" <http://www.cabi-bioscience.ch/wwwgisp/gtcsum.htm>;
- Predicting the Geography of Species Invasions using Ecological Niche Modeling (Peterson 2003) < http://www.specifysoftware.org/Informatics/bios/biostownpeterson/P_QRB_2003.pdf>;
- In Kenya, the process of weed invasions have been tracked using herbarium specimens, showing that the regional spread of weeds in Kenya was correlated with the change in agricultural systems (Stadler *et al.* 1998);
- The spread if invasive Argentine Ants (*Linepithema humile*) across the United States over the past 100 years was studied by Suarez and others (2001) using both museum collections, and observations <http://www-biology.ucsd.edu/news/article_051500.html>;
- In New Zealand, bioclimatic prediction is being used to monitor the potential distribution of weeds prohibited entry to New Zealand (Panetta and Mitchell 1991);
- In North America studies are being carried out on the introduced Saltcedar (*Tamarix ramossisima*), which is becoming a major pest species in arid areas of Mexico where it is a huge user of water, aggressively replaces native riparian vegetation, and reduces habitat for birds and other animals. Distributions are being modelled in native and introduced habitats to assist planning in control and eradication (Soberón 2004);
- In Brazil and North America, the invasive potential of *Homalodisca coagulata* an insect vector of a bacteria of orchard-based crops was studied using distribution models with GARP (Peterson *et al.* 2003a);
- In Australia, invasive species are now listed under legislation and species-occurrence data are used to track their spread and to monitor their control <http://www.deh.gov.au/biodiversity/invasive/index.html>;
- Species distribution models were used to assess the invasive risk of several bird and insect species (Peterson and Vieglais 2001) <http://www.specifysoftware.org/Informatics/bios/biostownpeterson/PV_B_2001.pdf>;
- Timely identification of pests can reduce need for costly control programs <http://www.bionet-intl.org/case_studies/case17.htm>.
- Harlequin Ladybird (*Harmonia axyridis*) study – a survey of an invasive species in the UK <www.harlequin-survey.org>

Arthropods and Annelids.

Approximately 4,500 arthropod species (2,582 species in Hawaii and more than 2,000 in the continental United States) have been introduced to the United States (Pimental 1999). In addition many aquatic invertebrates and earthworms have arrived. According to Pimental loc. cit., about 95% of the introductions were accidental.

Examples:

- North American Non-Indigenous Arthropod Database (NANIAD) is an on-line database of over 2,000 species of non-indigenous arthropods introduced into the Unites States of America <http://www.invasivespecies.org/NANIAD.html>.

Ballast Water

Ballast water in ships is a major source of introduced alien species into coastal habitats around the world. The identification of these species is an international problem as they may arise from anywhere in the world. The ability to use on-line primary species databases provides a major step forward in the identification and eventual regulation and control of these species.

Examples:

- The Northern pacific seastar (*Asterias amurensis*) has virtually wiped out a species of shellfish and is a major threat to the marine environment. It is also adversely affecting the Tasmanian and Western Australian fisheries. It was not identified as an introduced species until 1992, and thus attempts to control it were delayed. Distributed primary species databases may help to prevent such delays occurring in the future <http://www.fish.wa.gov.au/hab/broc/invasivespecies/seastar/>;
- The Zebra Mussel (*Dreissena polymorpha*) originated in Poland and in the former Soviet Union, and after introduction in Ballast water are now causing problems throughout northern Europe and the United States, including in the Great Lakes between Canada and the United States <http://nas.er.usgs.gov/taxgroup/mollusks/zebramussel/>;
- In Australia, the Ballast Water Management Strategy uses species-occurrence data to identify, for example, where ballast water should not be taken on because of 'hot spots' of particular species that may become pests <http://www.affa.gov.au/content/output.cfm?ObjectID=6F3A6281-9705-4878-9FA6836B5D6D5814>.

Biological control of pests

The use of biological control agents to control pests has been in operation for around 50 years, and their use is increasing. Species-occurrence data are used to help find suitable biocontrol agents and to monitor their effectiveness and possible spread.

Examples:

- Biocontrol of mealybugs in South Africa <http://www.bionet-intl.org/case_studies/case2.htm>;
- Taxonomy is used in the selection of bio control agents in Hawaii <http://www.bionet-intl.org/case_studies/case15.htm>;
- Weevils are being used to control *Eichhornia crassipes* in Australia and elsewhere <http://aquat1.ifas.ufl.edu/hyacin.html>;
- Rabbits are controlled in Australia using various virus species <http://www.csiro.au/communication/rabbits/qa1.htm>.

Biological control gone wrong

The use of biological control agents must be controlled, otherwise disasters can occur. Species-occurrence data can be used to study locations of possible biological control agents, and to predict their possible spread in the proposed country of introduction. Not all biological control introductions in the past have worked.

Examples:

- In Australia, the Giant Cane Toad (*Bufo marinus*) was introduced into Australia in 1935 to control two introduced pests of the sugar cane industry – the Grey-backed cane beetle and the Frenchie beetle. CSIRO in Australia is mapping the spread through museum records

and observations
<http://www.csiro.au/index.asp?type=faq&id=CaneToadControl&stylesheet=sectorInformationSheet>;

- Many species have been introduced into Australia and South Africa to control *Lantana* species. The majority of these have not worked for a number of reasons, although some have worked in Hawaii and elsewhere. Different biological control agents have different effects on the different phenotypes of *Lantana* occurring in Australia, and the use of species-occurrence data to map the origins and spread of those phenotypes and the relationships of the bio-control agents in those areas can help improve success rates (Day and Nesser 2000).

Opuntia species in Mexico and the biological control agent Cactoblastis cactorum

Opuntia is one of the most used genera of plants in Mexico and Central America (Soberón *et al.* 2001), and is 10th in agricultural importance in Mexico (Soberón *et al.* 2000). The moth *Cactoblastis cactorum* is one of the best-known examples of a successful biological program when it was used in Australia in the control of *Opuntia* species in Queensland and northern New South Wales (Debach 1974). Fears have now arisen about the introduction of the Cactoblastis moth into Mexico, and the Commission on the Conservation and Use of Biodiversity in Mexico (Conabio) is modelling the potential spread and impacts of the moth there.

Examples:

- Using species-occurrence data and species distribution modelling to examine the potential spread and impact of *Cactoblastis cactorum* on the more than 90 species of native cactus species in Mexico and North America (Soberón *et al*. 2001) <http://www.fcla.edu/FlaEnt/fe84p486.pdf>.

Studying coeveolutionary patterns

Museum collections have even been used to examine the rapid evolutionary response and adaptation of weeds to new environments.

Examples:

- In North America, studies on the co-evolution of parsnip (*Pastinaca sativa*) with the parsnip web worm (*Depressaria pastinacella*) have examined seeds from herbarium specimens to compare chemical co-evolution of the plants with the insect (Berenbaum and Zangerl 1998). http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=24890 .

Migratory Species

Migratory species, virtually by definition, range across political boundaries and thus their study requires data from a range of jurisdictions. In the past, it has been difficult to obtain data from areas of a species range that one may be studying from outside the researcher's own country. The availability of distributed data systems is now allowing for new opportunities for migratory species studies. Various agreements are now in place around the world to track and monitor migratory species and to exchange information, including species-occurrence data.

Examples:

- Convention on Migratory Species (Bonn Convention) <http://www.cms.int/>;
- Japan-Australia Migratory Bird Agreement (JAMBA) <http://www.austlii.edu.au/au/other/dfat/treaties/1981/6.html> and China-Australia Migratory Bird Agreement <http://www.austlii.edu.au/au/other/dfat/treaties/1988/22.html>;
- African-Eurasian Migratory Water Bird Agreement <http://www.unep-wcmc.org/AEWA/index2.html>;

- Global Register of Migratory Species (GROMS) <http://www.groms.de/>.
- Migratory Birds know no Boundaries An extensive information resource from Israel on migratory birds <http://www.birds.org.il/>

Tracking Migratory Species

The tracking of migratory species and where they move has been an ongoing process for many years. One of the problems in the past has been the lack of access to species-occurrence data. With the new availability of species-occurrence data, data from all the range states can be combined to track and monitor changes in patterns of behaviour, decline in numbers, life spans etc. Tracking may be through observation and counts, through banding and recapture, through use of satellite tracking devices, or by use of radioactive isotopes.

Examples:

- European Union for Bird Ringing <http://www.euring.org/>;
- Australian Bird and Bat Banding Scheme (ABBBS) <http://www.deh.gov.au/biodiversity/science/abbbs/>;
- The Monarch Butterfly (*Danaus plexippus*) migration is tracked from Mexico to the United States each year through the use of banding <http://www.uen.org/utahlink/activities/view_activity.cgi?activity_id=2030>;
- Hydrogen isotopes (heavy water or deuterium) are being use to track Monarch Butterfly (*Danaus plexippus*) breeding and feeding grounds (Wassenaar and Hobson 1998) <http://whyfiles.org/083isotope/2.html>;
- In Malaysia, sea turtles are being tracked across the world's oceans using satellite tracking devices <http://www.kustem.edu.my/seatru/satrack/>.

Monitoring Adelie Penguins in the Antarctic

The Adelie penguin has been identified as an important krill-dependent indicator species and is being used to monitor changes in critical ecosystem components for use in assessment of the conservation of marine living resources in the Antarctic. One project (Southwell and Meyer 2003) is studying the degree to which the feeding range of the penguins overlaps with the krill fishery in both time and space; variations in the penguins breeding success and food consumption from year to year and the factors responsible; and how much krill can be fished without affecting the penguins that depend on it.

Examples:

- Tracking Adelie penguins around Casey Station to monitor feeding habits (Kerry *et al.* 1999) <http://aadc-maps.aad.gov.au/aadc/metadata/metadata_redirect.cfm?md=AMD/AU/Tracking_SI>;
- Adelie penguin research and monitoring in support of the CCAMLR Ecosystem Monitoring Project Antarctic Science Project No. 2205 <http://cs-db.aad.gov.au/proms/public/report_project_public.cfm?project_no=2205>.

Wandering albatrosses and petrels

Albatrosses wander for thousands of miles around the southern oceans and generally only ever touch land to breed. Little is known of the movements of the different species and individuals – how far they range, where do they over winter, etc. Primary species-occurrence data are being gathered through the use of satellite tracking and observation (Croxall *et al.* 1993).

Examples:

- Platform Terminal Transmitters have been attached to Tasmanian Shy Albatrosses to track albatrosses over a four month period <http://www.wildlifebiz.org/The_Big_Bird_Race/152.asp>;

- Two species of albatross were tracked around Heard Island in the Antarctic <http://www.aad.gov.au/default.asp?casid=14718>;
- Satellite tracking of petrels and albatrosses from the tropics to the Antarctic (Catard and Weimerskich 1998).

Impact of Climate Change

Climate change threatens the survival of ecological communities, individual species, and human health and wellbeing. There have been many studies on the impact of climate change on human populations, on roads and dams, island populations, etc. Fewer studies, have examined the impact of climate change on biodiversity, but the use of species-occurrence data in environmental models to examine impacts is increasing, and studies have shown that impact is likely to be considerable. Howden *et al.* (2003), for example, identified impacts on Australia's coral reefs, on rainforests and rangelands, and on the distribution of birds, plants and reptiles. Recent studies have indicated that as many as 18-35% of species will become extinct before 2050 due to climate change (Thomas *et al.* 2004).

On Native Species

The availability of species-occurrence records through distributed systems such as the GBIF Portal has opened up new areas of research, and allows climate change impacts to be studies across ranges of species, climates and regions.

Examples:

- Studies in Australia on the impact of climate change on threatened species, estimated reductions in core climate habitat of between 82 and 84% with 12% of threatened species predicted to become extinct by 2030 (Dexter *et al.* 1995), and even currently non-threatened species with limited distributions, or with specific habitat or soil requirements were likely to be significantly impacted (Chapman and Milne 1998);
- Studies in Mexico looked at the impact of climate change on the fauna (Peterson *et al.* 2002a) <http://www.specifysoftware.org/Informatics/bios/biostownpeterson/Petal_N_2002.pdf>;
- A study in Brazil looked at the impact of climate change on cerrado species, and examined implications for conservation assessment and reserve selection (Siqueira and Peterson 2003) <http://www.biotaneotropica.org.br/v3n2/en/download?article+BN00803022003+item>;
- A study of 35 non-migratory European butterflies showed a major shift north in distribution over the past century of from 35-240 km that the authors contributed to global warming (Parmesan *et al.* 1999) <http://www.biosci.utexas.edu/IB/faculty/parmesan/pubs/Parm_Ntr_99.pdf>;
- Studies in birds in America has shown a shift in breeding dates in tree swallows (Dunn and Winkler 1999);
- A study of the adaptation of migratory birds to global climate change was conducted using the European Pied Flycatcher (*Ficedula hypoleuca*) Coppack and Both 2003) <http://www.rug.nl/biologie/onderzoek/onderzoekgroepen/dierOecologie/publications/803Pdf.pdf>.

On Primary Production

Not all climate change is detrimental, and for agriculture, some species will benefit. Other species will grow in places where they have previously been marginal.

Examples:

- In Australia, it is predicted that wheat yield may increase in some areas (Nicholls 1997);

- Studies in Denmark have shown that global climate change is likely to increase yields at high and mid-latitudes (Olesen 2001) <http://glwww.dmi.dk/f+u/publikation/dkc-publ/klimabog/CCR-chap-12.pdf>;
- Research is predicting that different agricultural and forest species will need to be planted in different areas, some areas will require the planting of new varieties, other species will need to be planted earlier, pesticide controls will need to be altered and water regimes may need to be examined <http://www.gcrio.org/gwcc/booklet2.html>.

Desertification

Climate change and desertification are two big issues facing the world. Priimary species data are being used as indicators of diversification under climate change

Examples:

- Grassroots indicators for desertification. Experience and Perspectives from Eastern and (Hambly and Angura 1996);
- Global Biodiversity Forum on Linking biodiversity and desertification: a strategic perspective <http://www.gbf.ch/desc_workshop_old.asp?no=6&app=&lg=EN&now=2>.
- In Cuba, biodiversity data are being used to develop an index of desertification (Negrin *et al.* 2003) <http://www.unccd.int/actionprogrammes/lac/national/2003/cuba-spa.pdf>;
- The trialogue of climate change, biodiversity and desertification <http://www.gdrc.org/uem/Trialogue/trialogue.html>.

Ecology, Evolution and Genetics

Primary species-occurrence data provides the raw material for revealing patterns, processes, and causes of evolution and ecological phenomena (Krishtalka and Humphrey 2000). The study of vegetation structure and composition is largely dependant on the availability of species-occurrence data. Much of the world's vegetation has been altered in recent centuries and thus the reconstruction of pre-settlement vegetation cover requires a combination of primary species data and modelling against soils, climate, and topography, etc.

Vegetation Classification

The classification and description of vegetation is a first step in understanding the vegetation, its functions and attributes. Primary species-occurrence data are essential for both the classification and description.

Examples:

- Gillison and Carpenter (1994) used functional attributes for the description and analysis of vegetation <http://www.cifor.cgiar.org/publications/pdf_files/WPapers/WP-03n.pdf>;
- VegClass: Vegetation Classification tool <http://www.cifor.cgiar.org/docs/_ref/research_tools/vegclass/>;
- UK Habitat Classifications <http://www.jncc.gov.uk/habitats/habclass/default.htm>;
- Vegetation Classification Standards (Federal Geographic Data Committee) < <http://www.fgdc.gov/standards/status/sub2_1.html>;
- Vegetation of southern Africa <http://www.plantzafrica.com/vegetation/vegmain.htm>.

Mapping Vegetation

Vegetation mapping is a key process in understanding the environment, and in providing a context for studying species and their associations. Vegetation mapping covers both the mapping of current vegetation cover as well as interpretation of past vegetation cover in areas that may now be cleared for urbanization, agriculture, etc.

Examples:

- Checklist of Online Vegetation and Plant Distribution Maps (Englander and Hoehn 2004) <http://www.lib.berkeley.edu/EART/vegmaps.html>;
- Australian National Vegetation Information System (NVIS) is using species distribution data from herbaria and on-ground survey to prepare a detailed vegetation map for the continent <http://audit.ea.gov.au/ANRA/vegetation/vegetation_frame.cfm?region_type=AUS&region_code=AUS&info=NVIS_framework>;
- The Australian Natural Resources Atlas v. 2.0 examines native vegetation types and extent in Australia, and looks at what the vegetation was like prior to European settlement <http://audit.ea.gov.au/ANRA/vegetation/vegetation_frame.cfm?region_type=AUS&region_code=AUS&info=veg_type>;
- USGS-NPS Vegetation Mapping Program <http://biology.usgs.gov/npsveg/>;
- Florida Coastal Everglades LTER Sited – Vegetation Map <http://fcelter.fiu.edu/maps/>.

Habitat loss

Habitat loss (including fragmentation) is considered to be one of the largest threats to biodiversity. The study of habitat loss is again dependant upon the availability of species-occurrence data – including data from museums as well as survey.

Examples:

- The study of woodland birds in Australia has shown a major decline as habitat fragmentation increases <http://www.wilderness.org.au/campaigns/landclearing/nsw/birdecline/>;
- Museum collections were used to show a change in proportions between species of small mammals in the prairies of Illinois coincided with habitat destruction (Pergams and Nyberg 2001) <http://home.comcast.net/~oliver.pergams/ratio.pdf>;
- A study of tropical forests in the Mbalmayo Forest Reserve in Camaroon, examined species richness for eight groups of animals and compared them with increased disturbance (Lawton *et al.* 1998) <http://invertebrates.ifas.ufl.edu/LawtonEtal.pdf>.

Ecosystem function

Ecosystem function describes the way in which ecosystem processes interact internally between its component organisms and externally with the physical environment, and include such processes as nutrient cycling, decomposition, water and energy balance, and flammability. Ecosystem health (Costanza *et al.* 1992) is very dependant on efficient ecosystem function. Many ecosystems around the world are currently undergoing dramatic changes in species composition due to the influence of human activity. These changes often lead to a reduction in species diversity and species richness and to changes in species composition. How these changes affect overall function of the ecosystem and thus its health is the subject of on-going research. This research is very dependant upon the availability of primary species-occurrence data.

Examples:

- The role of biodiversity in ecosystem function (Gillison 2001) <http://www.asb.cgiar.org/docs/SLUM%5C05-Ecological%20functions%20of%20biodiversity%5C05-2%20Does%20biodiversity%20play%20a%20significant.ppt>;
- Biodiversity and ecosystem function online <http://www.abdn.ac.uk/ecosystem/bioecofunc/>;
- BIODEPTH is a program looking at cosystem functioning in terrestrial herbaceous ecosystems <http://www.cpb.bio.ic.ac.uk/biodepth/contents.html>;
- BIOTREE is a long term project looking at tree diversity and function in temperate forests <http://www.biotree.bgc-jena.mpg.de/mission/index.html>;
- Soil microbiology is thought to have a key role in efficient ecosystem functioning (Zak *et al.* 2003) <http://www.bio.psu.edu/ecology/calendar/Zak.pdf >.

Survey Design - Finding the Gaps

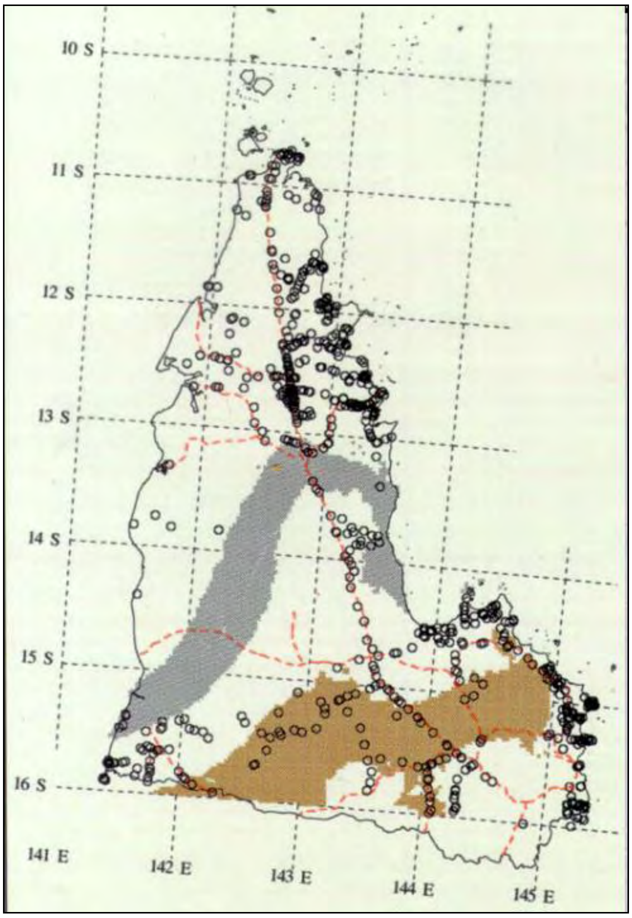

Fig. 7. *Environmental regions using climate classes derived from mean annual rainfall and temperature were identified and mapped using GIS. The proportion of biological collections was determined for each class, and surveys planned in areas that were relatively under-surveyed (Neldner et al. 1995).*

Species occurrence data are a key resource in determining priorities for planning future survey. Although some scientists fear that making their data available electronically will reduce funding support for new biotic surveys and collections (Krishtalka and Humphrey 2000), the opposite is proving to be the case, with increased support for gap filling. By making the data available, geographic, taxonomic and ecological gaps in knowledge are more easily identified, and thus new surveys and survey locations can be planned efficiently and with increased cost-effectiveness (Chapman and Busby 1994).

Examples:

- The U.S. GAP Analysis Program aims at identifying gaps in species conservation <http://www.gap.uidaho.edu/>;
- In Australia, environmental and species modelling and biological regionalisation was used to identify key areas of the Cape York Peninsula for further survey (figure 5). A program called VISTR (Visualisation of Taxa, Samples and Regions) was developed (Neldner *et al.* 1995);
- Tour 1 from GBIF Demonstration Project 2003: on the reliability and consistency of Neotropical species distributions can be used to determine appropriate sites for future survey <http://gbifdemo.utu.fi/>;

- A BIOCLIM analysis was used in Australia to predict likely habitat for Tarengo Leek Orchid (*Prasophyllum petilum*) based on climatic parameters of the known populations (NSW National Parks and Wildlife Services 2003) <http://www.nationalparks.nsw.gov.au/PDFs/recoveryplan_draft_prasophyllum_petilum.pdf>;
- The South Dakota Gap Analysis program used distributions of native vertebrates to determine survey locations <http://wfs.sdstate.edu/sdgap/sdgap.htm>.

Evolution, Extinction and Genetics

Species-occurrence data have been used to study evolution of species, to examine likely species distributions under previous climates, to examine causes of extinctions and to study genetic relationships.

Examples:

- Bioclimatic profiles of a species of *Nothofagus* (*Nothofagus cunninghamii*) were used to estimate Holocene climates in Tasmania (McKenzie and Busby 1992);
- Pollen evidence was used to reconstruct palaeoenvironments in the lower Gordon River valley in Tasmania (Harle *et al.* 1999);
- Species data are used to infer phylogenies <http://evolution.genetics.washington.edu/book/datasets.html>;
- The use of Ring species and DNA can infer evolutionary patterns in a range of species <http://www.origins.tv/darwin/rings.htm>;
- Studies in Australia are examining the reasons for extinction of the megafauna and the evolution of modern Australian faunal species <http://science.uniserve.edu.au/school/quests/mgfauna.html>;
- Evolution and Mass Extinction (Hunt 2001) <http://cwx.prenhall.com/bookbind/pubbooks/freemanea2/chapter3/custom5/deluxe-content.html>;
- In Canada, a range of projects is looking at Molecular Systematics and Conservation genetics. Projects include the conservation genetics of endangered species, evolution of unisexuality in reptiles, detection of cryptic species using DNA, etc. <http://www.rom.on.ca/biodiversity/cbcb/cbmolecu.html>;
- A study of the evolutionary history of amphibians used molecular data (Feller and Hedges 1998) <http://evo.bio.psu.edu/hedgeslab/Publications/PDF-files/101.pdf>;
- The evolution of pattern and mimicry is being studied with butterflies <http://evo.bio.psu.edu/hedgeslab/Publications/PDF-files/101.pdf>.

Genomics

Genomics is the study of genes and their functions. Primary species-occurrence data are being used in the study of genomics through frozen tissue collections, such as those at the American Museum of Natural History,

Examples:

- Plant Genome Databases <http://www.nal.usda.gov/pgdic/>;
- Institute for Comparative Genomics, American Museum of Natural History <http://www.amnh.org/science/facilities/hayden.php>;
- Using genetic data for conservation of the Arabian oryx (Marshall *et al.* 1999) <http://www.latrobe.edu.au/genetics/staff/sunnucks/homepage/papers/AnimalCons/Marshalletal98.pdf>;
- Ancient DNA techniques are being used to observe evolutionary processes and to construct phylogenetic trees from fossil bones discovered in the permafrosts of Alaska (Shapiro and Cooper 2003);

- In Finland, adaptive variation is being studied using genomes <http://cc.oulu.fi/~genetwww/plants/adaptive.html>;
- DNA bar-coding is being examined for use in biological identifications and conservation (Herbert *et al.* 2003) <http://barcoding.si.edu>.

Bioinformatics

In genome terms, bioinformatics includes the development of methods to search databases quickly, to analyse DNA sequence information, and to predict protein sequence and structure.

Examples:

- GenBank Database <http://www.ncbi.nlm.nih.gov/Genbank/GenbankOverview.html>;
- EMBL – European Molecular Biology Laboratory <http://www.embl-heidelberg.de/>;
- Bioinformatics: Sequence, Structure and Databanks – A Practical Approach (Higgins and Taylor 2000).

Microbial diversity and speciation

James T. Staley[2]

Since bacteria are the most ancient group of living organisms it is not surprising that the Tree of Life, based on small ribosomal RNA sequence analysis, indicates there are at least 40 kingdoms. Considering this high degree of diversity and the fact that micro-organisms are found in all ecosystems, some of which are extreme environments such as boiling hot springs and acidic habitats at pH 1, it is noteworthy that only about 6,000 species of Bacteria and Archaea have been described and named. One reason for the low number of species is that the species concept used for bacteria is very broad in comparison with that for animals and plants. Scientists are now questioning the microbial species concept not only because of its breadth, but because none of the known bacterial species can be considered endemic to a specific location on Earth. Recently, evidence for endemism has been reported when scientists look at the subspecies level.

Multi-locus sequence analyses of protein genes that are less highly conserved than ribosomal RNA are being used for studies of endemism.

Example:

- One example is that of *Helicobacter pylori* a human pathogen that causes gastric ulcers that may eventually lead to stomach cancer. Using sequence analysis of several protein genes, it has been found that human migration patterns can be discerned by the strains of *H. pylori* that have been harboured in *Homo sapiens* since they dispersed from Africa. Thus, the Maori strains of *H. pylori* contain unique strains that are clearly different from those of European ancestry whose populations migrated to New Zealand more recently. African strains were found in high frequency in West Africa as well as in African Americans. Other patterns have been discerned that can also be explained by human migrations that have occurred in the past 50,000 years (Falush *et al.* 2003);
- Evidence that non-pathogenic bacteria are endemic to hot spring habitats has been recently reported in this newly emerging field. If speciation events are occurring at the subspecies level in micro-organisms, this argues for the need for a redefinition of microbial species. Also, if endemic bacteria exist, this information could be very helpful in forensic studies, because the microbiota on objects removed from an area may contain genetic information about the source of the object;

[2] This section was authored by James T. Staley, University of Washington, Seattle, WA, USA.

- The study of speciation is the new revolution in microbiology. Eventually, the numbers of microbial species may exceed many millions.

Archaeological studies

Primary species-occurrence data in the form of fossil collections in museums are used in studying the archaeological history of species.

Examples:

- Researchers at the Illinois State Museum in Springfield are using museum-based fossil data in the scientific literature to plot ranges of North-American mammals over the last 40,000 years on computer-generated maps (Cohn 1995);
- New fossils in Ethiopia open a window on Africa's 'missing years' (Washington University in St. Louis News and Information) <http://news-info.wustl.edu/news/page/normal/575.html>;
- African Archaeological Database < <http://www.archaeolink.com/african_archaeology.htm>;
- The Age of the Megafauna (Australian Broadcasting Commission) <http://news-info.wustl.edu/news/page/normal/575.html>;
- The Zooarchaeology Laboratory Comparative Vertebrate Collection at the Arizona State Museum provides a resource for archaeological studies < <http://www.statemuseum.arizona.edu/zooarch/zooarch_browse.asp>.

Environmental Regionalisation

The dividing of an area into regions with similar environmental conditions is possible with the use of species information in conjunction with environmental data and remote-sensing images. Such regionalisations can be used for environmental planning at scales from regional to continental.

National Planning studies

Environmental regionalisations are an extremely valuable tool for planning of conservation and use of natural resources. In Australia, the Interim Biogeographic Regionalisation of Australia (figure 8) is used extensively for conservation planning, sustainable resource management and environmental monitoring.

Examples:

- Interim Biogeographic Regionalisation of Australia (IBRA) was developed using species data, remote sensing data and climate data (Thackway and Cresswell 1995) <http://www.deh.gov.au/parks/nrs/ibra/version5-1/index.html>;
- The Australian Government is using bioregions for setting of priority bioregions for developing a national reserve system <http://www.deh.gov.au/parks/nrs/ibra/priority.html>.

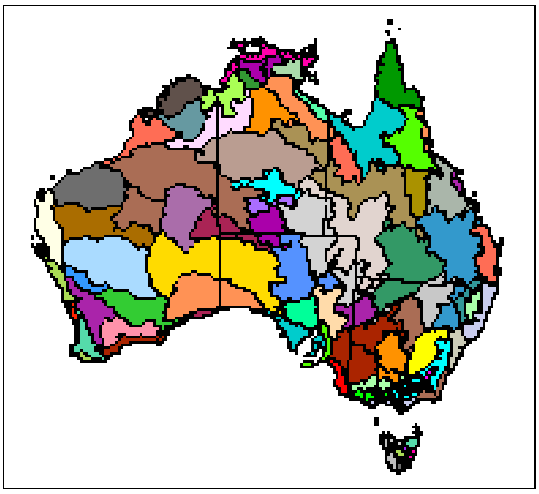

Fig. 8 *The Interim Biogeographic Regionalisation for Australia (IBRA) is a framework for conservation planning and sustainable resource management within a bioregional context. Regions represent a landscape based approach to classifying the land surface using a range of continental data on environmental attributes.*

Regional Planning Studies

Bioregional planning involves the development of approaches for identifying and characterising regional environmental patterns for use in environmental assessment and planning (Chapman and Busby 1994).

Examples:

- Bioregions are being used in Zimbabwe for conservation planning and for erosion control <http://www.lancs.ac.uk/fss/politics/people/esrc/pppage2.html>;

- A New Biogeographic Regionalisation for Tasmania (Peters and Thackway 1998) <http://www.gisparks.tas.gov.au/dp/newibra/Title&Background.htm>;
- The Australian Government is using bioregions for integrating conservation and regional planning <http://www.deh.gov.au/biodiversity/planning/index.html>. An example is with the Wimmera Catchment Management Authority Pilot Project (Birds Australia 2003) <http://www.deh.gov.au/biodiversity/publications/wimmera/methods.html>.

Marine Regionalisations

Creating meaningful environmental regionalisations of marine areas is not as simple as for terrestrial areas, however they are just as important for conservation planning.

Examples:

- The Interim Marine and Coastal Regionalisation for Australia was created using environmental data such as bathymetry along with species data <http://www.deh.gov.au/coasts/mpa/nrsmpa/imcra.html>;
- Global 200 Ecoregions: Marine <http://www.nationalgeographic.com/wildworld/profiles/g200_marine.html>;
- Canada's National Marine Conservation Areas System Plan <http://www.pc.gc.ca/progs/amnc-nmca/plan/index_E.asp>.

Aquatic Regionalisations

Aquatic regionalisations are not as common as terrestrial or marine, but are used for managing aquatic ecosystems

Example:

- The management of aquatic ecosystems using macroinvertebrate regionalisations (Wells *et al.* 2002).

Conservation Planning

In order to conserve biodiversity in a long-term sustainable manner, it is important to use species-occurrence data to determine conservation priorities. It is not possible to preserve all populations of all species on earth (Margules *et al.* 2002). It is not even possible to conserve representatives of all species in traditional reserves. Biodiversity has only recently become the most important consideration in reserve selection. Key elements of the priority setting process are complementarity, replication, representativeness and irreplaceability.

Gaston and others (2002) identified six distinct phases in the conservation planning process. The first of these is the compiling of data on biodiversity, reviewing existing data, collecting new data where time and resources permit, and collecting details on locations of threatened and other priority species in the region. The data are an essential first step, and none of the other processes will or can operate without the relevant data.

Rapid Biodiversity Assessment

Most rapid biodiversity assessment projects require extensive amounts of species-occurrence data in order to come up with a meaningful result. Such projects have been very expensive, and the collection of data, and especially species-occurrence data, has been the most time-consuming aspect of these projects (Nix *et al.* 2000)

Examples:

- The BioRap biodiversity assessment and planning study of Papua New Guinea <http://www.amonline.net.au/systematics/faith5a.htm>;
- Papua New Guinea Country Study on Biological Diversity (Sekhran and Miller 1995);
- Amazonian Biodiversity Estimation <http://www.amazonia.org/SustainableDevelopment/Jauaperi/Biodiversity/ALMA/ABDE/ABDE_3.htm>;
- Rapid biodiversity surveys in Indonesia <http://www.opwall.com/Indonesia_biodiversity_surveys.htm>;
- Rapid Ecological Assessment in the Spanish Creek Wildlife Sanctuary in Belize <http://biological-diversity.info/Spanish_Creek.htm>.

Identifying Biodiversity Priority Areas

Biodiversity conservation planning and assessment requires the identification of areas that represent the biological diversity of a region, country or biome (Margules and Redhead 1995). Setting priorities involves deciding what biodiversity to conserve and how much of each species, etc.

Examples:

- Tools for Assessing Biodiversity Priority Areas (Faith and Nicholls 1996);
- Practical application of biodiversity surrogates and percentage targets for conservation in Papua New Guinea (Faith *et al.* 2001);
- Biodiversity World – conservation assessment using biodiversity modelling <http://www.bdworld.org/index.php?option=content&task=view&id=16&Itemid=25>;
- The Biodiversity Toolbox for Local Government is designed to provide councils with the tools, resources and contacts to integrate biodiversity conservation <http://www.deh.gov.au/biodiversity/toolbox/index.html>;
- National Land and Water Resources Biodiversity Assessment (Identifying Priorities for Conservation)

<http://audit.ea.gov.au/ANRA/vegetation/vegetation_frame.cfm?region_type=AUS&region_code=AUS&info=bio_asses>;
- Establishing marine priority areas <http://www.mcbi.org/marineprotected/Marine.htm>;
- Workshop on priority-setting for biodiversity conservation <http://www.earth.nasa.gov/science/biodiversity/section_d2.html>;
- Papua New Guinea Conservation Needs Assessment (Alcorn 1993).

Reserve Selection

Once biodiversity assessment has been carried out, and priority areas for biodiversity identified, the next step is to select appropriate areas for reserves.

Examples:
- Gap Analysis is used in Idaho in the United States for reserve selection <http://www.gap.uidaho.edu/Bulletins/9/bulletin9/bulletin9html/aaoarsafipobanme.html>;
- The Australian Museum has a program to examine the use of genetic criteria in reserve selection <http://www.amonline.net.au/evolutionary_biology/research/projects/gcrs.htm>;
- Another project at the Australian Museum is looking at using dung beetles as indicator species to measure and compare genetic diversity and evaluating their use in reserve selection <http://www.amonline.net.au/evolutionary_biology/research/projects/ressel.htm>;
- A study in British Columbia examined sensitivities of reserve selection to decisions about scale, biodiversity data and targets (Warman *et al.* 2004);
- Margules and Pressey (2000) stressed the importance of both off-reserve and on-reserve conservation and the need to manage whole landscapes for production and protection;
- Gap Analysis and reserve selection reference list <http://www.apec.umn.edu/faculty/spolasky/reserve.PDF>;
- Pattern analysis allows for environmental representativeness in reserve selection (Belbin 1993);
- Designing protected areas and using critical habitat corridors for giant pandas in China (MacKinnon and De Wulf 1994).

Complementarity

The idea of complementarity is to select a set of conservation areas that together contribute a representation of a maximum number of species (Margules *et al.* 1988). Complementarity is an iterative process – for example if you are wanting every species represented, complementarity chooses the first area with the most species, then it looks for the next area that has the most species not already represented and so on. Species-occurrence data are essential in determining areas using these algorithms.

Examples:
- Complementarity, biodiversity viability analysis and policy-based algorithms for conservation (Faith *et al.* 2003);
- Identifying top priority areas as those that make the highest contribution to a representative complementary set (Faith and Walker 1997);
- A new database on the distribution of vertebrate species in a tropical continent allows new insights into priorities for conservation across Africa (Brooks 2001);
- In Oregon, reserve-selection algorithms were compared using terrestrial vertebrate data (Csuti *et al.* 1997);

- A recent whole-country planning study for Papua New Guinea illustrated the importance of complementarity-based trade-offs in determining conservation priorities (Faith and Walker 1996) <http://www.ias.ac.in/jbiosci/jul2002/393.pdf>.

Ex-situ Conservation

Not all biodiversity conservation can occur in formally established conservation reserves. Off-reserve or ex-situ conservation is also important and zoological and botanical gardens play an important role in the conservation of rare and threatened species and in captive breeding programs. Species-occurrence data are essential sources of information for institutions and individuals running ex-situ conservation programs.

Zoological Gardens

Zoos now play a major role in conservation of rare species. Many zoos have captive breeding programs, and some are being used to breed up populations of rare species for release back into the wild.

Examples:

- The Przewalski horse is being bred in zoos around the world for release back into the wild <http://www.imh.org/imh/bw/prz.html>;
- The IUCN is backing the captive breeding of foxes, wolves, jackals and dogs for reintroduction to the wild <http://www.canids.org/1990CAP/10captvb.htm>;
- Reproductive tissue from endangered animals is being preserved in Australia for future breeding programs <http://www.monash.edu.au/pubs/eureka/Eureka_95/freeze.html>;
- In 1995, zoological institutions around the world developed the World Zoo Conservation Strategy <http://www.zoo.nsw.gov.au/content/view.asp?id=47>.

Botanical Gardens

Botanical gardens play a similar role to zoos, but with plants. Many rare plants are grown and bred for release to nurseries, thus releasing pressure on wild populations, some species are reintroduced into the wild, and others are conserved in the gardens themselves.

Examples:

- The Green Legacy - botanical gardens and conservation in Canada <http://www.rbg.ca/greenlegacy/pages/botanical_pg2.html>;
- The growing of rare plants in Australian botanical gardens <http://www.anbg.gov.au/chabg/bg-dir/collections.html>;
- The Weight of a Petal: The Value of Botanic Gardens (Bruce Rinker) <http://www.actionbioscience.org/biodiversity/rinker2.html>;
- A Handbook for Botanic Gardens on Reintroductions of Plants to the Wild (Akeroyd and Wyse-Jackson 1995);
- A Reference List for Plant Re-Introductions, Recovery Plans and Restoration Programmes (Royal Botanic Gardens Kew) <http://www.rbgkew.org.uk/conservation/reintro.html>;
- The location of the Wollomi Pine (*Wollemi nobilis*) in Australia was kept secret while botanic gardens grew stock for distribution to nurseries to reduce pressure on wild stocks <http://home.bluepin.net.au/yallaroo/conservationandcult.htm>.

Wildlife parks

Wildlife parks – both zoological and botanical – are another place where ex-situ conservation is occurring.

Examples:

- The South Lakes Wild Animal Park in the UK has a large conservation program <http://www.wildanimalpark.co.uk/>;
- San Diego Zoo's Wild Animal Park also has some major conservation programs <http://www.sandiegozoo.org/conservation/zooprojects.html>;
- Cleland Conservation Park in South Australia aims to conserve both animals and plants <http://www.environment.sa.gov.au/parks/cleland/>;
- Many private sanctuaries are being established for the preservation of plants and animals <http://www.environment.sa.gov.au/biodiversity/sanctuary.html>.

Sustainable Use

There is an increasing move towards mixing conservation and sustainable use. Not all countries can lock up land in traditional conservation reserves, and are developing sustainable use areas ustilising local communities and biodiversity data.

Examples:

- In South Africa, the Ezemvelo Nature Reserve is being proposed as a economically independent conservation-based reserve that utilises its natural resources in a sustainable manner (Sonnekus and Breytenbach 2001);
- In Costa Rica, the Guanacaste Conservation Area has been set up as a sustainable-use reserve with the support of the local community (Janzen 1998, 2000);
- The United Nations Man and the Biosphere Programme aims to reconcile the conservation of biodiversity with its sustainable use <http://www.unesco.org/mab/>.

Seed Banks and Germplasm Banks

The conservation of biodiversity through the long-term storage and preservation of seeds and germplasm is another use to which species data is being put.

Examples:

- Millenium Seed Bank Project is a global collaborative project to safeguard plant species from extinction <http://www.kew.org/msbp/>;
- The Chinese Academy of Sciences is developing a germplasm bank for wildlife of SW China <http://english.cas.ac.cn/english/news/detailnewsb.asp?infoNo=24630>;
- GenBank Database <http://www.psc.edu/general/software/packages/genbank/genbank.html>.

Natural Resource Management

Improved information on biodiversity will enhance the ability of resource managers to identify areas of high species diversity, high endemism, and exploitable resources, and improve efforts at protecting and managing natural resources. (Page *et al.* 2004)

Land Resources

The need for management of land resources in a sustainable manner is becoming recognised as an increasingly important issue. The increasing wealth of high-resolution biodiversity data is essential for landuse planning and management decisions.

Examples:

- Natural resource management and vegetation – an overview – Australia. <http://audit.ea.gov.au/ANRA/vegetation/vegetation_frame.cfm?region_type=AUS&region_code=AUS&info=NRMV_overview>;
- Regional Land Use Plans and Land Resource Management Plans (LRMPs) in British Columbia <http://srmwww.gov.bc.ca/rmd/lrmp/>;
- In Cuba, biodiversity data are being used to fight against desertification (Negrin *et al.* 2003) <http://www.unccd.int/actionprogrammes/lac/national/2003/cuba-spa.pdf>;
- Managing Natural resources in Africa and the Middle East <http://web.idrc.ca/en/ev-3313-201-1-DO_TOPIC.html>;
- The IUCN Sustainable Use site <http://www.iucn.org/themes/sustainableuse/>;
- South African Institute for Natural Resources <http://www.inr.unp.ac.za/>.

Water Resources

Water resource management, involves sustainable management and use including the development of water quality indicators and the biological control of weeds.

Examples:

- Population growth (with demands for agriculture and hydroelectric power) is combining with climate change to create water stress in Africa (Schultze *et al*. 2001);
- The World Bank – Water Resource Management site <http://lnweb18.worldbank.org/ESSD/ardext.nsf/18ByDocName/WaterResourcesManagement>;
- US-China Water Resource Management Program <http://www.lanl.gov/projects/chinawater/main.html>;
- Macroinvertebrates are used as indicators of water quality (Maryland Department of Natural Resources) <http://www.dnr.state.md.us/streams/pubs/freshwater.html#Where%20and%20when%20are%20freshwater%20benthic>;
- The U.S. EPA water quality and aquatic biology program <http://www.epa.qld.gov.au/register/p00736ad.pdf>.

Environment Protection

Environment protection covers a broad area, and is mostly thought of as protecting the environment from human-induced pollution. But it is much broader than that, and involves protecting the environment from all forms of human-induced impact such as climate change, impacts of the built environment on the natural environment, etc.

Examples:

- Australia's Environment Protection legislation uses an on-line decision support system to monitor impacts of development, agriculture and fishing, etc. on matters of environmental significance such as World Heritage sites, threatened and migratory species, important wetlands. Primary species-occurrence data are a major source of background information for the decision support system (Chapman *et al.* 2001) <http://www.deh.gov.au/erin/ert/epbc/index.html>;
- The US Environment Protection Authority uses species-occurrence data for many aspects of environment protection <http://www.epa.gov/>.

Environmental Monitoring

Monitoring of the environment through time is an often-neglected issue, but one that is essential for continual management of environmental resources.

Examples:

- Long-term Monitoring of Australia's Biological Resources (Redhead *et al.* 1994);
- Environmental monitoring in Sweden <http://www.svenskamiljonatet.se/cbd/eng/hav/miljoovervakning.htm>;
- University of Waterloo students collect data in forest biodiversity plots every summer as part of a third year course in Environmental Monitoring <http://www.escarpment.org/Monitoring/mon_forestbio.htm>;
- The Albufera International Biodiversity Group (TAIB) uses volunteers to collect data for monitoring environmental change <http://www.medwetcoast.com/article.php3?id_article=200>;
- Birdlife International uses biodiversity indicators for environmental monitoring <http://www.birdlife.net/action/science/indicators/>.

Agriculture, Forestry, Fisheries and Mining

The fields of agriculture, forestry, fisheries and mining have been among the greatest users of primary species-occurrence data. The identification of appropriate areas for growing crops, the identification of wild relatives of key crop species for genetic breeding, the identification of new species for food, forestry, shelter, fibre and industrial uses, the identification of provenances for use in planting in different areas, the identification of biological control agents for weeds and diseases, the identification of key areas for forestry production and protection, both for plantation and native harvesting, identification and management of fisheries production, the identification of by-catch, the study of feeding habits, pesticides, contaminants, and the identification of possible mine sites; etc.

Agriculture

A new term, 'agrobiodiversity' or 'agricultural biodiversity', has recently been defined by Decision V/5 of the Fifth Conference of the Parties to the Convention on Biological Diversity, as including "*… all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agro-ecosystem* " (http://www.biodiv.org). This includes ecological services such as nutrient cycling, pest and disease regulation (natural biological control), pollination, wildlife habitats, hydrological cycles, carbon sequestration, and climate regulation as well as cultural aspects, including tourism (Miller and Rogo 2001).

The food industry in the United States alone is estimated to be worth $800 billion per year (Pimental *et al.* 1999). All of this is based on biological species whether they are plants such as corn, wheat, rice, soybeans, or other food crops, animals like cows, pigs and poultry, or fungi such as mushrooms. Biological species are also used in the agricultural industry for landscape restoration, biological pest control, sport, pets and food processing. Primary species-occurrence databases are a key source of information for use by agriculturalists.

New crops and wild relatives

The world is always looking out for new species for use in agriculture. Primary species databases are being used to identify wild relatives of species currently being used for agriculture, or new species that may have been used by indigenous peoples. In addition, wild relatives of cultivated crops are being examined for genetic transfer to control weeds, improve growth rates, reduce water use, etc.

Examples:

- Close relatives of cultivated rice, including *Oryza rufipogon*, *O. nivara*, *O. longistaminata*, and *O. glumaepatula* are commonly found or coexist in rice farming systems of many Asian, African, and American countries. The use of these species in cross breeding has been in practice for hundreds of years, and more recently biotechnology has been used to transfer specific genes to increase levels of beta-carotene, protein content, disease and insect resistance, herbicide resistance, and salt tolerance (Lu 2004);
- In Brazil, controlled and natural hybridisation is occurring between cassava (*Manihot esculenta*) and its wild relatives. Studies are being carried out to look for, or breed, new hybrids for improved production and fertility (Nassar 2003) <http://www.funpecrp.com.br/gmr/year2003/vol4-2/gmr0047_full_text.htm>;
- The Desert Quandong (*Santalaum acuminatum*) is a plant traditionally used by Australian aborigines. It is now being developed as a commercial food source <http://sres.anu.edu.au/associated/fpt/nwfp/quandong/Quandong.html>.

Provenances and wild relatives

The identification of new provenances of cultivated species has been a tradition going back many hundreds of years. Primary species-occurrence databases can now help in that search as point records are extracted over the Internet, allowing the identification of new populations and areas for study.

Examples:

- In New Zealand, four new provenances of the plant *Cordyline australis* were selected to examine their suitability for fructose production (Harris 1994);
- In Australia, suitable provenances of species of *Acacia* are being sought for use for grazing livestock (Dynes and Schlink 2002);
- In Central Africa, germplasm of eighty-five provenances of Eru (*Gnetum africanum* and *Gnetum buchholzianum*), species that are valued as highly nutritious green vegetables, have been selected for genetic improvement and ex-situ cultivation and management (Shiembo 2002) <http://www.fao.org/docrep/X2161E/x2161e06.htm>;
- Potential for Seed Gum production in *Cassia brewsteri* (Cunningham *et al.* 2001) <http://www.rirdc.gov.au/reports/NPP/UCQ-12A.pdf>;
- Seeds for Success program in the United States is collecting seeds of species for use in stabilisation, rehabilitation and restoration of degraded land <http://www.nps.gov/plants/sos/>.

Food processing

The use of species in food production goes back many thousands of years with the use of yeasts in the production of alcohols and bread, and bacteria for cheese production. For example, the many varieties and flavours of wine come from the extensive selection of possible grapes to be fermented and from the vast array of yeasts and bacteria that may be used. Winemakers and beer brewers are always on the lookout for new and improved yeast varieties.

Examples:

- The Role of Yeast in Production of Alcoholic Beverages. <http://www.botany.hawaii.edu/faculty/wong/BOT135/Lect14.htm>;
- Bacteria are used in the production and processing of sour creams, buttermilk, yoghurt, cheese, sauerkraut, pickled vegetables, chocolate, coffee, vinegar, etc. and manufacturers are always on the lookout for new and improved species to use to introduce new flavours and products <http://www.bacteriamuseum.org/niches/foodsafety/goodfood.shtml>.

Harvesting of wild populations

The harvesting of wild populations of plants and animals for food and ornament is another major industry that benefits from the availability of species-occurrence data and databases. The harvesting of native animals is a controversial subject, but it is an industry that is important in many developing countries. The use for forestry is considered elsewhere, but the harvesting of flowers from wild areas is a large industry in countries like South Africa and Australia. Species-occurrence data are used in the identification of species suitable for harvesting, and for determination of areas with sustainable populations.

Examples:

- Wildlife harvesting in the Fynbos area of South Africa provides income for 20,000 people (Lee 1997) <http://www.ars.usda.gov/is/pr/1997/971010.2.htm>;
- Some South American fruits and yams are grown under "semi-wild" cultivation, for example *Spondias mombin* (Campbell 1996) <http://www.hort.purdue.edu/newcrop/proceedings1996/V3-431.html>;

- Twenty two species of animal are harvested from the wild in Africa (Ntiamoa-Baidu 1997) <http://www.fao.org/docrep/W7540E/w7540e00.htm>;
- In Brazil, many native fruits are used for flavouring ice-creams and as fruit juices <http://www.maria-brazil.org/brazilian_sherbets.htm>.

Beneficial Insects in agriculture

As well as their huge detrimental impact on agriculture, insects are also a important positive contributor.

Examples:

- Honey industry profile (Saskatchewan Agriculture, Food and Rural Revitalization) <http://www.agr.gov.sk.ca/docs/crops/apiculture/HoneyIndustry.pdf>;
- Silk Business in Iran <http://www.iccim.org/English/Magazine/iran_commerce/no1_1999/17.htm>;
- The economics of apiculture and sericulture modules for income generation in Africa (Raina 2000);
- Cash crops (e.g. butterflies or chemical extraction), mini-livestock (Odhiambo 1977);
- Termite nests are also used for building materials (Swaney 1999: 435);
- Species-occurrence data was used to improve pollination in Oil Palms in Malaysia <http://www.bionet-intl.org/case_studies/case14.htm>.

Weeds and Pests

The financial impact of weeds, pests and diseases on agricultural production is enormous (Suarez and Tsutsui 2004). Species that generally cause the greatest impact are introduced from other areas (Pimental *et al.* 1999), and these are covered separately under the section on invasive species, above. Not all pests and diseases are introduced, however, and their identification, control and management can be important issue for farmers. Weeds for example can provide valuable food resources for pollinating insects. Often, past clearing of land for agriculture has meant increased grassland for grazing animals and seed-eating birds such as Kangaroos and Corellas in Australia. Primary species-occurrence databases can be important in the identification of weeds and pests of agriculture and for studying their distributions.

Examples:

- Some animals have adapted well to the changed landscape of Australia and their numbers continue to increase. These include western grey kangaroos (*Macropus fuliginosus*), galahs (*Cacatua roseicapilla*), ravens (*Corvus coronoides*), Australian magpies (*Gymnorhina dorsalis*), corellas (*Cacatua tenuirostris*) and the Port Lincoln Parrot (*Barnardius zonarius*). Other, related species can be very rare, so identification is important for their management (Hindmarsh 2003).<http://portal.environment.wa.gov.au/pls/portal/docs/PAGE/DOE_ADMIN/TECH_REPORTS_REPOSITORY/TAB1019581/WRM33.PDF>;
- Only 5 of 43 species of macropods (kangaroos) in Australia can be harvested, and counts are made every year to determine the numbers allowed for harvesting. Identification is important so as to get accurate numbers and so that more threatened species aren't killed by mistake <http://www.dfat.gov.au/facts/kangaroos.html>;
- Correct identification of a fungus of wheat in the USA saved $5 billion/year in wheat exports <http://www.bionet-intl.org/case_studies/case8.htm>.

Invertebrate pests

Invertebrate pests, especially insects, cause massive losses to production every year, and are a major cause of famine (plague locusts) in many parts of Africa and elsewhere. The identification of pests is another role where species data plays an crucial role.

Example:

- The National Centre for Integrated Pest Management in India, has developed a program to map the geographical distribution of all pests of major crops in the country <http://www.ncipm.org.in/Maps.htm>;
- The International Development Research Centre is setting up an insect identification and biosystematic service for agriculture Africa south of the Sahara <http://web.idrc.ca/en/ev-26155-201_870175-1-IDRC_ADM_INFO.html> ;
- Intercropping increases parasitism of pests (Khan *et al.* 1997).

Plant and animal pathogens

There are an estimated 50,000 parasitic and non-parasite diseases of plants in the United States alone, most of which are caused by fungus species. Mycological species databases, including living collections, can be important for the identification and control of many of these species.

Examples:

- The Ecological Database of the World's Insect Pathogens offers information on fungi, viruses, protozoa, mollicutes, nematodes, and bacteria that are infectious in insects, mites, and related arthropods <http://cricket.inhs.uiuc.edu/edwipweb/edwipabout.htm>;
- With links to primary species-occurrence databases, Kansas State University uses geographic tools to track plant pathogens <http://www.innovations-report.de/html/berichte/agrar_forstwissenschaften/bericht-27646.html>;
- Modelling the spatial distribution of important South African plantation forestry pathogens (van Staden *et al.* 2004).

Forestry

The forestry industry is an enormous industry around the world. It is an industry that has traditionally utilised native and wild populations, but one that is gradually moving toward plantation forestry. Primary species-occurrence data play a role in both areas, firstly through identifying species and areas for forest production, and attempting to balance that with conservation, and secondly in determining what species and provenances will most suitably grow where.

Balancing forestry and conservation

Native forest industries rely on species distribution data to find locations of new species and areas for forest production. Species-occurrence data are also used to develop sustainable forestry management processes through setting aside restricted areas for native harvest, and using methods described elsewhere in this paper (see Conservation Assessment) for determining those areas to be set aside for conservation.

Examples:

- National Indigenous Forest Inventory for South Africa (Wannenburgh and Mabena 2002) <http://www.dwaf.gov.za/Forestry/FTIS/symp2002/inventory.doc>;
- The National Forestry Programme for Swaziland examines biodiversity values and multi-uses of forestry land <http://www.ecs.co.sz/forest_policy/fap/index.htm>;

- Regional Forest Agreements in Australia. Government of Tasmania & the Commonwealth of Australia <http://www.affa.gov.au/content/output.cfm?ObjectID=89389274-95D8-4380-BD9BB177D644820A&contType=outputs>;
- Using process-based and empirical forest models in eucalypt plantations in Brazil (Almeida *et al.* 2003);
- Studies in Australia use species-occurrence data in modelling and conservation assessment to balance forestry and biodiversity (Faith *et al.* 1996).

Plantation forestry

The use of plantation forestry is increasing throughout the world, and techniques are being used to determine the most suitable location for species to be grown. Species-occurence data are linked with environmental modelling to determine climate profiles from native areas and then applying those profiles to areas and countries where the plantation is to be grown.

Examples:

- Matching Trees and Sites using environmental modelling (Booth 1996)
- Modelling Forest Systems. This book looks at forest models, tools and approaches to forest modelling, including distribution modelling – some of it using species-occurrence data. (Amaro and Soares 2003).

Provenance identification

The selection of the most appropriate provenance of a species to grow in a new plantation area is extremely important. The selection can not only use present-day conditions, but can model and select for future climate conditions, etc.

Examples:

- Selecting species and provenances of Australian trees for growing in Australia, China, Thailand, Laos, Cambodia, Vietnam, Indonesia, Philippines and Zimbabwe, as well as regions such as Southeast Asia, Africa, and Latin America (CSIRO Australia) <http://www.ffp.csiro.au/pff/species/>;
- Matching Trees and Sites using environmental modelling examines the provenances of tree species from Australia for planting in China and South-east Asia (Booth 1996);
- In India, new provenances of the genus *Leucaena* are being sought with the aim of finding provenances that can introduce straighter stems, later flowering and lower seed set. <http://www.forests.qld.gov.au/resadv/research/qfriconf/qfri6.htm>;
- In Vietnam, *Acacia* species and provenances are being selected for large-scale plantings (Ngia and Kha 1996). Between 1982 and 1995, 18 species and 73 provenances from 5 species of *Acacia* were trialed at 8 localities across Vietnam <http://www.forests.qld.gov.au/resadv/research/qfriconf/qfri6.htm>;
- Climate change studies in the UK, have concluded that new provenances of existing species will need to be found in order that new plantations may be adapted to the warmer, and possibly drier conditions expected in the future (Cannell *et al.* 1989).

Fishing

Fishing and fisheries are an important industry and user of species distribution data. With ever increasing pressure on fishing stocks as evidenced by the decline in stocks of Cod fish in the Northern Atlantic (Crosbie 1992, Meisenheimer 1998). Being able to track stocks and movement of fish throughout marine and fresh waters is essential to the long-term sustainable management of commercial fish stocks. The identification of species caught in by-catch is also important for conservation and resource management.

Resource management

Resource management of both marine and fresh-water fisheries is become a critical issue around the world. A large proportion of the world's coastal population is almost entirely dependant on the fishing industry for their livelihood. The use of distributed data and information to make important resource decisions is becoming increasingly important.

Examples:

- The Gulf of Maine Biogeographic Information System is developing a methodological framework for accessing and distributing marine biogeographic data. The system will provide information and tools for better understanding and regulating fish populations (Tsontos and Kiefer 2000) <http://gmbis.marinebiodiversity.ca/aconw95/aconscripts/gmbis.html>;
- The US National Marine Fisheries Service provides automated data summaries of US commercial fisheries landings for fish and shellfish. The volume and value of landings from 1950-2002 landings can be summarized by: years, states and species <http://www.st.nmfs.gov/st1/commercial/>;
- FAO Species Identification and Data Programme (SIDP) <www.fao.org/fi/sidp/products.htm>;
- Studies in the Bering Sea have examined long-term oceanic primary production and ecosystem changes and shown significant declines in productivity by as much as 25-45% between 1947 and 1997 (Schell 2000) <http://www.alaskasealife.org/documents/Education/Teacher_guide.pdf>
- The identification of marine hotspots in New Zealand, allows for protection of valuable spawning grounds <http://www.bionet-intl.org/case_studies/case25.htm>.

Overfishing

Overfishing of native stocks is becoming an ever-increasing issue. Overfishing of cod in the northern Atlantic has caused major disruption of whole populations of people, for example on Newfoundland where people have had to find new occupations. Species-occurrence data are used for monitoring stocks.

Examples:

- Closure of cod fishing Action Plan (CNLBSC 2003) <http://www.cbsc.org/nf/search/display.cfm?Code=6145&coll=NF_PROVBIS_E>;
- What is the problem with cod? (Meisenheimer 1998) <http://www.imma.org/codvideo/whatproblemcod.html>;
- A study of the effects of fishing on deep-water fish species to the west of Britain was carried out in the 1970s and 1980s (Basson *et al.* 2002).

Freshwater

Commercial freshwater fisheries are also important in many parts of the world. In many countries, freshwater fishing is largely recreational, but commercial fishing is still an issue in those countries, as well as in countries with large inland lakes, and large inland fishing industries.

Examples:

- Freshwater Fisheries Management Policy of the Victorian Government in Australia <http://www.nativefish.asn.au/fwpolicy.html>;
- Fish and Fisheries of the Great Lakes Region, Canada with information on species, ecology, etc.<http://www.great-lakes.net/envt/flora-fauna/wildlife/fish.html>;
- "Farming Freshwater Prawns" is an FAO technical paper that examines nomenclature and distribution as well as providing a manual for culture of the Giant River Prawn

(*Macrobrachium rosenbergii*).
<http://www.fao.org/DOCREP/005/Y4100E/y4100e00.htm#TOC>;
- Inland capture fisheries and enhancement: status, constraints and prospects for food security (Coates 1995).

Bycatch
The identification and reduction of bycatch from commercial fishing is becoming an international issue as more and more marine species are becoming endangered. The monitoring of bycatch has become a requirement of some governments, and methods to reduce the numbers of species and amount of bycatch have been put in place.

Examples:
- A program in the Gulf of Mexico looks at the effects of bycatch on the conservation of fisheries resources in the Gulf (Burrage *et al.* 1997). <http://www.rsca.org/docs/ib324.htm>;
- Tuna Bycatch Action Plan stresses the need for correct identification of turtles, and the need for species identification posters and booklets. <http://www.afma.gov.au/fisheries/etbf/mac/mac54/item3_2.pdf>;
- The CSIRO Fact Sheet on Conserving Australian Sharks and Rays also stresses the need for "identification guides to assist in the collection of comprehensive information on bycatch species to underpin sustainable management" <http://www.marine.csiro.au/LeafletsFolder/53guide/53.html>.

Contaminants
The identification of contaminants in fish and their monitoring through time to determine suitability for human consumption is another use for species-occurrence data. Fish are also good organisms for testing of water quality through the accumulation of toxins.

Examples:
- Testing for Persistent Environmental Contaminants in Fish and Wildlife (Schmitt and Bunck 1995);
- Integrated Fish Monitoring in Sweden (Sandström *et al.* 2004);
- Use of fish specimens from Richter Museum to analyse historic DDT levels in avian food webs <http://www.uwgb.edu/davisj/biodiv/richter/resources.htm>;
- National Contaminant Biomonitoring Program of the USGS studies concentrations of arsenic, cadmium, copper, lead, mercury, selenium, and zinc in freshwater fishes of the United States <http://www.cerc.cr.usgs.gov/data/ncbp/ncbp.html>.

Nursery and Pet Industry

Plant nurseries
The Nursery industry is a large user of species names and thus benefits greatly from the use of species-occurrence data. Nurseries are always looking for the names of the plants they sell, and information on their distributions for adding to the labels.

Examples:
- The Society for Growing Australian Plants tracks name changes for informing growers and nurseries that sell Australian plant species <http://farrer.csu.edu.au/ASGAP/changes.html>;
- The Ornamental Plants database provides details on hundreds of cultivated plants with names and information <http://www.msue.msu.edu/msue/imp/modzz/masterzz.html>.

Orchids and mycorrhiza

The cultivation of many terrestrial orchids requires an association with specific mycorrhiza and species databases can assist with the identification of these associations.

Examples:

- Many studies have been carried out at the Australian National Botanic Gardens on the symbiotic germination of terrestrial orchid species (Clements and Ellyard 1979) <http://www.anbg.gov.au/cpbr/summer-scholarship/2003-4-offer-clements.html>;
- In Costa Rica, studies on the relationship of mycorrhiza and orchid cultivation are being carried out at the Lankester Botanical Gardens (Rivas *et al.* 1998).

Pets

The pet industry is a huge industry world wide. Pet shops, etc. require information on the names and original localities of many of the animals they sell.

Examples:

- In the US alone, 19 million birds live as household pets <http://www.birdsnways.com/>;
- Index of exotic pets <http://exoticpets.about.com/cs/resourcesgeneral/a/exoticpetsatoz.htm>.

Mining

The mining industry would seem to be an unlikely user of species-occurrence data, but there are two major areas of biodiversity use in the mining industry. Some species are indicators of high mineral concentrations and are even used in mining in some rare cases; others are used in mine site regeneration.

Examples:

- *Terminalia alata* is used in India to indicate Copper mineralisation (Pujari and Shrivastava 2001);
- Phyto-mining is the use of plants to extract valuable heavy-metal minerals from soils <http://www.ars.usda.gov/is/pr/2000/000622.htm>;
- Phyto-mining of gold in New Zealand and Brazil <http://www.gold.org/discover/sci_indu/gold2003/pdf/s36a1355p976.pdf>;
- Phytoremediation uses plants to clean up soils <http://www.ars.usda.gov/is/AR/archive/jun00/soil0600.htm>;
- The influence of insects on soil chemistry may even be utilised in prospecting for minerals (e.g. Watson 1974);
- Rehabilitation of mines and other disturbed sites <http://www.otago.ac.nz/geology/features/restoration/wangaloa/wangaloa.html>;
- Species of the genus Polycarpaea have been used to indicate copper as they generally only grow on copper rich soils (Nicholls *et al.* 1965).

Mining and waste

Species-occurrence data are being used for biotechnology uses such as mining and pollution monitoring and control.

Examples:

- Bacteria are being used to clean up toxic waste sites including nuclear sites <http://sfgate.com/cgi-bin/article.cgi?f=/c/a/2003/07/14/MN103893.DTL>;

- Bacteria are being used to extract ore including copper, gold and iron and in waste management leading to cleaner mining technologies <http://www.bioteach.ubc.ca/Bioengineering/microbialmining/>;
- Plants are used as detectors for air pollution and as scavengers of air pollutants (Omasa *et al.* 2002) <http://www.cplpress.com/contents/C808.htm>;
- Lichens are used as pollution indicators <http://www.earthlife.net/lichens/pollution.html>.

Health and Public Safety

The importance of species data and their contribution to public health and safety, although increasing in importance, is still largely unknown by the general populace. As mentioned by Suarez and Tsutsui (2004) species-occurrence data "play a critical role in public health and safety as cornerstones in studies of environmental health and epidemiology". They also play a key role in security through their importance in the prevention, detection, and investigation of various types of bioterrorism (NRC 2003).

Health, both human and environmental, is being impacted upon by climate change along with the recent increase in terrorism and human, animal and plant migrations. Species-occurrence data can contribute valuable insights into the study of pathogens, vectors of diseases, and environmental contaminants (Suarez and Tsutsui 2004). Many diseases (human, animal and plant) are biodiversity-related, and the distribution of both the vectors and the disease agents themselves can be studied using species-occurrence data. When linked to biodiversity modelling programs, the potential spread and rate of spread of some of these species can be predicted, both under present day conditions and under altered climate change regimes, etc.

Diseases and disease vectors

Studies of the West Nile Virus in the Dominican Republic (Komar *et al.* 2003) examined the presence of West Nile virus in bird species and hypothesised possible linkages to migration routes of migratory bird species. The use of distribution modelling (Peterson *et al.* 2003b) successfully tested hypotheses that West Nile virus transmission on large geographic scales was by migratory birds, and using this information in conjunction with a simulation model allowed for new outbreaks and spread to be predicted (Peterson *et al.* 2003b).

Many other viruses are also transmitted by vectors, and entomological collections around the world include many records of mosquitoes which are responsible for the transmission of diseases, including malaria, avian malaria, dengue fever, equine encephalitis, and the already mentioned West Nile virus.

Species-occurrence data have also been used to construct evolutionary histories of viruses in order to develop more robust vaccines (Ferguson and Anderson 2002), to study the origins of HIV (Siddall 1997), to study the origins and track the movement of Avian Influenza (Bird Flu) in native and domestic bird populations (Perkins and Swayne 2002) and studying possible cross-susceptibility of the Rabbit CaliciVirus (RHD) in other animals (Munro and Williams 1994).

In addition, we now have the issue of emerging infectious and parasitic diseases, and the need to document transmission patterns. This cannot be done without species-level identifications of both adults and infective stages (larvae/juveniles) (Brooks and Hoberg 2000).

Examples

- West Nile Virus (Komar *et al*. 2003). <http://www.specifysoftware.org/Informatics/bios/biostownpeterson/Ketal_EID_2003.pdf>;
- Mosquito-borne diseases (Rutgers University and CDC) <http://www.rci.rutgers.edu/~insects/disease.htm>;
- Rabbit Haemorrhagic Disease (Munro and Williams 1994);
- Origins of HIV (Siddall 1997).

Bioterrorism

A key role in the use of species-occurrence data in controlling terrorism is in tracking the history of infectious diseases and in identifying their sources. Among some of the most important public health-related collections of species-ocurrence data are the examples of known viruses and bacteria that are retained and used for comparison with outbreaks of new infections. A recent example of their use was with the anthrax attack on the United States in 2001 where researchers at various Centers for Disease Control and Prevention used specimen collections from the 1960s and 1970s to attempt to identify the anthrax strains used (Hoffmaster *et al.* 2002).

One of the identified challengers to the museum community in the face of national threats of this nature is to be able to provide swift and accurate identifications of possible bioterrorism agents (Page *et al.* 2004).

Examples:

- Anthrax attack on the United States 2001 (Hoffmaster *et al.* 2002);
- Biological terrorism Risk Assessment (University of Kansas, Biodiversity Research Center) <http://www.specifysoftware.org/Informatics/informaticsbtra/>.

Biosafety

The flow of genes from modified organisms to their wild relatives is a recognised risk associated with genetically modified crops (Soberón *et al.* 2002). As noted by Soberón *et al.*, the risk is greatest when a crop "spontaneously hybridises with its taxonomically related species". Species-occurrence data are a necessity if scientists are going to be able to assess these risks by tracking spatial relationships between GMO crops and wild relatives, their potential distributions under various climatic conditions, and the reproductive biology of both groups of plants (Soberón *et al.* 2002).

Examples:

- The Mexican Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio) (http://www.conabio.gob.mx/), is using species-occurrence data obtained from herbaria around the world to study and model potential distributions, and to study the likelihood of genetic transfer (Soberón *et al.* 2002). This information is used several times a week to inform the Mexican Ministry of Agriculture (Soberón *pers. com.* Aug. 2004).

Environmental Contaminants

The monitoring of environmental contaminants in natural populations is another important health-related use for primary species-occurrence data. An example is the use of the Swedish Museum of Natural History's Environmental Specimen Bank to monitor contaminants in faunal species and to study the effects of noxious substances on endangered and threatened species. Another example is the tracking of pesticides, fungicides, etc. in streams through studying contaminants in populations of native amphibia. In conservation studies on the Californian Condor (*Gymnogyps californianus),* it was found that contamination with lead (and possibly DDT) were major causes of its decline towards extinction through increased mortality (Janssen *et al.* 1986). Museum collections have been used to examine lead and DDT levels through both time and space (Ratcliff 1967). Other studies have looked at increasing mercury levels in marine ecosystems by examining mercury levels in the feathers of seabirds breeding in various areas of the world and compare the levels achieved with historic specimens from the same localities held in natural history museums (Monteiro and Furness 1998, Thompson *et al.* 1998). Birds accumulate heavy metals from their food and secrete them into their growing feathers during molt (Green and Scharlemann 2003). Long-term changes and spatial variation in heavy metal concentrations can easily be studied using such collections.

Examples:

- Environmental Specimen Bank (Swedish Museum of Natural History) <http://www.nrm.se/mg/mpb.html.en>;
- Environmental Contaminants of Amphibians in Canada (*Froglog* 16: 1996) <http://www.open.ac.uk/daptf/froglog/FROGLOG-16-5.html>;
- Mercury in Feathers from Birds of the Southeastern Pacific: Influence of Location and Taxonomic Affiliation <http://cars.er.usgs.gov/posters/Ecotoxicology/Mercury_in_Bird_Feathers/mercury_in_bird_feathers.html>.

Antivenoms

Snakebite and spider bite are common in many parts of the world, and nowhere more so than Australia where more than 3000 cases are reported annually (Queensland Museum 2004). Many of the world's most venomous snakes are found in Australia. The accurate identification of a snake responsible for a bite allows for the correct antivenom to be administered. Species-occurrence data can limit the areas for which specific antivenoms may need to be stored, and assist in quicker identification of the snake through geographic sifting. This can be important from both from a health point of view, and because of cost. An ampoule of polyvalent antivenom (a cocktail of separate antivenoms) costs $1600 in Australia, compared to $300 to $800 (depending on the species of snake) for an ampoule of specific antivenom (Queensland Museum 2004). Victims of snakebite may require up to eight ampoules of antivenom, so the cost saving of an accurate identification can be significant, and in addition there are significant health benefits.

Examples:

- Queensland Museum antivenom project <http://www.qmuseum.qld.gov.au/features/snakes/saving.asp>.

Parasitology

Parasites are becoming recognised as significant components of the environment and are good models for evolutionary studies (Brooks and Hoberg 2001). Parasites are agents of disease in humans, domestic livestock and native wildlife, and maintain a significant role in ecosystem integrity and stability (Brooks and Hoberg 2000). Parasite collections have traditionally been held in large personal collections and have thus been less available to researchers than they may otherwise have been (Hoberg 2002). This is now being rectified with new distributed systems like the GBIF Portal. Specimen-based data can serve as historical and temporal baselines for understanding environmental change and human intervention on the distribution of parasites and pathogens (Hoberg 2002).

Examples:

- The United States National Parasite Collection (USNPC) is providing a major resource for systematic, taxonomic, diagnostic ecological and epidemiological research <http://www.anri.barc.usda.gov/bnpcu/>;
- The distributions of rodents have been used to study reservoirs and vector sites for a range of parasitic diseases, including Lyme disease – a parasitic disease transmitted to humans via tick bite, Lassa fever in Africa associated with multimammate rats, various hanta viruses in Argentina and Chile (Mills and Childs 1998) <http://www.cdc.gov/ncidod/eid/vol4no4/mills.htm>;

- Parasites are being used in studies of evolutionary biology (Dimigian 1999) <http://www.baylorhealth.edu/proceedings/12_3/12_3_dimijian.html>;
- Epidemiology of amoebiasis: an age-old problem solved by taxonomy <http://www.bionet-intl.org/case_studies/case1.htm> .

Safer Herbal Products

Many new herbal medicines are becoming available and being sold through pharmacists and health stores. The safety and purity of these medicines needs to be monitored and tested. To this information on their geographic distribution can be important.

Examples:

- Authentication of Chinese herbal medicines helps to deliver safer medicines <http://www.bionet-intl.org/case_studies/case3.htm> ;
- Testing and standardisation of herbal medicines <http://www.frlht-india.org/html/lab.htm#testingmedicines> .

Bioprospecting

Bioprospecting is the search for, and identification of, plants and animals that may provide products with potential economic value, such as new pharmaceuticals, foods, and other as yet-undiscovered uses. Species-distribution data are needed to assist in determining sites and likely species and requires taxonomic and phylogenetic research and distributional information from natural history collections (Page *et al.* 2004).

Pharmaceuticals

For centuries, plants and animals have been the source of healing products. Today, they are the basis of many of the world's pharmaceutical drug products. Primary species data are used to identify relatives of species that are already sources of active products and to find locations of those and other species for assay.

Examples:

- In Costa Rica, the National Biodiversity Institute (Inbio) is a major player in bioprospecting for pharmaceutical products in the forests of Costa Rica (Janzen *et al.* 1993) <http://www.inbio.ac.cr/en/>;
- Natural products research, especially novel chemical aspects of insect-plant interactions and arthropod venoms in Africa (Iwu 1996; Torto & Hassanali 1997; Weiss and Eisner 1998);
- Using plants to produce pharmaceuticals (Council for Biotechnology Information) <http://whybiotech.ca/canada-english.asp?id=3352>;
- In Brazil, the FAPESP-Biota program is funding a project to examine plants of the Mata Atlantica (Coastal rainforest) and Cerrado (savannah) for chemical and pharmacological products <http://www.biota.org.br/projeto/index?show+229>;
- The Amazon Rainforest is a source for present and future drugs <http://www.rain-tree.com/>;
- Ants as a source of pharmaceuticals (Majer *et al.* 2004)
- Plant-derived Drugs: Products, Technology, Applications <http://bcc.ecnext.com/coms2/summary__0002_001960_000000_000000_0002_1>;
- Chemotaxonomy of Xylariaceae uses bioprospecting to attain information on species of fungus. <http://pyrenomycetes.free.fr/xylariaceous/keydir/chemotaxonomy.htm>;
- Screening for bioactive compounds from Fungi using PCR (Polymer Chain Reaction)-based data (Stadler and Hellwig 2005).
- In Australia, chemical prospecting for pharmaceuticals in molluscs is being studied as a tool for conservation (Benkendorff 1999) <http://www.library.uow.edu.au/adt-NWU/public/adt-NWU20011204.154039/>;
- The mining for biodiversity products can be carried out in conjunction with deep sea mining <http://www.theworx.com/deepsea/mining.html>;
- Herbal medicines <http://hcd2.bupa.co.uk/fact_sheets/html/herbal_medicine.html>.

Forensics

Primary species-occurrence data are a source of information for use in forensic research. Forensic science is based on protocols that require accurate identifications of organisms and precise distributional information (Page *et al.* 2004). Collections in natural history museums contain a massive store of DNA information that can be used in profiling and in determining locations, etc.

Gene Fragments

The identification of genetic fragments using DNA and comparing that with information held in museums or primary species databases is a key use in forensics.

Examples:

- Gene fragments were used to track rhino poachers by looking for genetic signatures in products such as powdered Asian medicines and Yemeni ornamental daggers. Fragments were able to identify not only the species, but individual game reserves that the horn came from. *New Scientist* 2411 (2003). <http://www.newscientist.com/article.ns?id=mg17924110.700>;
- Blood evidence from dogs has been used to convict murderers and rapists <http://www-ucdmag.ucdavis.edu/sp02/feature_2.html>;
- Analysis of DNA from an asthma inhaler was used to identify the administration of performance enhancing drugs to a race horse <http://www-ucdmag.ucdavis.edu/sp02/feature_2.html>;
- Forensic DNA sampling has established that an introduced colony of tammar wallabies living on Kawau Island, in New Zealand, is almost certainly comprised of the descendants of a wallaby subspecies that vanished from mainland South Australia in the early 1900s. The subspecies is now being reintroduced to its original location <http://www.bio.mq.edu.au/school/mag/intro/98bytes/may98/Bytes_May98.html>;
- DNA evidence is commonly used to convict for illegal trade in endangered species <http://genetics.nbii.gov/forensics.html>;
- DNA was used to identify contraband meat smuggled into the USA as red colobus monkeys (Nash 2001).

Plant material

The identification of plant material and the use of herbarium collections to identify them, is used in legal cases involving endangered species – plants that are the source of rugs, plants that help identify the scene of the crime, etc. Herbs and grasses on clothing can track the movement of criminals, or the origin of illegally transported objects, etc. Only by comparison with known material can definitive locational and taxonomic information be determined.

Examples:

- By using a mass spectrometer to measure the ratios of carbon-12 to carbon-13, and nitrogen-14 to nitrogen-15, species of rhinoceros were identified in tracking poachers. The ratios vary depending on diet, and reveal whether horn came from white rhinos, which eat grasses, or black rhinos, which eat herbs and woody plants. Also by using optical emission spectrometers, the ratios of common trace elements such as iron and copper can identify locations where the material may have arisen *New Scientist* 2411 (2003). <http://www.newscientist.com/article.ns?id=mg17924110.700>;
- The identification of plant material, including cannabis is a common forensic use;
- The identification of leaves and fruits that may be found at a murder scene, or in a suspects car, etc. can help lead to a conviction <http://www.sfu.ca/biology/faculty/mathewes/>;

- The identification of plant parts in the intestinal tract of victims can aid in homicide investigations (Norris and Bock 2001);
- The identification of plant materials can be important in solving crimes (Lane *et al.* 1990).

Pollen

The pollen provides a key identification resource for use in forensic palynology. Forensic palynology is the study of pollen and powdered minerals. Their identification and location can be used to ascertain that a body or other object was in a certain place at a certain time.

Example:

- The Swedish Museum of Natural History maintains an international slide collection with more than 25000 pollen samples of different plant families <http://www.nrm.se/pl/samling.html.en>;
- The background and use of environmental profiling and forensic palynology (Wiltshire 2001) <http://www.bahid.org/docs/NCF_Env%20Prof.html>;
- The first conviction that used pollen analysis was in Austria in 1959. Pollen was used to identify a location where a body was buried using pollen in the mud on a suspect's boots <http://www-saps.plantsci.cam.ac.uk/osmos/os23.htm>;
- Pollen was used to identify the origin of a shipment of stolen Persian Rugs, although lack of suitable comparative species-occurrence data from Iran led to a failure to convict (Bryant and Mildenhall 2004) <http://www.crimeandclues.com/pollen.htm>.

Insects

Forensic entomology is used extensively to identify the time elapsed since the death of victims (Post-mortum Interval - PMI), to study whether bodies have been moved since death, to detect chemicals and poisons in bodies through the study of maggots, to track the movement of vehicles, and to determine the source of pest outbreaks (using houseflies and lesser houseflies) for city councils and health departments.

Examples:

- The use of forensic entomology <http://www.expertlaw.com/library/attyarticles/forensic_entomology.html>;
- Insects in legal investigations <http://www.forensic-entomology.com/>;
- The American Board of Forensic Entomology <http://www.missouri.edu/~agwww/entomology/>;
- Coleoptera and their significance in forensic entomology <http://www.beetlelady.com/hister.html>;
- Correct taxonomic identification of many insects and other Arthropoda can provide vital clues to the time and location of a death <http://www.bionet-intl.org/case_studies/case24.htm>
- The use of insects for determining Post-mortum Interval < http://www.absoluteastronomy.com/encyclopedia/F/Fo/Forensic_entomology.htm>;
- The use of maggots to determine time of death and to detect poisons and chemicals < http://www.benecke.com/suntel.html>.

Bird and Mammal Strikes

Bird strikes are a major problem with the safety of aircraft, etc. (Bird Strike Committee of the USA- <http://www.birdstrike.org/events/signif.htm>. The identification of these birds is essential to preventing future strikes, and species-occurrence data is an important tool in these identifications. Mammal strikes (e.g. large animal strikes with trains and road transport, etc.) can also be a problem in some areas.

Examples

- Bird Identification from the Smithsonian Institution (Dove et al. 2003). <http://wildlife.pr.erau.edu/BirdIdentification.htm>;
- Bird/Wildlife Strike Report Database, Environment Canada. <http://www.tc.gc.ca/aviation/applications/birds/en/default.asp>;
- Bird Strike Links from the International Bird Strike Committee <http://www.int-birdstrike.com/links.html>;
- German Bird Strike Committee (includes BIRDTAM). <http://web.tiscali.it/birdstrike/>;
- Bird Remains Identification System (BRIS) (Zoological Museum, Amsterdam) <http://www.christ-media.de/cgibin/auswahl.cgi?basket=180757&wahl=___2454629>;
- Effect of bird strikes and the Bird Strike Information System (IBIS) <http://www.icao.int/icao/en/jr/5308_ar1.htm>.

Border Control and Wildlife Trade

Wildlife trade is a large industry, but one that invites illegal activities. Border control is used to prohibit the entry into countries of diseases, illegally traded wildlife such as endangered species, or products from endangered species such as ivory, pests such as might be transported unintentionally in wooden products, drugs, etc. Species-occurrence data are used to provide border control agents with identification tools and means of identifying illegally traded and imported goods and to help them determine where they originated.

Border Controls and Customs

It is difficult for customs officers to know what is being illegally traded or not – what are pests that are prohibited etc. without good identification tools and access to primary species-occurrence data.

CITES

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (http://www.cites.org/) aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival. There are many listed species and groups of species, and it is difficult for customs officers to identify what might be an endangered species or not, and especially if a manufactured product or food has been derived from a CITES listed species.

Examples:

- Illegal bear parts seized by Customs Australia <http://forests.org/articles/reader.asp?linkid=32880>;
- Federal agents target illegal bird trade <http://www.internationalparrotletsociety.org/smuggle.html>;
- Illicit trade in orchids and wild plants (*Cites World* No 9, July 2002) <http://www.cites.org/eng/news/world/9.pdf>;
- An illegal shipment of 9,300 live turtles was made in Hong Kong (Traffic Bulletin vol. 19 2002) <http://www.traffic.org/bulletin/Nov2002/seizures3.html>;
- CITES Identification tools and Guides <http://www.cites.ec.gc.ca/eng/sct5/sct5_1_e.cfm>;
- Controlling the Shahtoosh trade in Tibet <http://www.met.police.uk/wildlife/new%20site%20docs/docs/shah.htm>;

Illegal Fishing

Illegal fishing is of major concern to most maritime countries. Many of the species taken are CITES species, but others not.

Examples:

- Ecuador seizes illegal Galápagos Island shark fins <http://www.planetark.com/dailynewsstory.cfm/newsid/22244/newsDate/16-Sep-2003/story.htm>;
- Illegal fishing threatens Galápagos Islands Waters <http://news.nationalgeographic.com/news/2004/03/0312_040312_TVgalapagos.html>;
- Illegal fishing continues to grow (FAO) <http://www.fao.org/newsroom/en/focus/2004/47127/>.

Drugs

Drugs and drug interception is another role for border control agents. The identification of drug and drug products is another use for primary species data.

Examples:

- Indian authorities have developed a database of Indian Medicinal Plants and species being traded as botanical drugs <http://www.frlht-india.org/html/crg.htm>;
- Regulating export of endangered medicinal plant species–Need for scientific rigour (Ved 1998) <http://www.ias.ac.in/currsci/aug/articles8.htm>.

Quarantine

Pests and Diseases

The importation of diseases and pests is of major interest and importance to agricultural industries as well as the general public. Again, the identification of pests and diseases can often be a problem for border control agents.

Examples:

- "Interception of potential agricultural, forest or medical pest species at U.S. borders will be greatly facilitated by access to a distributed network of taxonomic resources" (Page et al. 2004);
- Nematodes threaten US farmers <http://www.hqusareur.army.mil/opm/aug04.htm> and Mexican pecans <http://southwestfarmpress.com/mag/farming_nematodes_threaten_new/>;
- Please... don't bring pests or diseases with you to Australia <http://www.aust-immig-book.com.au/in_quarantine.html>;
- Australian Plant Pest Database <http://appd.cmis.csiro.au/>;
- In Namibia, identififcation of fruit flies allowed for more effective bilateral trade <http://www.bionet-intl.org/case_studies/case6.htm>.

Imported pets

The migration of people also means that pets are being transported across borders. Quarantine authorities need to monitor these for illegal importation, diseases, etc.

Wildlife Trade

Not all trade in wildlife is illegal, but controls of export and import permits requires knowledge and information on what species are being traded, and this requires primary species-occurrence data.

Examples:

- Wildlife trade and conservation in Australia <http://www.deh.gov.au/biodiversity/trade-use/index.html>;
- As part of its Wildlife Conservation Program, WWF Guianas is working with wildlife exporters and local governments to ensure that trade in wildlife is properly managed and based on the best scientific knowledge available. New Wildlife ID Manual <http://www.wwfguianas.org/Wildlife_IDman.htm>;
- Seahorses as wildlife trade – identification manuals <http://www.worldwildlife.org/trade/seahorses.cfm>;
- EU faces challenges in controlling Europe's demand for wild animals and plants <http://www.traffic.org/news/enlarge_european.html>.

Education and Public Outreach

Education at all levels; along with public outreach are regular uses for primary species-occurrence data.

School level education

School level education at all levels benefits from integration with museums as well as being involved in school-level biodiversity data projects.

Examples:

- Museum School Partnership program (Doctoral Dissertation) (King 1998) <http://home.iag.net/~ksking/muslearn.html>;
- The GLOBE Program – hands on education and science program <http://www.globe.gov/globe_flash.html>;
- The Waterwatch program in Australia is a program conducted between museums, government, schools and the community to carry out biodiversity and habitat assessments of wetlands in their area <http://www.waterwatch.org.au/>;
- The Natural History Museum in London has an extensive education program – Exploring Biodiversity <http://internt.nhm.ac.uk/eb/messages/probbrowser.shtml>;
- In America, the National Zoo Biodiversity Monitoring Project works with school children to survey and monitor biodiversity in their area <http://nationalzoo.si.edu/Publications/PressMaterials/BMPSchoolProjects.cfm>;
- In Hungary, the Toad Action Group monitors amphibians with the aid of school children <http://www.virtualfoundation.org/publicboard/display.cgi?_Hungarian_amphibian_biodiversity_monitoring_EPCE_Hungary+archive>;
- In England, as part of the Stag Beetle Biodiversity Action Plan, schools were involved in recording and mapping the location of stag beetles across the country <http://www.lbp.org.uk/03action_pages/ac30_comms8.html>;
- Biodiversity for kids' teacher's kit <http://www.bookshop.nsw.gov.au/pubdetails.jsp?publication=3403>.

University level education

Universities are the training centers for the world's biodiversity specialists and most maintain museum and herbarium collections, and collect species-occurrence data as part of many of their courses.

Examples:

- Duke University hosts undergraduate students in a summer research program Bioinformatic and Phylogenetic Approaches to the Study of Plant and Fungal Biodiversity. http://www.biology.duke.edu/reu/
- The Xishuangbanna Tropical Botanical Garden in China runs a graduate student training courses in Asia in conjunction with a number of international universities http://www.xtbg.ac.cn/english/PDF/gsxtbg.pdf

Training of Parataxonomists

The training of local peoples to be parataxonomists, requires extensive primary species data, including information on names, distributions, and often good image databases.

Examples:

- Training programs for parataxonomists have been developed by the National Biodiversity Institute (Inbio) in Costa Rica for use in the Guanacaste Conservation Area (Janzen *et al.* 1993, Janzen 1998);
- Training of local indigenous people has been carried out with insects in the Madang region of Papua New Guinea and in Guyana (Basset *et al.* 2000);
- In Hawaii parataxonomists are trained using insect processing by the Bishop Museum <http://www.bishopmuseum.org/research/natsci/guyana/LOGGING4.HTM>;
- Brazilian Pollinators Initiative <http://www.mma.gov.br/port/sbf/chm/doc/pollinas.pdf>;
- Taxonomic tools allow rapid problem solving by non-specialists <http://www.bionet-intl.org/case_studies/case5.htm>.

Public awareness

The public are increasingly aware and becoming involved in their local environment (see also public participation programs below). Many organizations are now attempting to make it easier for people to find out about their natural environment and what is in it. This can be as simple as making available guidebooks so that people can identify the birds that visit their gardens, through to much more detailed environmental descriptions of their local areas.

Examples:

- The National Biodiversity Network (NBN) aims to make it easier for people to find out about their natural environment <http://www.nbn.org.uk/>;
- The North Australian Frogs Database System (Frogwatch) provides information to the public about frogs, cane toads and frog diseases to the Northern Territory public <http://www.frogwatch.org.au/>;
- The Biodiversity Conservation National Strategy and Action Plan of Uzbekistan aims to increase public awareness in biodiversity <http://bpsp-neca.brim.ac.cn/books/actpln_uzbek/>.

Books and materials

The publication of books and materials – local guide books to plants and animals, posters, screen savers and calendars all help in improving public awareness of biodiversity. Primary species-occurrence data are essential in helping develop these materials.

Examples:

- Australian mammals poster <http://www.bookshop.nsw.gov.au/pubdetails.jsp?publication=492>;
- Fish Posters of the World <http://www.fishposters.com/index.html>;
- Animal Posters <http://www.realtime.net/~raintree/gallery/posters.htm>;
- Animal Screen Savers <http://www.tnpsc.com/ssaver/animals.htm>;
- NatureBase Screensavers of Western Australia <http://www.calm.wa.gov.au/screensavers/>;
- Wildlife calendars from Africa <http://www.wildlife-pictures-online.com/wildlife-shopping-1.html>;
- Lifemapper screensaver produces distribution maps <http://www.npaci.edu/online/v6.14/lifemapper.html>.

Museum displays

Museum displays are a major source of education and public awareness. In recent years, museum displays have taken on the education role with increased vigour. Primary species-occurrence data play a key role in the development of these displays.

Examples:

- As early as 1995, the Field Museum saw benefits of automating collections records beyond scientific research. The integration of audio and textual data with visual images allows people to see exhibits from different museums and consider alternative interpretations from their homes or offices (Cohn 1995).
- North Carolina Nature Museums and Science Centers <http://www.unc.edu/depts/cmse/museums.html>;
- Australian Museum "What's on" <http://www.austmus.gov.au/visiting/whatson/>.

Image Databases

Image databases are a valuable resource for development of virtual reference systems and on-line identification tools for biodiversity assessment (Oliver *et al.* 222). For example, by linking to an on-screen reference system of insect specimen images, several parataxonomists working on the same taxon in remote laboratories can make identifications simultaneously, limiting the need for repeated handling and damage to valuable reference specimens (Oliver *et al.* 2000).

Examples:

- High-definition images are a core component of an on-line invertebrate identification network being established at the Macquarie University in Sydney (Oliver *et al.* 2000);
- Australian Plant Image Database <http://www.anbg.gov.au/anbg/index-photo.html>;
- Type Photos at the New York Botanic Gardens <http://sciweb.nybg.org/science2/hcol/vasc/index.asp>;
- Woodpecker images and sounds <http://www.infochembio.ethz.ch/links/en/zool_voegel_spechte.html>;
- Natural History image collections on the Web <http://www.ucmp.berkeley.edu/collections/otherother.html>;
- Digital Orthoptera Specimen Access (DORSA) <http://www.dorsa.de/>;
- Australasian Bird Image Database <http://www.aviceda.org/abid/>;
- Imagens da Biodiversidade Brasileira <http://imagem.cria.org.br/>;
- Digital Florilegium – part of the *New Endeavour* project <http://www.invisible-consulting.com/endeavour/flora.php>;
- Google Images <http://www.google.com>;

Public Participation Programs

Public participation conservation programs are becoming popular events. These can involve assistance in managing a river catchment area for conservation, water use and production; community planting of degraded areas; or conducting community-based conservation assessment.

Examples:

- The Calabash Program in Africa is a program to improve public participation in environmental assessments in Southern Africa <http://www.sarpn.org.za/documents/d0000772/index.php>;

- The Inter-American Environment Program of the Environment Law Institute is supporting and encouraging public participation in protecting landscapes in Argentina and in Conserving Community Lands in Mexico <http://www2.eli.org/research/interamerican2.htm>
- In Australia, the Federal Government funds community organizations to plant up areas of land degradation, high erosion, develop wildlife corridors, etc. Primary biodiversity data are used to identify suitable plant species and areas for planting <http://www.landcareaustralia.com.au/>;
- Again in Australia, Integrated Catchment Management Plans, sees community groups work closely with State and Federal Governments to plan and implement management plans for managing the resources, including water and biodiversity, and to balance that with agricultural production <http://www.dlwc.nsw.gov.au/community/index.html>;
- In Connecticut, in the United States, in the BioBlitz, program scientists work with community groups to carry out a rapid biodiversity assessment of local areas over intensive weekend programs (Lundmark 2003) <http://www.mnh.uconn.edu/BioBlitz/>;
- In the UK, the Natural History Museum the Walking with Woodlice project uses schools, local clubs, and individuals to survey UK woodlice <http://www.nhm.ac.uk/interactive/woodlice/biodiversity.html>;
- The Alcoa Frogwatch Program aims to involve a large number of people of all ages in actively helping to increase the quality of large-scale frog habitat <http://frogs.org.au/frogwatch/>;
- Total Catchment Management – public participation <http://www.dlwc.nsw.gov.au/community/index.html>;
- National Biodiversity Network’s Local Records Centers <http://www.nbn-nfbr.org.uk/nfbr.php>.

Tree of Life

The Tree of Life Web Project and similar collaborative projects provide information about the diversity of organisms on Earth, their history, and characteristics.

Examples:

- Tree of Life <http://tolweb.org/tree/phylogeny.html>;
- Diptera species pages <http://www.diptera.org>.

Ecotourism

Ecotourism is rapidly becoming one of the largest sources of income for many biodiversity-rich countries. UNEP recognises ecotourism as of special interest because of the role it can play in conservation, sustainability and maintenance of biological diversity (http://www.uneptie.org/pc/tourism/ecotourism/home.htm). Primary species-occurrence data are important in the development of good ecotourism programs – in the development of guidebooks, pamphlets, and information products and in helping countries determine suitable areas for use as ecotourism sites.

Valuing Ecotourism

One of the pressures against ecotourism is being able to put a value on biodiversity, conservation and ecotourism as an alternative to consumption and more intensive uses. But in many ecotourism projects, ecotourism and production can work side by side.

Examples:

- Valuing a tree for ecotourism <http://www.nuevomundotravel.com/nuevomundo.php?c=129>;
- Valuing ecotourism in the Sierra Tarahumara region in Mexico <http://www.srs.fs.usda.gov/econ/research/std43_8.htm>;
- Valuing Ecotourism as an Ecosystem Service (The Nature Conservancy) <http://nature.org/event/wpc/files/drumm_presentation.pdf>;
- The Economics of “Eco Tourism”: A Galapagos Island Economy-wide Perspective (Taylor *et al.* 2002) <http://www.reap.ucdavis.edu/working_papers/jet-galapagos.pdf>.

Training Guides and Operators

The training of tour guides and tourism operators in understanding biodiversity is an area where primary species-occurrence data play a key role. Quite often, reference collections are made and kept at ranger stations, and carried by guides, and these require primary species data for identifications and training.

Examples:

- Eco-certified ecotourism in Australia <http://www.ecotourism.org.au/eco_certification.asp>;
- Ecotourism certification workshops <http://www.planeta.com/ecotravel/tour/certification.html>;
- Ecotourism Training Manual for Protected Area Managers (Strasdas 2002);
- Training Manual for Community-based Tourism (Inwent Zschortau, Leipzig, Germany) (Hausler and Strasdas 2003).

Guide Books

Guidebooks, pamphlets and other publications are an essential part of ecotourism and like guidebooks mentioned elsewhere are dependant upon species-occurrence data for their preparation.

Examples:

- Examples can be found in any bookshop or on the web of tour guidebooks, and most have an ecotourism section;

- A Guide to the Birds of Panama (Ridgely and Gwynne 1989);
- Costa Rica's National Parks and Preserves: a visitor's guide (Franke 1999).

Gardens, Zoos, Aquariums, Museums and Wildlife Parks

Botanical gardens, zoos, aquariums, wildlife parks and museums all play a part in ecotourism. Many new aquaria, for example include an underwater viewing area with access to the open sea. Most botanic gardens, zoos and wildlife parks maintain displays of the fauna and flora of the local regions and museums usually have extensive natural history displays. Most of these also have an education component. The labelling and information attached to these exhibits requires good data and information to prepare and maintain, including the names of the organisms involved and their distributions.

Examples:

- Monterey Bay Aquarium <http://www.mbayaq.org/>;
- Kirstenbosch National Botanical Garden <http://www.nbi.ac.za/frames/kirstfram.htm>;
- Jurong Bird Park, Singapore <http://www.birdpark.com.sg/Main/>;
- Jersey Zoo and Durrell Wildlife Conservation Trust <http://www.durrellwildlife.org/>;
- Smithsonian National Museum of Natural History <http://www.mnh.si.edu/>;
- Virtual Library: Museums around the world <http://vlmp.museophile.org/world.html>.

Art and History

Art has played an integral role in understanding and conservation of biodiversity. Most early scientific expeditions included an artist amongst their entourage to record the biodiversity. Today, artists continue to paint nature, and seek information on the names and locations of the subjects they paint. History is also a user of primary species-occurrence data. Early explorers were also natural historians and collected biodiversity specimens. With many centenaries and bicentenaries of these explorations coming up, many researchers are attempting to trace the steps of these early explorers and species-occurrence data are a major source of information for them.

History of Science —Tracking Explorers and Collectors

Early and modern explorers and scientists have deposited voucher specimens in natural history collections. "These specimens document the paths and objectives of the explorers and scientists over the centuries and provide a unique and irreplaceable source of historical data" (Page *et al.* 2004). As collections have aged, the year in which they were collected has become increasingly important (Winker 2004).

Examples:

- Nature's Investigator: The Diary of Robert Brown in Australia 1801-1805 (Vallance *et al.* 2001);
- Identifying collection patterns using Mexican bird specimens (Peterson *et al.* 1998);
- The *New Endeavour* is a project to revisit the landfalls of Captain James Cook's voyage in HMS Endeavour (1768-1771) http://www.invisible-consulting.com/endeavour/
- History of systematic botany in Australasia (Short 1990);
- Plant collectors in Brazil (Koch 2003) <http://splink.cria.org.br/collectors_db>;
- Lewis and Clarke Expedition in America <http://www.cr.nps.gov/nr/travel/lewisandclark/encounters.htm>;
- Australian Plant Collectors and Illustrators 1780s-1980s <http://www.anbg.gov.au/bot-biog/index.html>.

Art and Science

As mentioned above, art played an important part in early scientific discoveries. There were no cameras around and paintings were the only representation available of many plants and animals. Some early artist's interpretations of plants and animals was so detailed that many regard them as superior to many modern photographs.

- Sydney Parkinson was the artist on Cook's voyage of discovery to the South Seas in 1768-1771. He painted many animals (<http://pages.quicksilver.net.nz/jcr/~parkinson.html>), insects (<http://www.nhm.ac.uk/services/ibd/gfx/te/vod/17.jpg>) and plants (<http://internt.nhm.ac.uk/cgi-bin/perth/cook/>) and made the first sketch of a kangaroo <http://www.nhm.ac.uk/library/art/drawingconclusions/more/hibiscus_more_info.htm#collection>;
- Ferdinand Bauer (1760-1826) is regarded as one of the most remarkable botanical artists of all time (Bauer *et al.* 1976) <http://nokomis.com.au/html/biography.html>;
- John Gould's Birds of Asia <http://www.jadestonegallery.com/printgallery/gould/birdsofasia.htm>;
- Birds of the World – McClung Museum Special Exhibition 1997 <http://mcclungmuseum.utk.edu/specex/birds/birds.htm>;

- The World of Insects in Chinese Art: A Special Exhibition of Plant-and-Insect Paintings was an exhibition held at the National Palace Museum in Taiwan in 2001 <http://www.taiwanheadlines.gov.tw/20010816/20010814f2.html>.

Indigenous Art

Indigenous art and artefacts are a major source of income for indigenous peoples. Increasingly, artists want to supply information about the subjects of their art or the materials that make up the artefacts and products.

Examples:

- Untapped potential for cooperation between science and technology for mountain conservation in the Andes and Himalayas (Camino 2002) <http://www.mtnforum.org/resources/library/camia02a.htm>;
- *Canna indica* is commonly used in jewellery and for other purposes <http://waynesword.palomar.edu/pljune98.htm>;
- Nickernuts (*Caesalpinia bonduc*) are used for necklaces in Ecuador <http://waynesword.palomar.edu/nicker.htm>;
- Feathers have been a traditional adornment in many societies, The use of Birds-of-Paradise in Papua New Guinea is a good example (Frith and Beehler 1998)
- Yams are used for masks in Papua New Guinea <http://www.art-pacific.com/artifacts/nuguinea/yamwoodo.htm>;
- Shells, feathers, grass twine and other materials are commonly used in indigenous art <http://www.lostworldarts.com/new_page_2.htm>;
- Wool is used in the Andes and Himalayas <www.andeansoftware.com>;
- Fibres are used in basket making <http://www.aotearoa.co.nz/flaxworks/>;
- Bamboo and other woods are used in making musical instruments <http://www.canne-et-bambou.com/eng/bamboo_flutes.htm>;
- Bark is used for paintings by indigenous Australians <http://www.aboriginalartonline.com/art/bark.html>.

Stamps

Most modern societies around the world use biodiversity on their stamps. These stamps often include scientific as well as common names, and stamp producers rely on primary species data for these identifications.

Examples:

- Australian Stamps: Bush Tucker <http://www.auspost.com.au/philatelic/stamps/index.asp?link_id=2.608>;
- Birds on stamps <http://www.birdtheme.org/regions/region.html>;
- Kyrgyzstan animal stamps <http://ecopage.freenet.kg/biodiversity/animals.html>;
- Fijian stamps often include plants, insects and other animals <http://www.stampsfiji.com/stamps/peregrine_falcon/index.html>.

Society and Politics

Many of the uses of species data in society and politics are covered under other topics; however, several uses do not seem to fit easily elsewhere.

Social Uses of Biodiversity

Biodiversity sits within the social context of human population – the competition between conservation and the need for food and shelter for survival is a never ending conflict. Many new studies are looking at the interaction between biodiversity and the social culture of humans.

Examples:

- Areas of high avian endemism also hold dense human populations and rapid rates of habitat loss, thus human population density and growth rates must be factored into conservation priority setting (Brooks 2001);
- Other important-and “often sensitive and contentious-parameters include the distributions of military conflict, refugee movements, timber and mining concessions, commodity production, bushmeat hunting, and the narcotics trade” (Brooks 2001);
- Several projects of the Biota/FAPESP Program in São Paulo, Brazil are examining social aspects of biodiversity
    - One study is looking at an environmental atlas to help in planning a balance between human activities and biodiversity <http://www.biota.org.br/projeto/index?show+192>;
    - Another study is examining the use of natural resources for fishing, artefacts and for spiritual purposes by coastal inhabitants. The study is examining uses and local nomenclature as well as examining how the communities live and fish, and what effects their activities may have on the environment <http://www.biota.org.br/projeto/index?show+226>;
- Mobilising European social research potential in support of biodiversity ecosystem management (SoBio) (European Centre for Nature Conservation) <http://www.ecnc.nl/doc/ecnc/press/070404.html>;
- Unit for Social and Environmental Research – Chiang Mai University <http://www.sea-user.org/>;

Anthropology and Language

Anthropological studies, and even some biological studies (Basset *et al.* 2000) have been attempting to link indigenous nomenclatural systems for species to the Linnaeus system.

Examples:

- In Papua New Guinea, studies are attempting to link local forest species nomenclature to species names as part of a project to train local people as parataxonomists and collectors of insects (Basset *et al.* 2000);
- Primary species data have been used to compare primate proteins <http://www.bioquest.org/bioinformatics/module/tutorials/Anthropology/>;
- Plant species data are used to identify species used in diets to track migration patterns (Newton-Fisher 1999) <http://www.budongo.org/nen1000/reprints/NewtonFisher_1999_diet.pdf>.

Ethnobiology

Local knowledge about useful plants and animals, extending back more than 300,000 years, is an important subject of research by ethnobotanists (Gómez-Pompa 2004) and ethnozoologists. The integration of this knowledge with distributional studies from primary species-occurrence data is an important area of research.

Examples:

- Some anthropology studies look at the use of plant and animal species in healing, medicine, and for food <http://www.library.adelaide.edu.au/guide/soc/anthro/subj/med.html>;
- Laboratory of Ethnobotany houses thousands of records of species used for food and medicine <http://www.umma.lsa.umich.edu/ethnobotany/ethnobotany.html>;
- Nuaulu Ethnozoology – A Systematic Inventory by Roy Allen from the University of Kent at Canterbury <http://lucy.ukc.ac.uk/csacpub/ellen_ch1.html>;
- *Acacia* in Australia: Ethnobotany and Potential Food Crop (Lister *et al.* 1996) <http://www.hort.purdue.edu/newcrop/proceedings1996/v3-228.html>;
- Ethonzoology of the Tsou People: Fishing with poison <http://tk.agron.ntu.edu.tw/Segawa1/fishing_poison.htm>
- Native Peoples, Plants and Animals <http://www2.sfu.ca/halk-ethnobiology/>;
- Ethnozoological Research on Reptiles on Mt. Kilimanjaro <http://www.uni-bayreuth.de/departments/toek2/claudia/fEthnozoology.htm>;
- Ethnobotany: Plants and People Interacting <http://maya.ucr.edu/pril/ethnobotany/Start.html>.

Data Repatriation

The Convention on Biological Diversity (CBD) calls for repatriation of information to countries of origin. More recently, the idea of one to one data repatriation of museum and herbarium collections has moved more toward the idea of data sharing, and especially through use of on-line data availability using portals such as the .

Examples:

- Report on study on data sharing with countries of origin (GBIF) <http://www.gbif.org/Stories/STORY1079623109>;
- Only 0.8% of the world's beetle researchers reside in Africa and few of the type specimens (Miller and Rogo 2001);
- The Natural History Museum in London is working in Chile on Access to Genetic Resources, Benefit Sharing and Traditional Knowledge <http://www.darwin.gov.uk/news/projects/access_gen.html>;
- The Natural History Museum is also working on the repatriation of herbarium data for the flora of Bahia, Brazil <http://www.darwin.gov.uk/projects/details/7108.html>
- Using Virtual museums to increase information repatriation and sharing *Whole Earth* 2000 <http://www.findarticles.com/p/articles/mi_m0GER/is_2000_Fall/ai_66240384>;
- A Mexican case study on a centralised database from World Natural History Collections (Navarro *et al.* 2003) <http://journals.eecs.qub.ac.uk/codata/Journal/Contents/1_1/1_1pdf/DS105.Pdf>.

Biodiversity collecting

In many countries the development and expansion of protected areas is in some cases making it more difficult for scientists to collect and study biodiversity in these areas. Because of this, existing species-occurrence data will need to be relied on even more heavily in those areas where access for new collections may be restricted.

Recreational Activities

Recreational activities form another use for species-occurrence data. Many recreational activities involve biodiversity in one way or another – fishing, hunting, bird and whale watching, gardening, bushwalking, horse-riding, etc.

Recreational fishing

Recreational fishing is a large industry, and fishermen want to know what the fish is that they have caught – where certain species of fish occur and when, etc. All of this information is based on primary species-occurrence data.

Examples:

- Recreational fishers in Western Australia want habitat protected to improve recreational fishing <http://www.recfishwest.org.au/PolicyFishHab.htm>;
- In planning for zoning on the Great Barrier Reef, 36% of all submissions were from recreational fishers <http://www.gbrmpa.gov.au/corp_site/management/zoning/rap/rap/overview/intro/recfish.html>;
- Recreational fishing in Belarus is a major cause of biodiversity decline <http://www.iucn-ce.org.pl/documents/belarus.pdf>;
- Recreational fishing is being considered in management of fishing resources in the Upper Paraná River Basin in Brazil <http://www.unep.org/bpsp/Fisheries/Fisheries%20Case%20Studies/AGOSTINHO.pdf>.

Hunting

Like recreational fishers, hunters want to know what species they are hunting and where and when they occur. Conservations are also involved in knowing what species hunters are taking so that they can be taken into account in species management.

Examples:

- Hunting and Biodiversity in Atlantic Forest Fragments, São Paulo, Brazil <http://www.wildlifetrust.org/huntipe.htm>;
- Extinction caused by hunting <http://www.virtualglobe.org/en/info/env/04/diversity07.html>;
- Impacts of hunting on native species in New Zealand <http://www.biodiversity.govt.nz/picture/biodiversity/state/hunting.html>;
- The North American Hunting Heritage Accord plans for sustainable hunting <http://centralflyway.org/Hunting_Accord_Draft.html>.

Photography and Film-making

Photography of wildlife is another major recreational activity that relies on primary species-occurrence data for identification, and for determining where to find certain species to photograph, etc. Photographers are responsible for books, calendars, stamps, documentaries, etc. as well as on-line collections.

Examples:

- North American Nature Photography Association <http://www.nanpa.org/index.html>;

- The Finnish Nature Photographers Association <http://www.luontokuva.org/>;
- The Discovery Channel <http://dsc.discovery.com/>;
- Nature and Wildlife Movies <http://www.dropbears.com/b/broughsbooks/movies/nature_wildlife.htm>;
- David Attenborough Films <http://www.bbc.co.uk/nature/programmes/who/david_attenborough.shtml>.

Gardening

Gardening is a passion among many, and the need to know what the plants are, essential to most gardeners. Books and magazines on gardening are constantly being marketed and all rely on species-occurrence data for their information. A number of people are also starting to get into organic gardening and are searching for species for growing.

Examples:

- Royal Horticultural Society <http://www.rhs.org.uk/research/biodiversity/index.asp>;
- Gardening for Biodiversity <http://www.english-nature.org.uk/news/story.asp?ID=257>;
- Organic gardening books <http://supak.com/organic_gardening/organic.htm>;
- Australian Plants online – Society for Growing Australian Plants <http://farrer.riv.csu.edu.au/ASGAP/apoline.html>.

Bushwalking, Hiking and Trekking

Bushwalking, hiking or trekking in natural areas is a common pastime that often involves people wanting to know what the species are that they pass.

Examples:

- Bushwalking in New South Wales <http://www.npansw.org.au/web/activities/bushwalking.htm>;
- Hiking in Guatemala <http://www.guatemalaventures.com/hiking_tours.htm>;
- Hiking in Southeastern Arizona <http://www.geo.arizona.edu/geophysics/students/tinker/SEhiking.html>;
- Trekking in Ecuador <http://www.surtrek.com/ecuador/adventuretours/trek_podocarpus.htm>;
- Tramping in New Zealand <http://www.enzed.com/tramp.html>.

Bird Observing

Bird observing is a major recreational activity around the world, with many bird-observers clubs and bird activities. All rely on being able to identify the bird they have seen and thus rely on guide books and field guides created from primary species-occurrence data.

Examples:

- Birding.com <http://www.birding.com/>;
- National Audibon Society <http://www.audubon.org/>;
- Birding in Canada <http://www.web-nat.com/bic/>;
- Birds Australia <http://www.birdsaustralia.com.au/>;
- Birding Africa <http://www.birding-africa.com/>.

Human Infrastructure Planning

Planning of human infrastructure – roads, powerlines, subdivisions, etc. – requires species-occurrence data for finding the best place to build, and to do the least harm to the environment.

Risk Assessment

The building of roads and services requires risk assessment involving the most cost effective placement from both financial and ecological points of view. The management of weeds and hazardous vegetation on public lands, and the decision as to what species should be planted along roads and streets also involves risk assessment and species identifications.

Examples:

- Rights-of-Way Environmental Issues in Siting, Development and Management (Electric Power Research Institute) <http://www.epri.com/destinations/descriptions/57_row.pdf>;
- Management of noxious weeds and hazardous vegetation on public lands – risk assessment for humans and non-target species <http://www.fs.fed.us/r3/projects/ro/ea-noxiousweeds/ea-weedsappa.html>;
- Land use impact costs of transportation (Litman 1995) <http://www.agenda21.ee/english/transport/landuse_costs_extern.pdf>;
- Significant costs in road maintenance can result from use of comprehensive biological survey <http://www.bionet-intl.org/case_studies/case19.htm>.

Landscaping

Tree roots of certain species can cause great damage to houses, sewage lines, etc. Street trees are often planted under powerlines and have to be trimmed at great cost as they get too tall, other species crack pavements and roads. Some species are more susceptible to damage in cyclones and tornadoes, etc. The selection of species that save energy and use less water can be important in some areas of the world. The identification of trees for planting in sensitive locations and the identification of plants from their roots, etc. can require information from primary species-occurrence data.

Examples:

- Using dune vegetation to stop coastal dune erosion <http://www.epa.qld.gov.au/environmental_management/coast_and_oceans/beaches_and_dunes/coastal_dunes/>;
- A Benefit-cost analysis of planting street tree species in Modesto, California (McPherson 2003) <http://www.treelink.org/joa/2003/jan/01McPherson.pdf>;
- Landscaping to save energy <http://www.pioneerthinking.com/landscape.html>;
- Tree roots a growing problem (South East Water Ltd, Melbourne, Australia) <http://www.sewl.com.au/sewl/upload/document/treeroots.pdf>;
- Windbreak trees for economic biodiversity (Stace 1995) <http://www.newcrops.uq.edu.au/acotanc/papers/stace.htm>;
- Planning tree windbreaks in Missouri <http://muextension.missouri.edu/xplor/agguides/forestry/g05900.htm>;
- Different species have differing abilities to ride out cyclones <http://www.plant.id.au/home/guide_view.aspx?id=15>.

Wild Animals and Infrastructure

Wild animals and human infrastructure always leads to clashes. Animals are killed on highways and roads, birds get sucked into aircraft engines, and wind turbines, dams stop species migrating up stream to spawn, etc. Primary species data are important in understanding species behaviour, locations etc.

Examples:

- Environment Canada is reducing wildlife roadkill <http://www.pc.gc.ca/pn-np/ab/banff/docs/routes/chap3/sec4/routes3d_e.asp>;
- The U.S Critter crossings reduce roadkills <http://www.fhwa.dot.gov/environment/wildlifecrossings/index.htm>;
- Avian interactions with utility structures, wind turbines and communication towers (EPRI's Destinations 2005) <http://www.epri.com/destinations/product.aspx?id=309>;
- Dams are being removed to save salmon <http://www.wildsalmon.org/library/lib-detail.cfm?docID=300>.

Building timbers

The selection of plant species for use in buildings for termite resistance, railway sleepers, bridges, fences, and power poles requires research into suitable species.

Examples:

- Termites and houses <http://www.ces.ncsu.edu/depts/ent/notes/Urban/termites/termites.htm>;
- Species of eucalypt are used in Australia for furniture, railway sleepers, bridge construction, flooring, etc. <http://www.tpcvic.org.au/page_timber_info.htm>;
- Acceptable species for use as power poles in Australia <http://www.daleandmeyers.com.au/species.html>;
- Incorrect identififcation of termites can be costly <http://www.bionet-intl.org/case_studies/case20.htm>.

Aquatic and Marine Biodiversity

Aquatic and marine biodiversity is largely covered under other topics above; however, they are covered separately here as there are some specific marine and aquatic biodiversity systems that require specific species-occurrence data.

Examples:

- Ocean Biogeographic Information System (OBIS) <http://www.coml.org/descrip/obis.htm>;
- Gulf of Maine Biogeographic Information System Atlas (GMBIS) <http://gmbis.marinebiodiversity.ca/aconw95/aconscripts/gmbis.html>;
- Riverine aquatic protected areas: protecting species, communities or ecosystem processes? (Koehn 2003);
- Census of Marine Life – "is a growing global network of researchers in more than 70 nations engaged in a ten-year initiative to assess and explain the diversity, distribution, and abundance of marine life in the oceans -- past, present, and future" <http://www.coml.org/coml.htm>.

Conclusion

As seen throughout this document, uses for primary species-occurrence data are endless and touch just about every aspect of human endeavour, along with every part of the globe. They extend from uses for day to day survival such as food and shelter, through to education and learning, to pleasure and recreation. Most of us rely on these data without even thinking about them or even knowing they exist. But without them, whether held in museums or herbaria, in bird-observers databases or in survey databases held by Universities, individuals and corporations, we would not have the understanding of biodiversity that we have today, and our survival would be even further jeopardised than it already is.

We need to make maximum use of these data to better understand our biodiversity and our planet – to mitigate and monitor changes to our environment, to improve, conserve and sustainably use the resources we rely on and to educate and train future generations to appreciate and understand the biodiversity on which the data are based.

There are sure to be many uses that this document has missed, and it has been impossible to reference every example. It is hoped that the document may be made "live" in some format so that it can be kept updated and so that new uses can be added, possible by the on-line users of the data themselves.

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