

# **UK Taxonomy & Systematics Review - 2010**

**Results of survey undertaken by the Review Team at the Natural History Museum  
serving as contractors to the  
Natural Environment Research Council (NERC)**

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## Introduction

Taxonomy is the scientific discipline of describing, delimiting and naming organisms, both living and fossil, and systematics is the process of organising taxonomic information about organisms into a logical classification that provides the framework for all comparative studies.

*“The state of Taxonomy and Systematics in the UK is unsatisfactory – in some areas to the point of crisis – and more needs to be done to ensure the future health of the discipline.”*

This was the central conclusion of the unprecedented third inquiry into systematic biology by the House of Lords Science and Technology Committee. In response to a specific recommendation in the Committee’s report, the Natural Environment Research Council (NERC) commissioned the UK Taxonomy & Systematics Review. This was to focus particularly on strategic science needs and on identifying the roles that different parts of the UK taxonomy and systematics community can play in their delivery.

The Review was in three parts. Firstly, it was charged with identifying the current status and trends in the UK taxonomy and systematics sector, and producing a report summarising all major UK institutions that undertake taxonomic and systematic work.

The analysis included:

- the nature and extent of funding for taxonomy and systematics in UK institutions and the requirements of the various funders;
- current numbers of taxonomists and systematic biologists in the UK (by institution and in total);
- trends in the numbers of taxonomists and systematic biologists and sources of young skilled staff;
- gaps and overlaps in expertise and collections.

The second part of the Review was to produce an assessment of needs for the outputs from taxonomy and systematics activities and research, focusing on:

- an assessment of the elements of NERC’s strategy ‘Next Generation Science for Planet Earth’ that will require new taxonomic and systematic biology knowledge and skills;
- an assessment of the key issues in taxonomic and systematic biology research that could attract Research Council funding and contribute fundamentally to the UK science base;
- an identification of topics, technologies or mechanisms that need research and development to most effectively ramp up taxonomic and systematic biology work to meet societal needs;
- an assessment of operational requirements.

The third part of the Review was to produce strategic recommendations for the future development of taxonomy and systematics in the UK. The strategic recommendations flow from the evidence presented to the House of Lord inquiry and from their deliberations; they flow from the data gathered by this review, and were amplified and focused by direct input from the wide range of stakeholders who participated in our surveys and in a community consultation held at University College, London. The recommendations were formulated by an Expert Working Group working under the leadership of Prof Charles Godfray (see Appendix 1 for Group members).

Simultaneously with the NERC strategic review, the BBSRC commissioned the development of a roadmap for the delivery of e-taxonomy (= taxonomy on web) in the UK, led by Professor Frank Bisby (Reading University). The Linnean Society, in

response to the House of Lords report, also undertook a review of taxonomy and systematics based on consultations with a range of stakeholders including 15 membership organisations, 11 local and regional museums and 12 other relevant bodies. In the context of all this activity we considered it important to ensure efficient and comprehensive engagement with stakeholders, so the NERC review has maintained close links with both of these initiatives and shared a common platform at community events.

This report presents the results of the surveys and community consultation events undertaken during the UK Taxonomy & Systematics review. The recommendations formulated by the Expert Working Group are informed by and flow from the evidence presented here, but are published separately.

## **PART ONE: Current Status and Trends**

### **1. Current Manpower and Trends**

Taxonomists are unevenly distributed, with the highest density clusters located around the key resources - the reference collections housed in museums and botanic gardens. Substantial numbers of professional taxonomists are also employed in government laboratories, in industry, in Research Council (RCUK) institutes and in universities. In addition, the UK has a large and important community of volunteers engaged not only in taxonomy but also in a wide range of taxonomy-dependent tasks such as local and regional biological recording, and monitoring the progress of Biodiversity Action Plans. In the light of this spread it has not been a trivial task to quantify the number of active taxonomists in the UK.

#### **1.1. Taxonomy of taxonomists**

Drawing the defining line between a taxonomist and a naturalist with strong identification skills is somewhat arbitrary. The RSPB has over one million members in the UK, many of whom are highly proficient in bird identification. However, we considered it necessary to exclude this army of ornithologists from our calculations because it would inflate the apparent size of the overall taxonomic skills base in the UK but provide no insight into the availability of taxonomic expertise relevant to the vast diversity of plant, animal, fungal, protistan and microbial species that make up the ecosystems which provide the services upon which we depend. Similarly, Hopkins & Freckleton (2002: *Animal Conservation* 5: 245-249) noted that in the UK 'there are 210 members of the recording scheme devoted to the study of the 510 species of ants, bees and wasps but "scarcely more than half a dozen" who contribute information on the occurrence of the 6000 parasitic Hymenoptera species which can only be identified with taxonomic skills'. Throughout our surveys and this report it is the expert taxonomists with developed, research level skills that we have focused on.

In order to get improved resolution of the spread of taxonomic skills in the UK, it is necessary to differentiate between three strands of expertise:

- (i) identification (using existing handbooks, floras and keys to identify species)
- (ii) descriptive and revisionary (describing & delimiting new species, undertaking taxonomic revisions, producing monographs)
- (iii) phylogenetic (generating insight into evolutionary relationships between taxa)

These three expertise strands depend upon differing skill sets. In the UK they are often

supported by different funding agencies and, it appears, are in different states of health as sub-disciplines. We considered it important to differentiate between the strands and to look at the trends for each separately. Our survey looked for the primary expertise as it related to the work of individual taxonomists, but many have skills across all three strands so the distinction between strands is not absolute and cohort sizes are estimates.

## 1.2. Numbers of Taxonomists in the UK

The total number of taxonomists in the UK directly identified in this survey is 727 but we recognise that there is an un-sampled tail to this distribution consisting of volunteers and professional taxonomists at organizations that were not surveyed.

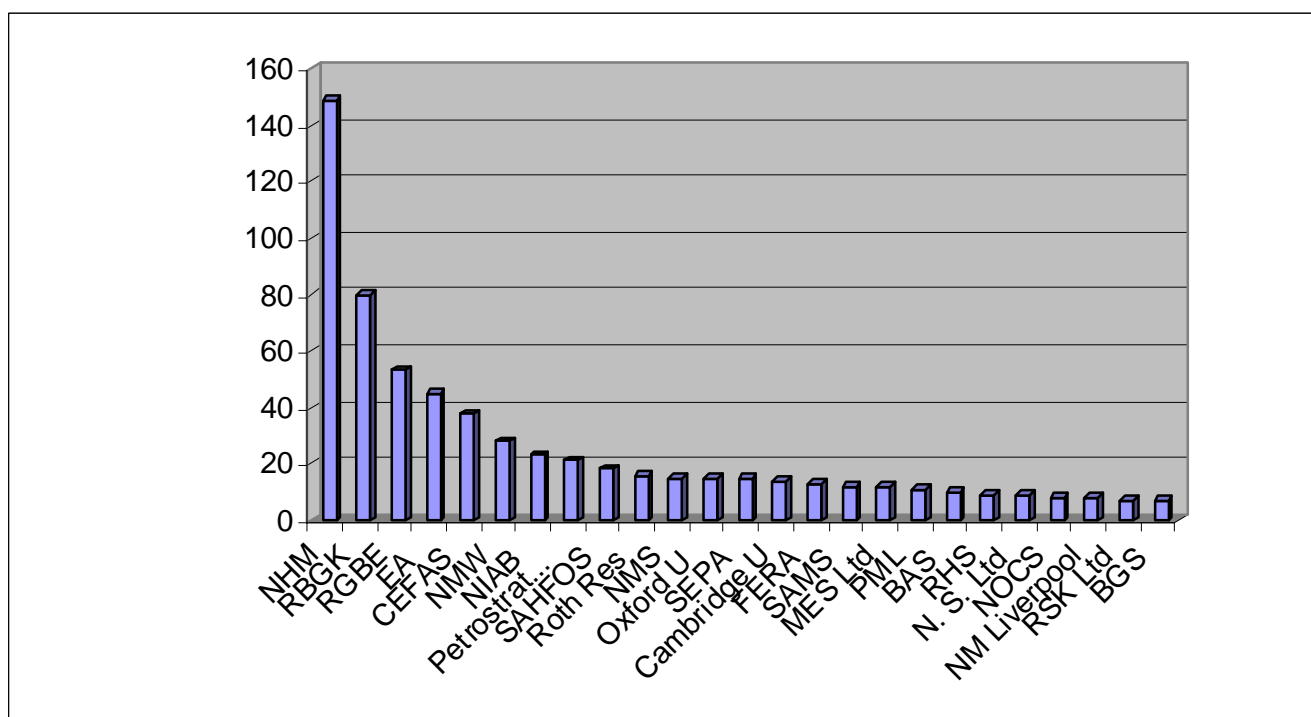


Fig. 1.1. The numbers of taxonomists in 25 of the largest UK organizations

The three largest taxonomic institutions are the Natural History Museum, the Royal Botanic Gardens, Kew and the Royal Botanic Gardens, Edinburgh (Fig. 1.1). Together with the other National Museums, these institutions represent core national capability in taxonomy and systematics.

The second major category of institutions engaged in taxonomy comprises the government laboratories, such as the Defra labs (CEFAS, FERA, NIAB), the Environment agencies (EA, SEPA, NIEA), and the RCUK labs (Rothamsted Research, IFR, PML, NOCS, SAMS, BAS, BGS). Taxonomists at government laboratories, such as the Centre for Environment, Fisheries and Aquaculture Science (CEFAS - 38 taxonomists), the Scottish Environmental Protection Agency (SEPA – 15 taxonomists in Marine Science section), and the Food and Environment Research Agency (FERA – 13 taxonomists), are primarily involved in UK-orientated environmental monitoring programmes and in discharging a range of statutory responsibilities for the identification of pests and diseases. The taxonomy and systematics undertaken by Research Council institutes such as Rothamsted Research (BBSRC – 16 taxonomists) and the Plymouth Marine Laboratory (NERC – 11 taxonomists) is typically integrated into their major agricultural and environmental research programmes.

Included for the first time in any UK taxonomic review is a significant range of small commercial companies involved in consultancy work, particularly in the areas of environmental impact assessments and biostratigraphy. Detailed information was available for a sample of individual companies. For example, Petrostrat Ltd, employing 21 taxonomists, is one of the largest of the UK-based stratigraphy companies and is included in the overall analysis together with some smaller companies (Network Stratigraphic Consulting Ltd, BP Exploration Ltd) for which precise data are available. A submission from the industry liaison officer of the Micropalaeontological Society confirmed that there are more than 20 companies in this sector, employing a total of about 150 to 180 postgraduate level taxonomists. The environmental consultancy sector is similarly vigorous in the UK with a large number of companies. Again, most companies are relatively small: in the marine sector, for example, Marine Ecological Survey Ltd, employing 12 taxonomists, is one of the larger companies.

The university sector is under-represented in this survey, primarily because the number of taxonomists in UK universities, with some notable exceptions, is now generally small and sampling effort in the long tail of the distribution is high for little return. The three universities (Reading, Imperial College and Glasgow) that were the focus of the 1990s taxonomy initiative by NERC were specifically included in our survey, as were universities with large taxonomic collections and/or museums, such as Oxford, Cambridge and UCL. The un-sampled tail to this distribution includes many university departments where one isolated taxonomist, sometimes two, works. Taxonomists working in palaeontology departments have also been significantly under-sampled. The number of taxonomists in UK universities is small. University-based taxonomists reaching retirement age have typically not been replaced by taxonomists, and this is the sector that has undergone the most marked decline since the mid-1990s.

Few local and regional museums employ taxonomists. The most recent comprehensive survey of UK museums (Williams, B. 1987 *Biological Collections UK*) found 254 institutions holding biological collections, of which only a quarter (64) had a specific natural sciences curator. Geology collections (comprising rocks and minerals as well as fossils) were reviewed earlier, in 1980 (Doughty: *State and status of geology in UK Museums*). Doughty reported on collections housed in 283 institutions, of which only about a tenth (29) had dedicated curatorial staff. In response to the recommendations in the 1987 biological collections report, the strategic decision to create a series of specialist peripatetic natural science curator posts was taken and these were set up on a regional basis. A review of collections in the Eastern Region of England undertaken for the MLA (Museums, Libraries & Archives) showed the overall picture remains the same today, with most collection-holding institutions lacking a specialist natural history curator or sharing a peripatetic curator.

Students are under-sampled as only a few institutions returned survey information on their students. However, analysis of postgraduate theses submitted to the British Library (see [www.theses.com](http://www.theses.com)) indicated that the number of theses classified as systematics or taxonomy was consistently low between 2005 and 2008 (less than 20 per year) for systematic botany, systematic microbiology and zoological taxonomy. While this is not a comprehensive list of theses produced in the UK it does indicate a relatively low level of doctoral training in the field. The large taxonomic institutions host many postgraduate students - about 150 at the NHM and 80 at RBG Kew at any one time – according to oral evidence given to the House of Lords inquiry. But, these address a wide range of taxonomy & systematics related topics and, in the case of RBG Kew, only about 18% (15 of the 80) contain a substantial proportion of descriptive taxonomy.

In the UK an enormous amount of biodiversity information has been gathered over the years by volunteers who organise themselves through many national and local societies

and recording schemes. The voluntary sector, with its core of expert amateur naturalists, is an important repository of taxonomic expertise. The volunteers monitor changes in their local fauna and flora, provide records for biological recording schemes, and generate data for Biodiversity Action Plans. We gathered no new data on numbers of volunteers engaged in taxonomic work and it is problematic to accurately estimate numbers. There are 75 record centres around the UK listed on the local records centre contact database ([www.nbn-nfbr.org](http://www.nbn-nfbr.org)), but the emphasis for this community is on identifications. The directory of British & Irish natural history and related societies (see [www.nhm.ac.uk](http://www.nhm.ac.uk) website) has 1540 societies listed, however only a small subset of these are actively involved in taxonomic research. These provide a common forum for professional and volunteer taxonomists. In our survey, we sought to include only those volunteers who have expert identification skills and who either produce some descriptive taxonomy, or are involved in training others through organised courses or through the activities of taxon-based learned societies. These are the individual volunteers likely to have impact on the state of health of their taxon-specific areas and who need to be considered in strategic planning. We estimate that there are about 120 to 150 volunteers in this category.

The main survey identified 727 taxonomists in the UK. Commercial consultancy and stratigraphy companies which were identified to us by representatives of those sectors but which were not sampled directly, contribute approximately 180 more individuals to the total. In addition, our focus was on large and mid-sized institutions so there is undoubtedly a long un-sampled tail to this distribution consisting of expert amateur naturalists and organizations where only one or two isolated taxonomists work and where sampling effort would be high for little return. An estimate of this might add another 150 to 180 taxonomists to the total, so a maximum of about 1100 seems appropriate to mark the number of active taxonomists in the UK.

### 1.3. Numbers of Taxonomists in Different Expertise Strands.

Identification skills are extremely important in the commercial sector. We estimate that companies involved in stratigraphy and in environmental consultancy employ in excess of 250 analysts in the UK whose primary work is identification. These small specialist companies are at the high skills end of the knowledge-based economy. Staff at government labs (e.g. CEFAS & FERA) and in environmental agencies (e.g. EA & SEPA), involved statutory monitoring duties, and at research organizations such as the Sir Alister Hardy Foundation for Ocean Science (SAHFOS), also spend the majority of their time on sample identification and analysis. Curators at museums and botanic gardens of all sizes also spend a significant proportion of their time making identifications. We estimate that there is a cohort of about 600 professional taxonomists in the UK primarily engaged in such diagnostics work (i.e. they make identifications). While classified as taxonomists, these identification experts are mainly users of the products of descriptive and revisionary taxonomists who generate the identification keys and handbooks.

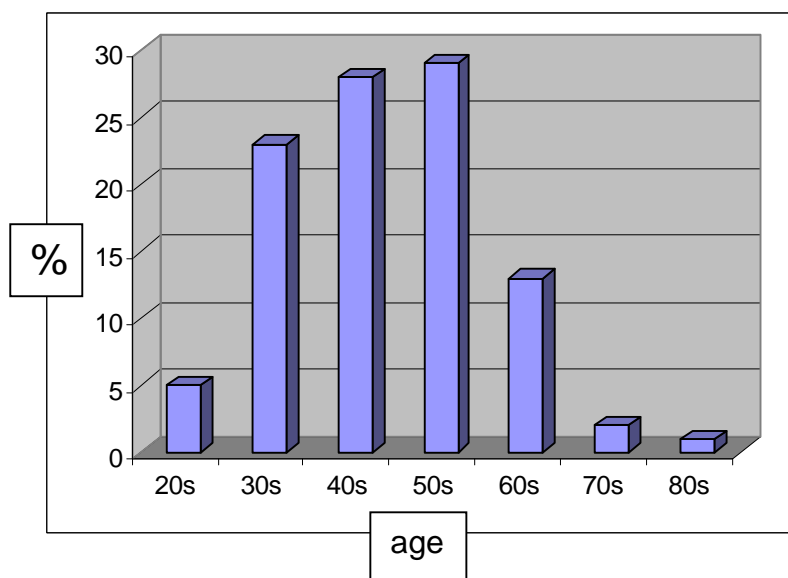
Phylogenetic research is undertaken predominantly in the academic sector - at the largest taxonomic institutions and the universities. However, some phylogenetic work takes place in Government laboratories (e.g. FERA, SCRI) and at Research Council laboratories such as the Institute for Food Research and Rothamsted Research (both BBSRC) and the British Antarctic Survey (NERC), and some taxonomists with phylogenetic skills are also employed in the commercial R & D sector, in areas such as pesticide development and research into resistance mechanisms. We estimate that there are about 100 systematic biologists in the UK who are primarily engaged in generating and interpreting phylogenies.

Excluding the estimated 600 taxonomists engaged primarily in diagnostics work using their identification skills, and the estimated 100 systematists involved primarily in phylogenetic research, we estimate that the descriptive and revisionary skills cohort consists of about 400 taxonomists in the UK. These are the taxon-based experts, who describe new species and whose expertise includes morphology, as well as behaviour, ecology, etc. Nested within this group are the key individuals who are the natural historians of their taxon and who perform the vital role of integrating taxonomic information with knowledge of whole organism biology. When concern has been expressed over the decline of taxonomy in the UK, it usually was with reference to decreases in the numbers of these taxon-based experts.

We gathered data on taxon coverage but we did not obtain sufficient detailed data to perform a meaningful gap analysis. These data confirm that there are taxa (including some groups of higher plants and many groups of invertebrates, fungi and micro-organisms) for which no cutting-edge expertise is available in the UK, but this has long been the case. For some of these taxa expertise is available within Europe, but for others there is currently a dearth of expertise in Europe, or even globally. There is currently no formal system for strategic expertise mapping or expertise development planning at the UK national level, or at the European level, although the possibilities of establishing such a system have been discussed and some informal planning occurs. Although this review is UK focused, the international dimension is clearly relevant to any discussions on duplication of effort or global capacity in any given taxon.

#### 1.4. Age Distribution

There has been concern expressed repeatedly, for example in evidence submitted to 2007-08 House of Lords inquiry, that the population of taxonomists in the UK is ageing and that too few young taxonomists are being recruited into the national pool of expertise. We found that the age distribution of taxonomists in the large taxonomic institutions (NHM, RBGK and RBGE), the national museums and academia is unimodal (Fig. 1.2), with the mode in the 50s age category. The combined 40s and 50s age categories together comprise 57% of the total workforce. Recruitment into the 20s category is low (5%) but almost certainly reflects a typical academic career path which consists of a PhD studentship and one or two postdoctoral fellowships - carrying a



*Fig. 1.2. Age distribution of active taxonomists in national museums, the royal botanic gardens and academia [Sample size N =377].*

taxonomist into the 30s age category before they are in position to compete for a permanent position. Comparable data are available for staff involved in the teaching of chemistry at UK universities (Gagan, 2008: *Review of student learning experiences in chemistry*). A survey of total of 237 chemistry staff at 45 universities revealed a unimodal age distribution, with a strong peak in the 40-49 age category. The 40s and 50s together comprised 62% of the total surveyed.

These data are in contrast to the age distribution in the commercial and government monitoring sectors where the emphasis is almost solely on diagnostics/identification, rather than descriptive taxonomy or phylogeny. Here the mode is in the 30s age group, and the combined 20s and 30s age category comprises 64% of the total work force. The difference between the two datasets is marked. In the commercial and government laboratory sectors where monitoring is the goal, diagnostics is the primary task and the profile shows that the workforce is significantly younger than in the large taxonomic institution/academia sector. One factor at work here is the difficulty in retaining trained staff in environmental consultancies. This was clearly and repeatedly articulated as a problem by industrial representatives during the community consultation, although there was no consensus over the underlying causes. The destination of staff leaving the consultancy sector is unknown but the in-depth survey of route-to-post suggests that very few move into taxonomic research.

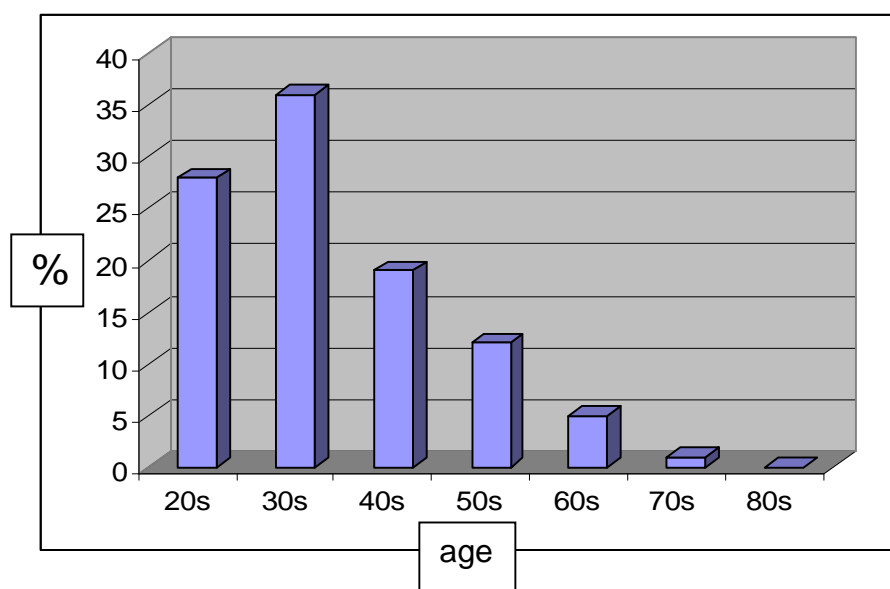


Fig. 1.3. Age distribution of taxonomists in commercial sector (Fugro, ERT, MES, IECS, BP), the monitoring sector (FERA, CEFAS, NIAB) and long time-series research sector (SAHFOS, PML). [sample size N = 126]

Data on the age distribution of micropalaeontologists working in the stratigraphy sector were made available to the survey team. Based on about 100 expert taxonomic micropalaeontologists, the age distribution is unimodal and resembles that in Fig. 1.2, with the mode in the 50s category. Retention of skilled staff in the stratigraphy sector does not appear to be a problem - in fact the problem clearly articulated by the biostratigraphy industry is that the supply of trained graduates and postgraduates has dried up and that recruitment difficulties are threatening the long-term competitive edge of this industry (see §6.1).

We have very few data on age distribution in the voluntary sector. Data presented as evidence to the House of Lords inquiry indicates that natural history societies and

wildlife trusts are experiencing a fall in recruitment of younger members and an increase in the average age of members. Although these data are fragmentary they are in accord with previously expressed concerns over an ageing population of volunteer taxonomists in the UK. In the Hertfordshire Natural History Society, for example, the mode is strongly in the 50s and the over three quarters (76%) of members are aged 50 or over (Fig. 1.4).

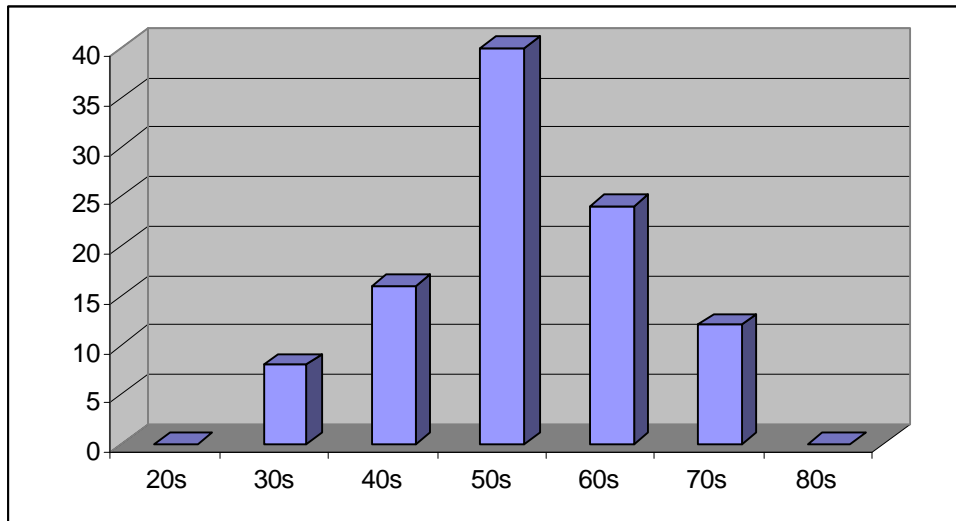


Fig. 1.4. Age distribution of members of the Hertfordshire Natural History Society (from written evidence submitted to House of Lords by Biosciences Federation) [sample size N = 25]

Data available from taxon-specific learned societies also allow us to get a partial picture (Fig. 1.5) of the retired segment of the volunteer community. This includes retired professional taxonomists who tend to remain active after retirement and often channel their activities via such societies. The age distribution of algal specialists in the UK is probably quite typical: the peak is in the 50s age category and members can remain active well into their 80s.

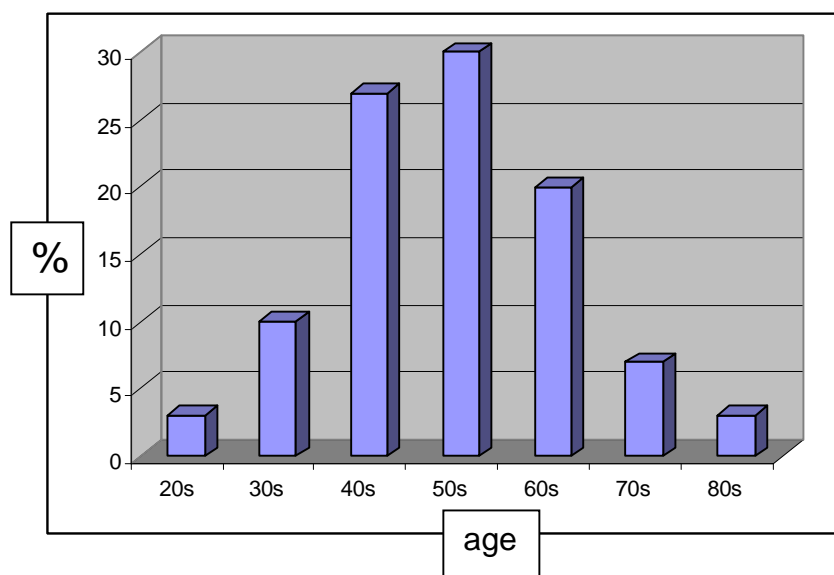


Fig. 1.5. Age distribution of algal taxonomists in the UK (data from The Phycologist & from the Linnean Society report) [Sample size N = 31]

In summary the idea of an ageing population of taxonomists holds true for the voluntary sector and for the membership profile of many learned societies. In the environmental

consultancy industry and in monitoring organisations, the workforce of analysts is comparatively young but there are concerns over retention of skilled staff, particularly in the consultancy sector. In contrast, in the biostratigraphy industry staff retention is not a major issue, but there are serious concerns over the failure of the supply chain of trained graduates and postgraduates because the expert workforce is ageing. Age data for large taxonomic institutions/academia were reasonably extensive (N = 377), and we consider that the age distribution reflects the norm for this career path. The mode is in the 50s, the 40s and 50s categories together comprise 57% of the total, but the 30s category comprised another 23%. Our data do not support the widespread view of an ageing skills base in the large taxonomic institutions/academia sector.

### 1.5. Succession Planning

Three quarters of the 160 taxonomists interviewed considered their area of taxonomy in the UK to be in an “unhealthy” state and the main stated cause for their concern was the apparent lack of succession planning in institutions that house taxonomic expertise. The definition of “succession planning” apparent here is the like-for-like replacement of taxon-based expertise. Respondents were frustrated at this situation because mentoring a successor is a more efficient and more effective method of maintaining expertise levels than leaving a new taxonomist to acquire expertise in isolation. Expressed concerns over the ageing skills base and concerns over the lack of formal succession planning are frequently merged into a view that the UK expert on a particular taxon is approaching retirement and there is no direct replacement in the pipeline.

Our survey of institutions revealed a complex picture across the UK. Commercial consultancies and institutions involved in monitoring or long time-series analysis typically have like-for-like succession planning. In organizations such as The Sir Alister Hardy Foundation for Ocean Science (SAHFOS), succession planning is very well developed since the maintenance of a standard analytical methodology over decade-long time scales is a high priority for the organization. In contrast, recruitment of research taxonomists at universities, national museums and the Royal Botanic Gardens is often, although not exclusively, targeted at the most outstanding individuals irrespective of their taxon specialization, as in other scientific disciplines.

The majority of the UK institutions included in our wider survey indicated that they did not have a formal system for succession planning – in part reflecting a flexible, market-driven approach. However, nearly half (45%) of taxonomists interviewed succeeded someone in their current research position, compared to 55% who occupied new posts. It seems likely that a significant amount of informal succession planning does take place, but this does not amount to a strategic plan to maintain national capability in any particular taxon.

### 1.6. Trends

The only previous, large scale attempt to quantify the availability of taxonomic expertise in the UK was the survey performed by the Systematics Forum published in 1996. Participation in the Systematics Forum survey was voluntary and based on self nomination. The headline results of Systematics Forum survey were revised and partially updated in 2002, and summary figures from this revised version were submitted to the House of Lords 2007-08 Follow-up Inquiry, as part of the evidence given by EDIT. This dataset was made available to the review. The Systematics Forum survey recognized only one category – “taxonomist” – and counted a total of 861 taxonomists in the UK. Despite the precision, such a figure is hard to interpret and did not provide a meaningful measure of the state of health of the discipline.

We identified about 740 taxonomists during this review, but have robust data to indicate that the overall taxonomic skills envelope for the UK probably encompasses about 1100 individuals. Only about 400 of these are taxon specialists engaged in descriptive and revisionary studies. This figure is in no way comparable with the headline number of 861 taxonomists identified by the Systematics Forum survey. Firstly, the constituencies are very different: the Systematics Forum figure focused more on academia and learned societies and included few data from industry or from government laboratories. Secondly, the data aggregation processes are different, with the former based on self nomination compared to the targeted, institution-based approach we employed in the current review. Effectively, there is no suitable, large-scale baseline against which we can compare our new data on the state of taxonomy and systematics in the UK. This makes the identification of trends more difficult, and forces us to rely on fragmentary data and on indirect metrics derived from the outputs of taxonomy or taxonomy-dependent research.

Trends within some individual institutions are documented in evidence submitted to the House of Lords inquiries. The number of taxonomists employed by CABI International, for example, shows a precipitous decline since 1992. Given the age distribution of the remaining four CABI taxonomists, it can be projected that only a single taxonomist will remain by 2012. However, this example reflects a policy change in a single organization.

Table 1. Number of taxonomists employed by CABI International

Expertise	1992*	2002*	2010**
Bacteriology	1	0	0
Entomology/arachnology	12	0	0
Mycology	15	7	3
Nematology/parasitology	6	1	1

[\*data from House of Lords Inquiry, \*\*data updated by interview].

Analysis of manpower trends at the Natural History Museum reveals only a small decline in scientific staff numbers over the same time frame (1992 to 2008). The Linnean Society presented evidence that there were 200 full time equivalent posts (FTEs) in life sciences at the museum in 1992-3 and that this had fallen to 189 FTEs in 2006-7. Other changes have also occurred: the percentage of core staff undertaking descriptive taxonomy in the life sciences as some part of their job fell from 50% in 1992-3 to 38% in 2006-7. So the proportion of staff at the natural history museum engaged in descriptive and revisionary taxonomy has fallen by 12% over the past 15 years. This fall is almost certainly a reflection of the necessity to invest FTEs in developing institutional capability in molecular methodology, and in rapidly expanding fields such as bioinformatics and e-taxonomy. Taxonomy has become much broader in scope and in order to sustain excellence in this competitive global arena, all of the UK's large taxonomic institutions have had to invest in developing capacity to embrace the full range of new technologies.

Submissions to the House of Lords 2007-08 inquiry pointed to the near collapse of taxonomy in British universities. The Botanical Society of the British Isles commented that "*species identification skills and other field skills are hardly taught at undergraduate levels at universities*". Comparison with the 1996 Systematics Forum database does support the generalization that there are fewer taxonomists engaged in descriptive taxonomy or revisionary studies. This decline extends even to microbial groups. In evidence, the Society for General Microbiology commented "*the number of active prokaryotic taxonomists in UK institutions is declining. Specifically, two very active (and internationally renowned) university groups have been lost in recent years, one due to retirement of the group leader, and one due to....suspected RAE pressures*". However,

we found no evidence of a decline in numbers of researchers involved in phylogeny. The British Antarctic Survey, for example, reported that “*We have recently expanded our molecular phylogenetics team at BAS and see it as an important growth area for the future.*”

Indirect measures include, for example, the trend in volume of taxonomic publications by UK taxonomists. Hopkins & Freckleton (2002 – *Animal Conservation* 5: 245-249) analysed an 84-year series of entomological papers published by a UK journal prior to 2001. They found that “professional taxonomy appears to have undergone a long and continuing decline since this peak [in 1950s and 1960s]”, a trend that was “consistent with other studies”.

The UK is not unusual in identifying a decline in the skilled taxonomist workforce. There are numerous reports that the number of trained and practising taxonomists is declining worldwide (e.g. Kim & Byrne, 2006 *Ecological Research* 21: 794-810). The House of Lords inquiry received evidence that taxonomy was in decline in Europe and in New Zealand. A recent review of the status and trends in taxonomy and systematics in Canada (<http://www.scienceadvice.ca/en/publications/assessments.aspx>) documented that there was a loss of taxonomic expertise in highly diverse and poorly understood taxonomic groups and noted that, as taxonomists retire, they are not being replaced. The review panel concluded that Canada was not equipped to fully understand the challenges of its biodiversity resources. The decline in numbers of taxonomists is most apparent and most consistent in developed countries, but the growing number of new species descriptions generated by taxonomists based in countries such as Brazil and China, perhaps indicates that the global picture is not one of uniform decline.

## **2. Collections**

The UK is richly supplied with natural history collections and with culture collections supported by a variety of funding regimes, both private and public. The collections serve a diversity of purposes, from entertaining and informing, through teaching and reference, to research.

### **2.1. Natural History Collections**

Natural history collections are distributed throughout the UK and range in scale from the local town museum up to the large university and national museums. Important reference collections have also been developed by Research Council institutes such as the British Antarctic Survey. Museums and botanic gardens of all sizes are important in providing initial contact with wildlife for an increasingly urbanised population, thereby helping to inspire and educate a new generation of naturalists. Reference collections are an integral part of the infrastructure underpinning the disciplines of taxonomy and systematics, and are viewed as such by the European Commission, for example. They support the need for increasing accuracy of modern identifications and act as vouchers for historical records where species concepts or names have changed over time. They are considered here primarily in this context.

In 1987 there were 254 institutions holding biological collections, and insects, mollusc shells, and vertebrates comprised the bulk of the zoological holdings, with other invertebrates being poorly represented (Williams, B. *Biological Collections UK*). There were 16 provincial institutions with large herbaria (defined as holding over 50,000 specimens). Geographical coverage data indicated that material of both British and international origin is widely dispersed across different institutions. Type specimens were held at 52 institutions, but study of smaller collections often reveals hitherto

undocumented types. In 1980 Geology collections were housed in 283 institutions, of which 64 included type specimens (Doughty, P. *State and status of geology in UK Museums*). Collections may increase in size over time but, for most, their core content does not change significantly even over decadal time scales. These reviews still provide an accurate general picture of the distribution of natural history collections.

Historical contingencies have resulted in the wide dispersion of collections amongst many types of UK institutions, from major international museums and botanical gardens to university based and more locally focused collections. In the past, each of these served a different audience and purpose, but in recent years some rationalisation of collections has taken place. Some collections once held separately have been physically merged, for example, the palaeontological collections in Scottish Universities have been merged onto a single site, and many small university collections in the UK are either being sent abroad (e.g., the Solanaceae collection from the University of Birmingham to Nijmegen), or amalgamated into larger collections (e.g., the Combretaceae collection of the University of Leicester into the herbarium of the Natural History Museum, or the collection of the University of Glasgow into RBG Edinburgh). There is currently no national approach to collections.

Small university natural history collections often contain type specimens, reflecting the historic interest of staff. However they are particularly vulnerable to changes in institutional priorities, with shifts in research interests of staff and in curriculum content resulting in changes in patterns of collections usage. The larger and more important university collections provide a more secure home for teaching and research material and may contain significant numbers of types. Funding for university collections is provided by the Higher Education Funding Council for England (HEFCE) and the Scottish Funding Council (SFC), and this is part of the heterogeneous support base for national capability in taxonomy.

Most local and regional collection-holding institutions lack a specialist natural history curator or share a peripatetic curator. The Renaissance in the Regions initiative of the MLA outlined a need to “develop subject/discipline based networks” which would enable museums to share skills and expertise and to work together to make more effective use of their collections. Supported by a subject specialist network exploratory grant, NatSCA (Natural Sciences Collections Association) developed a framework partnership involving the Natural History Museum, London, the World Museum Liverpool, and museums from the regional hubs. This framework is the template for a national subject specialist network linking up the regionally based pilots.

Many organizations keep important reference collections. FERA, for example, holds the National Collection of Plant Pathogenic Bacteria, and has recently received the nematode reference collection from Rothamsted Research. Consultancy companies and monitoring agencies also maintain reference collections. New collections continue to be established according to need.

All collections duplicate curatorial tasks; visitors must be looked after, specimens must be cared for, kept free from pests and sent on loan. As more access to collections becomes digital, institutions with like collections are considering merging or at least sharing duplicated functions to increase efficiency. Collections held on different sites can be managed on-line as a single entity and searches via the website can bring together all material, as has been established for the UK National Culture Collection. Centralised on-line facilities provide ready access to data from widely dispersed collections: the *Index Herbariorum*, is a good example as this is a guide to the approximately 350 million dried plant and fungal specimens contained in nearly 4000 herbaria all around the world.

Research on these same collections, however, is generally not duplicated across institutions.

## 2.2. Culture collections

Microbial culture collections, as depositories of the majority of characterised taxonomic groups, and much of the cultivated diversity, are essential for conservation, maintenance and supply of cultures for research, including taxonomic research, and for industry. They contain living organisms and function varies depending on the nature of the component organisms. For example, collections of pathogens have different roles to those of environmental isolates, but all provide secure, quality assured storage of isolates from research programmes and many are commercially valuable. Deposition of strains is required by research councils and journals, and for patent deposits.

The UK houses important collections of living organisms. Together the collections listed in Table 2 comprise the UK National Culture Collection (UKNCC), with holdings of over 2200 algae and protozoa, over 20,000 animal cell lines, over 25,000 bacteria and over 25,000 fungi - more than 73,000 cultures in total.

Table. 2. UKNCC holdings and parental organizations

<i>Collection [Parental Organization]</i>	<i>Size of Collection</i>
CABI Genetics Resource Collection [CABI]	19,000 filamentous fungi, 270 yeasts, 1700 plant pathogenic bacteria
CCAP Culture Collection of Algae & Protozoa [Dunstaffnage Marine Laboratory (NERC)]	2200 freshwater & marine strains
ECACC European Collections of Cell Cultures [Health Protection Agency]	20,000 animal cell lines, etc.
NCWRF National Collection of Wood-Rotting Macro-Fungi [Building Research Establishment]	600 fungi
NCIMB National Collection of Industrial, Food & Marine Bacteria [BBSRC]	8500 strains
NCPF National Collection of Pathogenic Fungi [Health Protection Agency]	2500 accessions
NCPPB National Collection of Plant Pathogenic Bacteria [FERA (Defra)]	5500 accessions
NCPV National Collection of Pathogenic Viruses [Health Protection Agency & Wellcome Trust]	-
NCTC National Collection of Type Cultures [Health Protection Agency]	10,000 bacteria & mycoplasmas
NCYC National Collection of Yeast Cultures [Institute of Food Research (BBSRC)]	2800 yeasts

The UKNCC was established to coordinate marketing and research activities between these collections and, despite the diversity of holdings and of parental or funding organizations, the accessions databases for these collections can be searched via a single portal ([www.ukncc.co.uk/](http://www.ukncc.co.uk/)). The UKNCC model demonstrates how integrated access can be provided to the benefit of a wide range of public and commercial users.

Conservation of the all of the vast diversity of microorganisms is not feasible, with current technology, and is limited by our inability to propagate many strains identified using molecular methods. All collections are subsidised (e.g. as units within research institutes, or through government or research council support), threatening their long-term security and the considerable investment that resulted in their isolation and characterisation. Collection activities (accessions, maintenance, storage, distribution, patent deposits) cannot be financed by sales or by charging for storage and patent deposit services. Researchers need to take into account the costs of these essential activities and incorporate them into their research grants, but it should be recognised that material in these collections, originating from publicly-funded research, are being made available to a range of users.

### **3. Funding Taxonomy & Systematics in UK**

Core funding of national capability of taxonomy and systematics comes primarily from DCMS (Grant-in-Aid to the Natural History Museum), from Defra (Grant-in-Aid to the Royal Botanic Gardens, Kew) and from the Scottish Government's Rural and Environmental Research and Analysis Directorate (Grant-in-Aid to the Royal Botanic Gardens, Edinburgh). Core funding for The National Museum of Wales is from the Welsh Assembly Government, for The National Museum, Scotland, from Scottish Government, for the National Museum Northern Ireland, from the Northern Ireland Assembly, and for the National Museums Liverpool, from DCMS. These organizations are the major custodians and key sponsors of national capability, but the stakeholder community extends throughout almost all branches of government, industry, academia and civil society.

Funding for research in taxonomy and systematics also comes from RCUK, primarily from NERC and BBSRC. In evidence to the House of Lords inquiry, the BBSRC estimated its spend on systematics and taxonomy research in 2007/08 as £15.3M, and of this less than 1% was for taxonomy-based (descriptive strand) research, with the majority being systematics based (phylogenetic strand). NERC's Taxonomy Initiative in the 1990s was highly successful and its legacy is visible in taxonomy and systematics in the UK today. Currently, there is no thematic programme on taxonomy and systematics, so NERC support is in the form of responsive mode grants, fellowships and studentships. In supplementary evidence to the House of Lords Inquiry in 2008 NERC stated that over the 5 years from 2002-2006 it awarded £11.3 M to biodiversity related responsive mode grants that included an element of systematics and taxonomy. In the same period 9 of the 154 fellowships awarded by NERC included an element of systematics and taxonomy, to a value of just over £2M. The average allocation in the period 2005-2007 for systematics and taxonomy PhD studentships was in the region of £1 M per annum. In addition some taxonomy is supported at NERC research centres via national capability funding.

The funding streams that support taxonomy and systematics in the UK are extremely diverse. Over the past 5 years the 160 taxonomists in our in-depth survey were in receipt of a total of 174 grants in excess of £10K, from 74 different funders. The top funding bodies are NERC and the Darwin Initiative, closely followed by the European Union, Defra (other than Darwin Initiative), the Leverhulme Trust, BBSRC and the National Science Foundation (USA). The list of funding bodies has a long "tail" with 51 different bodies each giving a single grant in excess of £10K (Fig. 3.1) (see Appendix 4).

The list of funders also testifies to the international collaborative nature of science funding: the European Union is third in the grant funding league, but the list also includes national research agencies in the USA (NSF), Germany (DFG), Spain (FCT),

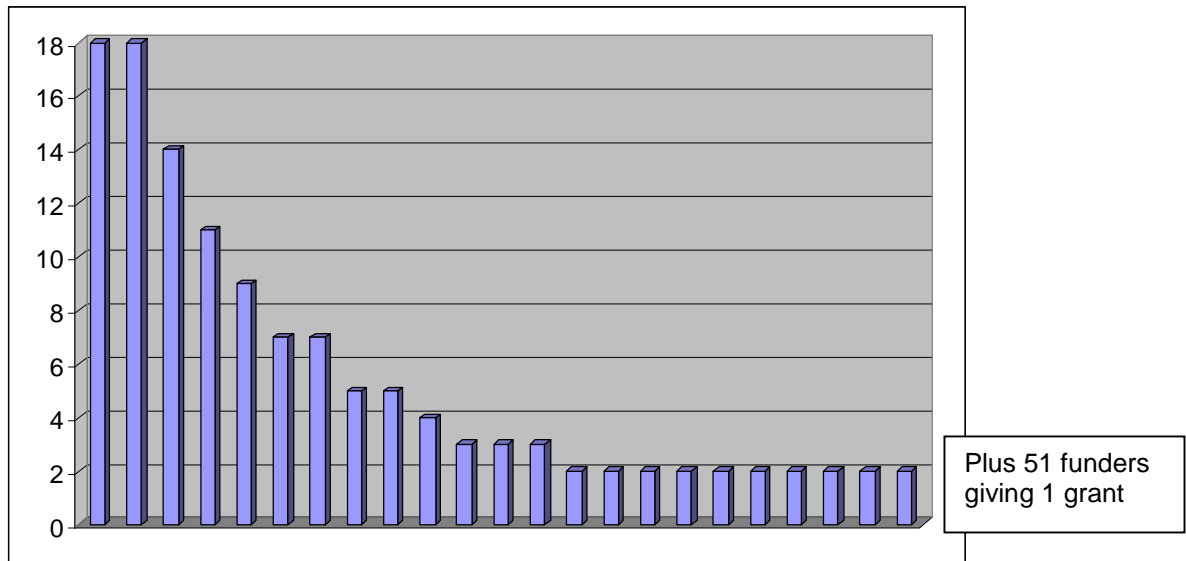


Fig. 3.1. Numbers of respondents holding grants in excess of £10k from specified funding bodies. [Data from in-depth sample N = 160] [see Appendix 4]

Japan (JSPS), Belgium (FWO), EU/Russia (INTAS) and South Africa (NRF), other foreign governments (e.g. Thailand, Portugal, Oman), and international NGOs (e.g. GBIF, IAPT, IUCN). In addition, many charitable trusts based abroad appear on the list, including: Gordon & Betty Moore Foundation, Andrew W Mellon Foundation, Carlsberg Foundation, and the A P Sloan Foundation.

The broad spread of UK Government departments and Agencies represented on the list demonstrates the direct engagement of the taxonomy community with delivery of policy. Government Departments include: Defra, DfiD, DECC, and BIS. Agencies include: the British Council, Environment Agency, Scottish Natural Heritage, Scottish Environmental Protection Agency, Northern Ireland Environment Agency, and Natural England. In other evidence received the CCW (Countryside Council for Wales) also sponsored contracts with a taxonomic component, although it was not listed in the survey of the 160 respondents. Funding for the collections at UK university museums has come in part from HEFCE and SFC.

Industry also commissions taxonomic or systematic research. Companies involved in funding our respondents included Rio Tinto, Boots, GlaxoSmithKline, British American Tobacco, Syngenta, Alcoa and Leatherhead Food Research. Most of the research commissioned by these companies was more phylogenetic in emphasis, although some identification work was involved.

Commercial consultancies working in monitoring and in environmental impact assessment directly service the needs of their clients, who fund the work. Taxonomists working in taxonomic institutions and in academia also undertake consultancy work. The emphasis of such work is usually expert identification.

The large taxonomic institutions receive much of their core funding directly from government – DCMS (The Natural History Museum), Defra (RBG, Kew) and the Scottish Government’s RERAD (RBG, Edinburgh). However, the funding model supporting taxonomy & systematics in the UK is well and truly mixed with significant grant or commissioned research income coming from research councils, industry, charitable trusts, and NGOs, as well as from government departments and agencies. The international dimension is also very significant with grants funds flowing from the EU,

foreign governmental research agencies (sometimes foreign governments themselves), international NGOs, and from trusts based abroad. With some exceptions, the grant and commercial research income was for projects exploiting identification and phylogenetic skills. Additional funding for work in the descriptive and revisionary taxonomy strand was limited.

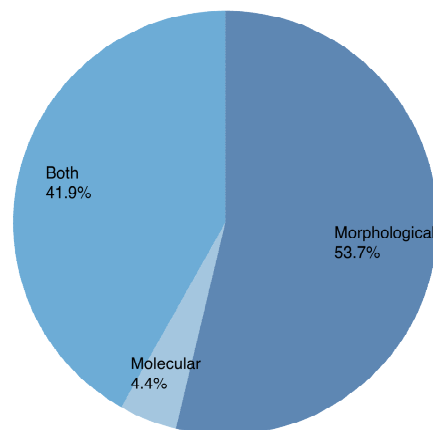
## **PART TWO: Assessment of Needs**

### **4. Technologies and Methods**

Professional taxonomy is at a critical time in its history. Pivotal to its future development are the rapidly expanding fields of high throughput sequencing, automated digital data gathering, biodiversity informatics and comparative genomics. Incorporating these technologies will be critical to the success of taxonomy and systematics.

#### 4.1. Molecular methods

Molecular sequencing methodologies have revolutionised most biological disciplines, including taxonomy & systematics. In the professional taxonomy sector the uptake of molecular methods has been high and molecular diagnostics are already widely used in the identification of crop pathogens, animal and plant viruses, and vectors of medical importance, by organizations such as Defra's FERA laboratory, the Natural Resources Institute (NRI, part of University of Greenwich), and the Natural History Museum. Just over 46% of taxonomists in the in-depth survey employed molecular techniques, mostly in combination with morphological techniques. Over 95% utilized morphological techniques - just over half (53.7%) using them exclusively. Despite concerns expressed by many representatives of the voluntary and commercial sectors, the survey shows that currently very few systematic biologists (4.4%) used purely molecular techniques.



*Fig.4.1. Methodologies utilized by taxonomists [In depth survey, N = 160]*

This result is not consistent across the population surveyed. Partitioning the dataset shows that no older (age 50+) respondents used purely molecular approaches, while the proportion using purely morphological techniques rose to 63.6%. In contrast, more (7.1%) younger scientists (under 40) applied purely molecular research techniques and slightly fewer (50%) employed only morphological techniques.

There is no doubt that taxonomy and systematics have benefited enormously from the development of molecular-based tools, such as bar-coding (the use of sequence data for a standard gene as a species identifier). Initial fears that the development of bar-

coding might take funds away from other areas of taxonomy have largely been proven unfounded, at least in Canada where relevant data exist (Packer *et al.*, 2009: *Canadian Journal of Zoology* 87:1097-1110). Sequence data have proved to be immensely valuable in systematic biology, providing information not only on identity, but also on phylogenetic relationships, and on questions such as geographical origin, for example, of the precise genetic type (haplotype) of invasive species or pathogens. High-throughput next generation sequencing now provides opportunities for relatively inexpensive bar-coding of, for example, whole ecosystems or entire regional floras and faunas. This could help greatly with species discovery and extends the reach of taxonomy by facilitating identification where no diagnostic keys exist. Bar-coding opens up the identification process to non-experts and, in doing so, could encourage more people into taxonomy.

In previous inquiries by the House of Lords (2002-03 and 2007-08) there has been an underlying sense that the future availability of novel molecular-based tools may in part compensate for the continuing contraction in the UK taxonomic skills base. The idea of a quick technological fix being just around the corner may in part explain the apparent reluctance to take decisive action to address the decline in the discipline. The reality of this becomes a central issue when considering a strategy for maintaining national capability.

Interestingly, we found the wider community of taxonomists in the UK to be polarized in their view of bar-coding. The advances in sequencing technology, driven largely by the needs of international biomedical research, have ensured that unit costs for sequencing have fallen significantly. Next generation sequencing, although it demands big resources for creating and handling enormous data volumes, plus high performance computing facilities for analysis, has opened up exciting possibilities for professional research taxonomists. Molecular diagnostics are becoming a routine identification method for all kinds of organisms and there is considerable optimism, amongst researchers, that bar-coding will soon become cost effective for use in monitoring programmes.

This contrasts with the view expressed strongly by commercial consultancies and some monitoring organizations, that bar-coding isn't yet cost effective for the scale of their surveys, and is not feasible given their time constraints. Similarly, volunteer taxonomists who typically lack access to molecular facilities, view bar-coding as inappropriate for biological recording, for monitoring and for the delivery of field data in support of Biodiversity Action Plans. Many pointed to the need for a system that would operate in the field - the hand-held bar-coder - but considered that it remains only a distant possibility.

The availability of sequence data has led to a quantum leap forwards in microbial taxonomy and systematics. Sequence data are also essential for phylogenetic analysis, for functional genomics and for metagenomics. Molecular diagnostics are already widely used where cost effective - in medicine, in agriculture and in phytosanitary monitoring, for example. When bar-coding of entire faunas and floras reaches critical mass (defined as when the sequence you're trying to match is more likely to be in the database than not), then sequence data will become invaluable for making or verifying identifications of environmental samples. The delivery of operational level identifications in industry, in policy-led environmental monitoring, and in some areas of research will continue to depend on morphological techniques, at least in the medium term. Neither bar-coding nor any automated identification system will perform the role of integrating taxonomic information with knowledge of whole organism biology.

## 4.2. Taxonomy on the Web

Like many other information-rich areas of science, taxonomy is already heavily dependent on the web. The web facilitates global networking between taxonomists, it provides access to expertise and information on collections and on distributions, it enhances quality control through the provision of expert-verified directories and registers, and it already delivers operational level taxonomic resources such interactive keys, descriptions, illustrations and distribution maps. Taxonomy on the web is expanding fast and it is a global enterprise in the process of evolving into modern biodiversity informatics. The original focal points around the world, where exceptional leadership had been shown by individual scientists or institutions in developing on-line taxonomic facilities – have now become nodes in a global network.

The e-taxonomy world is becoming well joined up, primarily because huge effort and considerable resources have been invested in standardizing systems to ensure interoperability between different initiatives and to maintain functionality between components of distributed networks. Groups such as TDWG (the Taxonomic Database Working Group) have helped to define and promote sets of international standards for descriptions data, for collections data and for geospatial data. For many taxa, Global Species Directories already exist or are under development. However, most are incomplete and even when at a very high degree of completeness (e.g. FishBase, AlgaeBase), such directories continue to grow as new species are described, new synonyms recognised and new localities discovered.

Much of the basic cyber-infrastructure is in place, so that the web can serve as a clearing house for vast quantities of information, currently fragmented and at badly-mapped locations. Important challenges remain, particularly in the area of automated digital data gathering, which have the potential to become powerful tools for the routine expansion and updating of global species directories, for example. The BBSRC funded roadmap for the development of e-taxonomy should have a view as to the priorities for the development of the infrastructure required to support 21<sup>st</sup> Century e-taxonomy. The vision of future taxonomy developed by the European Union network of excellence EDIT, explores some of the possibilities offered by the web (<http://www.e-taxonomy.eu/files/Taxonomy21report.pdf>).

On-line identification facilities are in demand by users of taxonomy. New approaches, such as scratchpads, have been developed that provide user-friendly technology enabling taxonomists to get their work onto the web with minimum expense and maximum functionality. The rate limiting step is finding experts able and willing to generate web-based identification systems. This is exactly the same situation as for hardcopy keys, guides and handbooks - successful handbook/identification key series, such as those published by the Linnean Society and the Royal Entomological Society, are unable to find authors, as noted by the House of Lords Inquiry. This is not a technology problem: it is a shortage of available expertise problem.

Web-based taxonomic facilities are accessed by the global community of biodiversity scientists, but with a few exceptions, such as GBIF (the Global Biodiversity Information Facility), are usually maintained by core funding from national sources. Global Species Directories (GSDs) are typically created by interested taxonomists and housed at their home institution (often universities). Institutional priorities change and university funding is far from secure, so these GSDs have a tendency to migrate to organizations where there is greater long-term security, such as large museums, botanic gardens, national data centres or international NGOs. These institutions currently serve as custodians of facilities with a global user community, and represent high visibility national contributions

to global taxonomic enterprise. Long term institutional commitment, even at this level, is ultimately dependent on government policy.

Dialogue with the UK user communities during this review, especially with commercial and voluntary sectors, placed the highest priority as the creation of better and more comprehensive identification keys to the UK fauna and flora to support them and other users of taxonomy in making accurate identifications. Ideally, these should be on-line because they can be updated easily and quickly, thus preserving their functionality in a dynamic area of science. An unanswered question is: how should the creation and maintenance of such systems be supported? The R & D phase is eligible for research council funding, but after initial system development such systems are often considered to be more in the realm of infrastructures. The continuing improvement and updating of digital resources is essential but difficult to fund. Identifying a mechanism for the long-term funding of these systems after they have been assimilated into the infrastructure remains a strategic priority.

## **5. Demand for Taxonomy**

The ERFF (Environment Research Funders' Forum), now merged with the Living with Environmental Change (LWEC) partnership, have just identified the critical skills gaps in the environmental sector over the next ten years

[http://www.ukcds.org.uk/\\_assets/file/publications/ERFF-Most-Wanted-report.pdf](http://www.ukcds.org.uk/_assets/file/publications/ERFF-Most-Wanted-report.pdf).

Taxonomy and Systematics was directly identified as one of the headline critical gaps. The specific needs were in applying understanding of taxonomy and systematics in various disciplines, in identification skills across all organisms and in biological monitoring. These skills are crucial for "monitoring and understanding the functionality of the marine environments", and for "recognising the role of biodiversity and ecosystem resilience in a changing climate"

Critical shortage of the same skills, however, was also apparent in other headline areas, including Fieldwork – where "survey skills including species identification" was identified as a specific need, and Sustainability Science and Planning - where "environmental impact assessment" was highlighted as a specific need. Many small UK commercial companies are active in the latter sector, and their evidence submitted during this survey confirms that the skills shortage has already been felt in the commercial sector.

### **5.1. Microbial Taxonomy**

Comparative analysis of whole genome sequences is increasing our understanding of bacterial phylogeny (including true Bacteria and the Archaeobacteria) and has significant potential in defining core and accessory genetic content and functional potential of phylogenetic groups. The increasing ability to sequence genomes from single cells enables genome sequence analysis of uncultivated organisms. In the long term this should provide more comprehensive and informed taxonomy and result in better diagnostic systems and higher standards for identification. Genome analysis also has greater potential for defining the 'relevance' and 'applied value' for both ecological and evolutionary studies, critically through relating groupings to function.

The fundamental reasons for taxonomy (to discover, describe, delimit and classify diversity, to define evolutionary relationships etc.) are common across the domains and kingdoms of life. Some practical considerations are also common; cross referencing, grouping and naming strains (sequences) with similar characters, the application of molecular approaches for much of the (unculturable) diversity and the prediction of characteristics from phylogeny for accurate identification. Medical and veterinary

microbiology are major users of systematics and identification tools, and there are many industrial applications, in mining and in the oil and gas sectors for example, that require accurate identifications.

## 5.2. Next Generation Science for Plant Earth

Key themes in the NERC strategy for 2001-2012 depend on taxonomy and systematics. Within the overarching challenge of understanding the role of biodiversity in ecosystem processes, key questions revolve around detecting the impact of environmental change on biodiversity and the impact of biodiversity loss on the resilience of ecosystems. The strategy points to the need for improved indicators of trends and patterns in biodiversity loss, and investigation of the threshold beyond which extinctions will increase in frequency and irreversible ecosystem change might take place. Monitoring, managing and understanding the functional significance of changes in biodiversity requires knowledge of species identity – and depends heavily on the outputs of taxonomy.

For microorganisms in particular there are strong scientific reasons for engaging in systematics research which focuses on ecosystem function, because the extent of functional redundancy, the existence of keystone species and the links between bacterial and archaeal diversity and ecosystem functioning, stability and resilience are poorly understood.

NERC recognised in its strategy that the changing environment will alter the spread of diseases – and that there was a need to increased knowledge of the underlying processes that cause diseases to spread. Taxonomists are typically in the front line for the diagnosis of emerging disease threats, providing information on the identity of disease vectors, invasive species, etc. Understanding the deep connections between biological evolution and the global environment through long time scales, provides insight into the forces that have driven global change and into the responses of organisms to such changes. Palaeontological taxonomy and systematics underpins the study of the processes adaptation of biological systems in response to environmental change.

## **6. Recruiting & Training Next Generation of Professional Taxonomists**

Serious concerns over the training and recruitment of the next generation of taxonomists have been expressed repeatedly, not only in evidence submitted to the House of Lords inquiries by numerous stakeholders but also by industry. The situation in the biostratigraphy industry seems typical:

*“The UK currently has a very active biostratigraphy industry built on microfossil taxonomy that underpins the global energy industry but there are signs that the once healthy supply of trained micropalaeontologists out of UK tertiary education is in steep decline.”*

Dan Finucane, BP Exploration Ltd.

This sentiment was strongly echoed by companies from the environmental consultancy industry (both marine and terrestrial). In fields as diverse as micropalaeontology, marine biology and terrestrial ecology, it appears that UK universities are not producing the trained postgraduates that industry is looking to recruit. More generally, in our survey of UK taxonomists the primary areas of concern expressed were typically related to the lack of training in the respondent's particular area of expertise, and the subsequent fear of a loss of expertise nationally.

The 2007-08 House of Lords inquiry highlighted the importance of inspiring children and fostering their interest in biodiversity and the environment. It considered that a greater

component of biodiversity-related topics, including taxonomy, should be included in school curricula and that field study should be encouraged. Opinions expressed during our surveys and community consultations fully endorse this view. The decision to focus this Review on the post-graduate sector was made by the Expert Working Group and the Review team, but has not gone without criticism. A marine consultancy company, EMU Ltd, commented “*We strongly disagree with ... the postgraduate emphasis. It is important to inspire, educate and expose students as early as possible to taxonomy*” and “*We have found undergraduates to be exceptionally enthusiastic...*” Similarly, the decline in field skills prompted the House of Lords inquiry to recommend that “*field study trips ... should be encouraged as a means of engaging and stimulating young people (as future volunteers) to become involved in biological recording*”. We strongly support these conclusions but our focus was primarily on postgraduate training because of the limited time scale of this Review.

### 6.1. Qualifications

The great majority (85%) of professional taxonomists have postgraduate qualifications, either at masters or doctorate level. In our in-depth survey of 160 taxonomists, we found relatively few (8.8%) entered professional employment in taxonomy directly from their first degree, and ever fewer came direct from school.

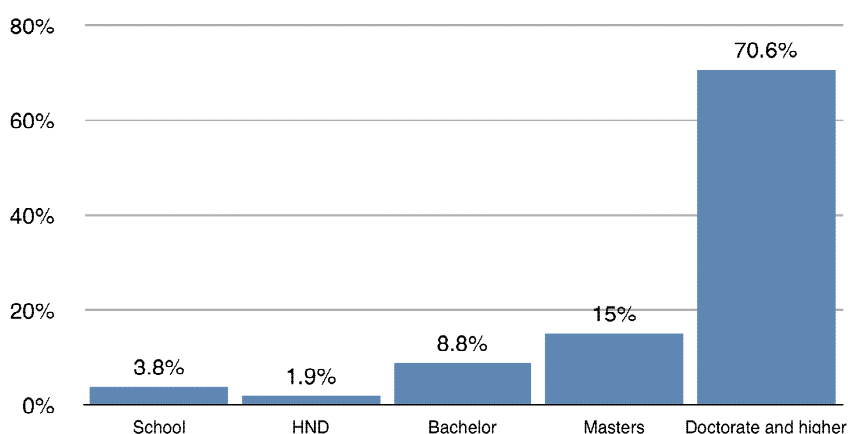


Fig. 6.1. Highest qualification obtained (In depth survey N = 160)

The commercial sector is not well represented in the data from the in-depth survey (Fig. 6.1). However, our Review received a substantial volume of written and oral evidence from the biostratigraphy and environmental consultancy industries. A Masters level qualification was the basic entry level qualification for micropalaeontology analysts and until recently five universities (Aberystwyth, Hull, Sheffield, Southampton and UCL) produced a supply of qualified postgraduates sufficient to meet demand. For a variety of reasons, but most commonly the retirement of the key course tutor, all five of these courses have now closed, the last being the Masters in Micropalaeontology at UCL which closed in 2008.

Demand for trained micropalaeontologists has fluctuated in the past, in part with the fortunes of the oil industry and in part with changing technologies. It is currently high since the last decade has seen a change in the role of micropalaeontologists in the oil and gas sector, with the advent of horizontal drilling. Oil production from particular oilfields has been increased by up to 30% using geosteering techniques, and these require the presence of on-site micropalaeontologists. There is no sign of decreased demand for trained taxonomists in this area and the specialist workforce is ageing (the

mode is in the late 40s to 50s), but virtually no micropalaeontologists are being trained in the UK. This is threatening the viability of a specialist industry where the UK was the global leader and there is currently no forum within which a dialogue over the future training needs can take place between the industry and the universities.

Submissions from the marine sector of the environmental consultancy industry similarly point to the failure of universities to produce, in this case, undergraduates with the appropriate skills. Companies commented that “*graduates often lack taxonomic skills*” [Marine Ecological Survey Ltd] and provided as evidence: “*Recently we advertised for experienced marine taxonomists. No applicants emerged with a suitable level of experience. This pattern has been common to recruitments over the past several years.*” [EMU Ltd.].

In summary, the biostratigraphy and environmental consultancy industries are specialized sectors of the knowledge-based economy, dependent upon a highly trained workforce of professional taxonomists making expert identifications. Both are ill served by UK universities which no longer provide an adequate supply of trained graduates and post-graduates to meet demand. Undergraduate courses lack appropriate taxonomic content, and there are too few or no suitable Masters courses, depending on discipline. The continuing decline in numbers of taxonomists employed in UK universities contributes to this failure of the supply chain of trained graduates by reducing their ability to teach taxonomic topics.

## 6.2. Taxon-specific Expertise

Over half of those surveyed (56%) considered that their training was of high quality and prepared them well for the taxonomic work they are currently undertaking. A third of respondents felt their training prepared them only moderately well, and an often cited factor for the lower marking was the need to apply molecular methods, which had not been included in the training curriculum when the respondent completed their qualification. Working in taxonomy and systematics is a long term career choice, since 78% of respondents entered the field directly after their final academic qualification. The proportion attracted to taxonomy subsequently was relatively low (22%).

Interestingly, even the high base level of formal academic qualification (Fig. 6.1) does not produce a fully trained taxonomist. Asked where their key taxonomic training took place, 38% of our survey respondents indicated that they were self taught (Fig. 6.2), typically on-the-job. The explanation for this disparity is that most taxonomists acquire basic thematic and analytical training during their postgraduate studies but familiarity with the organisms is acquired subsequently, so there is a major element of taxon-specific in-post learning involved in building the required experience for a professional taxonomist. Only the core skills in comparative morphology and analytical methods are transferable.

Concern was repeatedly expressed over the lack of available taxon-specific training in the UK. In industry this lack has been addressed “locally” by establishing in-house training systems. Many companies train their own staff and consider this investment to be a high priority despite the impact on their profit margins. Taxon-specific identification-skills training is also offered by many UK companies, for example Neflex Petroleum Consultants Ltd offers micropalaeontological training to their clients including field courses. Other models exist: for example, RSK Carter Ecological Ltd, together with Reading University, have co-appointed a taxonomist to lecture on the Masters in Plant Diversity as well as provide expert identifications for the consultancy. The Institute of Ecology and Environmental Management (IEEM) also organises and runs courses of behalf of its members.

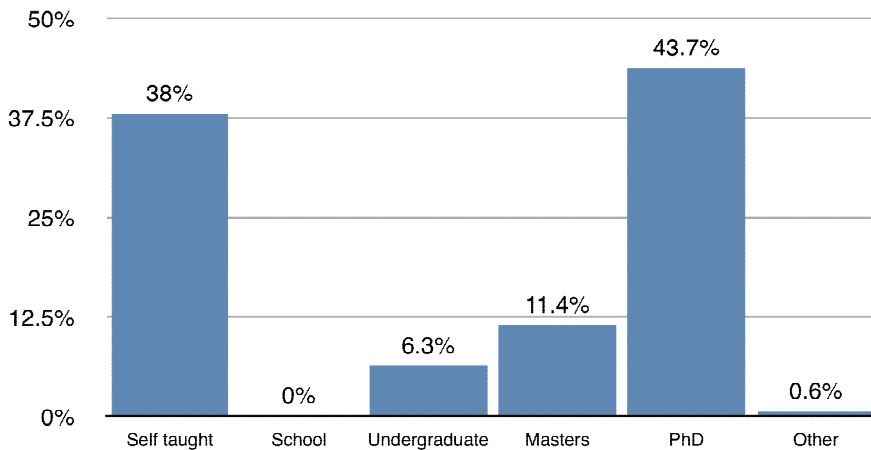


Fig. 6.2. Responses to question: Where did you acquire your taxonomic expertise? (In depth survey N = 160).

An impressive 84% of respondents interviewed are involved in providing training related to taxonomy and systematics (Fig. 6.3). Half of those provide training focused solely on practical taxon-based skills, another 41% focus on both taxon-based skills and thematic

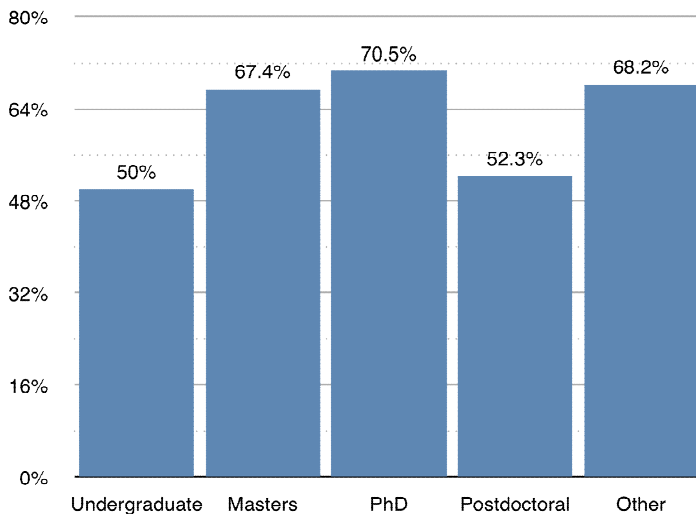


Fig. 6.3. Level of training provided by professional taxonomists (In depth survey N = 160).

skills. The remaining 9% focus on purely thematic training. This training is provided at all academic levels from undergraduate to postdoctoral fellowship. Much of the training involves informal mentoring, of volunteers for example, and was included in the “other” category.

The very high involvement of taxonomists in the provision of training reflects the highly diverse and specialized nature of the skills and knowledge base required by taxonomists. Taxon-specific skills can only be provided by taxon specialists and this is indicative of a rather fragile system. In taxa where there are only one or two UK taxonomists, skills must be transferred in a timely manner by the taxon-specialists. If it is not then there is a

risk that the expertise in identification of that taxon will be lost nationally...and this is an issue over which considerable concern was expressed by the voluntary sector.

### 6.3. Training Courses

Despite this heavy involvement in training, the majority (77.8%) of those surveyed were of the opinion that training in taxonomy and systematics in the UK was in a poor state. Where positive comments were offered these tended to focus on specific examples, such as the MSc on plant biodiversity and taxonomy run jointly by Edinburgh University and RBG Edinburgh, the MSc in Plant Diversity run by Reading University and the Royal Botanic Gardens, Kew (and other partners), or the MSc in Advanced Methods in Taxonomy and Biodiversity run by Imperial College and the Natural History Museum London (and other partners). These partnerships between degree-awarding universities and major taxonomic institutions typically combine thematic training with taxon-based projects. Short, taxon-based courses have been established by various organizations. The Field Studies Council, for example, runs a variety of courses in partnership with Birmingham University, and several learned societies, the British Entomological and Natural History Society and the Botanical Society of the British Isles, for example, run training workshops. Such courses are vital in maintaining a broad base in taxonomic identification skills.

We found that several other kinds of partnership schemes to improve the provision of taxon-based identification skills have been created in the UK. A successful, customer-driven example is the apprenticeship scheme established by Scottish Natural Heritage (SNH) and Royal Botanic Gardens, Edinburgh to create a group of skilled lichen-identifiers. The ability to identify lichens was fundamental to SNH's biodiversity monitoring programme, so a partnership was established which trained 12 apprentices in lichen identification. [One person going on to join RBGE as a professional lichen taxonomist.] The British Trust for Conservation Volunteers (BTCV) Natural Talent scheme is also involved in taxonomic training through its apprenticeship scheme. This is supported by the Heritage Lottery Fund and is delivered by BTCV and partners in the conservation sector in Scotland and Northern Ireland.

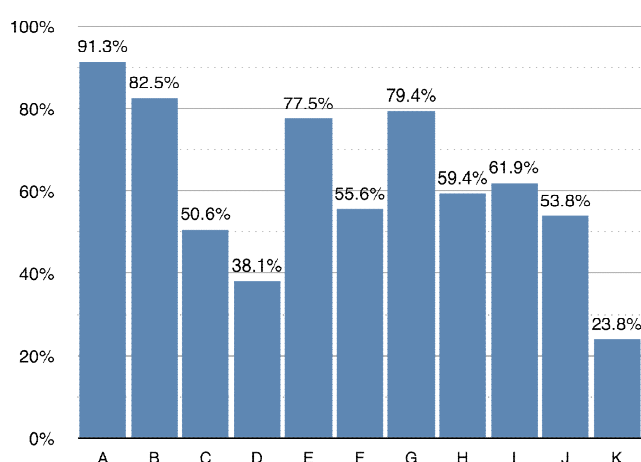
The decline in descriptive and revisionary taxonomy in UK universities has weakened their ability to respond to the training needs in the taxonomy sector, particularly with respect to taxon-specific expertise. Strategically there is the danger of falling below critical mass in an ever-increasing list of taxa - if there is no-one to deliver training then expertise will not be renewed and national capability will be eroded (unless taxonomists trained outside the UK are brought in). If the involvement of UK universities in such training is to grow again then, in the short term at least, it will be necessary for them to engage taxon-based expertise wherever it may be found: in Europe, in taxonomic institutions, in commercial companies or in the voluntary sector. Training solutions are likely to involve a wider range of partners than in the past and mechanisms should be established by which training needs can be clearly articulated and communicated. The Research Councils (BBSRC and NERC) have an important role in supporting PhD level training in the UK and are key stakeholders in postgraduate training.

## **7. Performance Indicators**

The House of Lords 2007-08 inquiry concluded that the perception that the Research Assessment Exercise (RAE) criteria do not favour systematics was still widespread and that the RAE was still having a negative impact on the choices of career-minded scientists in taxonomy. It recommended that criteria appropriate to systematic biology

research should be incorporated into the new replacement mechanism (the Research Excellence Framework).

Taxonomists produce an extremely broad range of outputs (Fig. 7.1) including identifications, descriptions, databases, and the deposition of voucher specimens. About 60% undertake taxonomic revisions, and about half generate phylogenetic trees and produce identification keys. Over half contribute to web pages but only 38% generate molecular sequence data. If the data are partitioned on the basis of age, the older taxonomists (ages 50 to 79) deliver a wider range of taxonomic outputs than younger (ages 20 to 39). Surprisingly, more older taxonomists also contribute to taxonomy/systematics-related web pages (59.1%) than younger ones (47.6%). The only output category where more younger taxonomists contribute more than older is the generation of sequence data (42.9% for compared with 28.8% for the older age category).



*Fig. 7.1. Outputs of modern taxonomists. A – Identifications, B – Descriptions, C - Phylogenetic Trees, D – Sequences, E - Voucher Specimens, F - Web pages, G – Databases, H – Checklists, I – Revisions, J - Identification Keys and K – Other. Figures given are percentages of the 160 individuals interviewed producing each class of output.*

The survey found that the great majority of taxonomists does not find it difficult to publish taxonomic papers, in part because it is always possible to find an obscure journal that will take descriptive taxonomy. Those respondents who did find it difficult to publish specifically qualified this statement with “in higher impact journals”. Researchers in the commercial sector reported insufficient time to publish their taxonomic findings.

The impressively wide range of outputs produced by modern taxonomists (Fig. 7.1) adds evidence in support of the recommendation by the House of Lords inquiry, that appropriate performance metrics be developed for taxonomy and systematic biology. The view of the community is that neither the RAE nor its successor, the Research Excellence Framework, is an appropriate metric against which to judge the delivery of national capability - a new mechanism is needed. Developing an appropriate mechanism remains a high priority since continuing failure to recognise and reward excellence, because of inappropriate criteria and metrics, is having a negative impact on recruitment in the discipline.

## 8. Supporting Operational Level Taxonomy

### 8.1. The Voluntary Sector

In the UK an enormous amount of biodiversity information has been gathered over the years by all sorts of organisations and individuals. Most are volunteers who organise themselves through many national and local societies and recording schemes. These local and national specialist societies are an important avenue for the recruitment and mentoring the new generation of volunteers. They maintain specialist libraries and collections, support publications, and promote the recording and study of many groups of organisms. The valuable contribution made by volunteers in the delivery of government policy objectives was recognised by successive House of Lords inquiries. These volunteers monitor changes in their local fauna and flora, provide records for biological recording schemes, and generate data for Biodiversity Action Plans. Local recording schemes gather data on the distribution of all kinds of species. The UK government (through its conservation and environmental agencies), local government and non-government wildlife-related organisations also collect and use biodiversity data.

The principal means of collation and interpretation of these data is the network of local records centres and the national Biological Records Centre. The participants in biological recording are represented by the National Federation of Biological Recorders (NFBR). The very best recording schemes, such as that organised by the British Trust for Ornithology, train volunteers to collect detailed data on abundance, breeding status, distribution and movements (in this case, of birds). Their achievements demonstrate the potential contribution of such large, volunteer workforces.

Recognition of the importance of the contributions made by this large community of volunteer taxonomists has resulted in enhanced levels of support, particularly in the areas of data access and data security. The National Biodiversity Network (NBN) Gateway acts as a “data warehouse” for UK biodiversity information, providing quick and easy access to records. Currently over 500 datasets and over 55 million records are stored on the NBN Gateway and can be put to multiple uses, for example, to analyse distribution records or to generate maps. As well as securing and providing access to accumulated species records, the NBN functions to improve networking within this sector. The success of the NBN was recognised in the 2007-08 House of Lords inquiry.

In addition to making identifications and generating distribution records, volunteers are also major contributors of descriptive and revisionary taxonomic studies. In the decade from 1998 to 2007 a total of 6,133 new species and subspecies was described from terrestrial and freshwater ecosystems across Europe (Fontaine, 2010: *European Bounty for Taxonomists*. Nature 468: 377). The great majority of these species were arthropods (insects and arachnids especially) and they were described by 1,349 authors, of which the professional status of 1,020 could be assessed. Only 41% were professional taxonomists, the rest were volunteers (retired taxonomists, students, and amateur naturalists). Nearly 60% of the new species described from Europe in that decade were described by people who were not paid as professional taxonomists. Similarly volunteers undertake as much revisionary work as professionals: from the same European decadal dataset over half (54%) of the species placed in synonymy were placed there by volunteer taxonomists.

Local and regional museum collections often comprise locally sourced specimens that function as stable reference points for biological recording schemes. Easy access to such voucher specimens is essential for quality control, and the existence of local collections around the UK is a significant asset. Quality control is a particular issue with species/distribution records where no voucher specimens exist that permit verification.

Quality control of historic records is particularly important in the context of documenting and measuring the extent or impact of environmental change. As a minimum, data quality statements should be provided.

Volunteer taxonomists are typically self-taught both in thematic skills and in taxon-specific expertise. They may or may not have formal qualifications in biology or palaeontology but they have typically benefited from the guidance and mentoring provided by experienced fellow members of learned societies or partners in recording schemes. The skills here are more taxon-specific and less thematic. More formal training programmes have also been established by some of the better resourced taxon-based societies. A key issue for the voluntary community is maintaining critical mass: with declining membership there is increasing danger that such informal mentoring as well as the more formal training might collapse.

## 8.2. Access to Resources

Experienced volunteer taxonomists periodically need access to the national collections to examine type or historic material. Such interactions between professional taxonomists and volunteer specialists can work to the mutual benefit of both, with the national collections being enhanced by the addition of specimens and by input of specialist knowledge (curators in the large taxonomic institutions tend to be generalists), and with the volunteer getting access to types and other key specimens, to literature and to other resources. Access to literature can be a particular problem for the voluntary sector - on-line access to journals can be expensive - so this is an important issue. Initiatives such as the Biodiversity Heritage Library, which is making key works available on-line should ease this situation in time, but more can be done.

Quality assurance can be a sensitive issue for both professional and volunteer taxonomists, and opinions on quality control in the voluntary sector in particular can be quite polarised. The scale of the descriptive and revisionary taxonomic work generated by volunteer taxonomists within Europe is impressive: nearly 60% of the descriptions of new terrestrial and freshwater animal species were generated by people who were not paid as professional taxonomists (Fontaine, 2010: *European Bounty for Taxonomists*. Nature 468: 377). There are numerous animal and plant taxa for which the experts in the UK carry out their taxonomic studies either as a volunteer or while working in industry. The large taxonomic institutions have neither the manpower nor the expertise to provide quality control services for identifications across the whole range of UK taxa. However, they can help by providing access to relevant literature and reference collections. In systematic biology, as in most areas of science, quality control is ultimately a community responsibility.

The marine consultancy sector has established an agreed industry-wide set of standards for taxonomic identification. The National Marine Biological Analytical Quality Control Scheme (NMBAQC) was developed on behalf of the UK competent monitoring authorities in order to provide a source of external Quality Assurance for laboratories engaged in the production of marine biological data. This highly successful scheme organizes taxonomic training and runs intercalibration workshops and assessments. It provides a model of best practice.

Support to the voluntary sector is being improved: for example, the Natural History Museum has recently opened the Angela Marmont Centre for UK Biodiversity. This new facility is intended to provide a hub for volunteer taxonomists and amateur naturalists working on British wildlife. It offers an identification and advisory service where people can bring or send specimens, or submit images for identification, and can obtain advice on British plants and animals. A fully equipped laboratory is available for use and the

centre provides access to the NHM's UK reference collections and UK natural history library. There are also workshop and meeting room facilities for taxon-based learned societies to use. Facilities such as this are vital in helping to fill gaps in the suite of resources available to the voluntary sector but, as pointed out by the Linnean Society Review, more needs to be done outside of the London region.

Operational level taxonomy mainly takes the form of expert identifications and is dependent upon the availability of identification keys, whether web-based or hard copy. Our consultation with the community revealed that support for operational taxonomy, whether in industry, in the voluntary sector, or in research institutions should be improved. The nature of the support wanted was discussed at the community consultation event and the highest priority was placed on the creation of a system to allow the authoritative identification of every species in the UK. The system envisaged would utilize appropriate technologies: molecular diagnostics for microbes and tiny eukaryotes, morphological for metazoans and higher plants, and a mixture for fungi and other taxa.

## **9. Issues for Research Council Funding - contributing to UK Science Base**

This review is highlighting key avenues for improved Research Council funding which emerged from the surveys and from consultation with the community, including the commercial sector. These include:

- How to strengthen taxon-based training
- How to create an all-taxon inventory and identification guide to UK or European biota (given the increase in introductions of pests and invasive species)
- How to use next generation sequencing data to strengthen taxonomy across all three strands: identification, revision and phylogeny
- How to develop mechanisms to support the maintenance and improvement of databases
- How to improve automated digital data capture in taxonomy
- How to bridge the gap between morphology-led and molecular-led taxonomy.

Finding successful solutions to these issues will help to ensure the viability of the commercial sector and the vitality of the voluntary sector, as well as help to ensure that national capability in taxonomy and systematics is maintained.

## 10. Summary: Key points to emerge from surveys and consultations

Taxonomy and Systematics is a vibrant and exciting area of science - it generates novel information on the identity and distribution of living organisms, from bacteria to vertebrates and flowering plants, and it generates hypotheses on the very origin of life and the evolutionary interrelationships of the vast diversity of species on the planet. Its products provide the basic lexicon of the living components of ecosystems - and we all depend upon ecosystems for our continued well-being. As a scientific discipline it must compete to attract the best brains, to attract funding and, like all disciplines, it must continually develop and test new ideas and new technologies as it adapts to its ever-changing societal context

The key findings are:

1. There are about 1100 active taxonomists in the UK, but three strands of expertise must be distinguished; diagnostics, descriptive/revisionary and phylogeny.
2. Over half (600) of UK taxonomists are involved primarily in diagnostics (identification) using the products of other taxonomists. Large numbers work in industry, in government labs, in environment agencies and some in academia.
2. About 100 taxonomists are engaged in phylogenetic research in the UK. These systematics studies are carried out primarily in academia.
3. The pool of taxon-based experts comprises about 400 taxonomists who are engaged in descriptive, delimiting and revisionary studies.
4. The age distribution in the professional sector does not support the prevailing view of an ageing skills base, although in some other sectors, the volunteer taxonomists, for example, there is evidence supporting this view.
5. The number of taxonomists engaged in descriptive, delimiting and revisionary studies has declined particularly strongly in universities.
6. The apparent lack of like-for-like succession planning in institutions of all sizes is a major cause for concern across the broad community of stakeholders.
7. Funding for taxonomy is pluralistic: core funding comes from at least three different government departments; grant or project funding is obtained from a wide range of sources both national and international.
8. Most taxonomists (85%) have postgraduate qualifications but taxon-specific expertise is typically built up in post.
9. University training is failing to provide suitably trained graduates or postgraduates for jobs in commercial biostratigraphy and in the environmental consultancy sector.
10. New and effective ways of providing taxonomic training are emerging, some involving multiple partners.
11. Professional taxonomists produce a very wide range of outputs, most of which are not captured by current performance metrics.
12. A healthy voluntary taxonomy sector is vital for the delivery of government policy but it requires support from the professional sector.

## **PART THREE: Appendix 1 to 4**

### **Appendix 1: Membership of Expert Working Group**

Prof Charles Godfray CBE FRS, Chair,  
Prof Michael Akam FRS,  
Prof Mark Bailey,  
Prof Mark Blaxter,  
Prof Mark Chase FRS,  
Prof Richard Fortey FRS,  
Dr Sandy Knapp,  
Dr Ian McLean,  
Prof Geoff Boxshall FRS (Survey team Leader).

## **Appendix 2: Survey methods**

Two surveys were undertaken. They were designed to supplement the evidence submitted to the House of Lords follow-up inquiry into Systematics and Taxonomy (2007-08). In our view the submitted evidence was still “current” and should not be ignored: it would be unreasonable to request the many institutions that submitted evidence to repeat that process. Our aim was to generate a view of the state of systematic biology that reflected the wide spectrum of perspectives of the diverse stakeholders representing industry, government, the research community and the voluntary sector.

### **1. Envelope Survey**

We needed to estimate the overall taxonomic skills envelope for the UK. Previous attempts to quantify the availability of taxonomic expertise, e.g. the survey performed by the Systematics Forum in 1996 (submitted to HoL inquiry by EDIT), recognized only one category – “taxonomist”. In order to get improved resolution, we differentiated between three strands of expertise:

- (i) identification (using existing handbooks, floras and keys to identify species)
- (ii) descriptive and revisionary (describing new species, undertaking taxonomic revisions, producing monographs)
- (iii) phylogenetic (generating insight into evolutionary relationships between taxa)

We recognized that individual scientists may have skills across all three strands, but in this survey we asked for the primary expertise as it related to their work.

We took the version of the Systematics Forum database that had been submitted as evidence to the House of Lords Committee inquiry in 2002 and initially updated it from institutional websites and from direct personal information from highly networked individuals. Subsequently we targeted large and mid-sized institutions with direct requests for information on: numbers of staff, use of volunteers, strand of expertise, taxon coverage, age range and whether a succession policy operates at the institution level.

The envelope survey was focused on large and medium sized institutions and its coverage was weakest in the long tail of the distribution, i.e. in smaller organizations and universities employing isolated or small numbers of taxonomists. The list of such taxonomists was compiled by updating the Systematics Forum database by reference to institutional websites and by consulting with key networked individuals on the Expert Working Group or working in the large taxonomic institutions. No new sampling of volunteer taxonomists was undertaken partly because this sector was the focus of the review undertaken by the Linnean Society (Cutler & Temple: Taxonomy & Systematics Review, 2010) which held 29 meetings with representatives from a range of membership organisations specialising in different taxonomic groups, from institutions holding collections and other bodies employing taxonomists and systematists or using the products of their research. They also received correspondence from a further nine organisations. Their approach was complementary to the main NERC survey.

Sampling of palaeontologists was incomplete. Few data on palaeo-taxonomists were included in the Systematics Forum database that served as our start point for the university sector and, while our focus on institutions allowed us to capture the commercial micropalaeontological sector and the larger universities, it means that the numbers of taxonomists in university departments was underestimated.

## 2. In-Depth Survey

A questionnaire was prepared to gather detailed data on: expertise, qualifications, methods used, training received and given, route to post, funding sources, income generation, taxonomic outputs, resources, and views on state of discipline. Some confidential personal information was gathered, for example on age, to allow us to address demographic trends within the community.

Face-to-face interviews, around the questionnaire, were conducted with a total of 160 taxonomists, between December 2009 and June 2010. Interviews were held during site visits at a wide variety of institutions across the UK. The sample included students, professional taxonomists and retired scientists - the criterion for inclusion was active engagement in the production and/or use of taxonomic knowledge.

The list of organizations included the major taxonomic institutions, Research Council and Defra laboratories, universities, learned societies and industry. Visits were made to: Natural History Museum, London; Royal Botanic Gardens, Kew; Royal Botanic Gardens, Edinburgh; Marine Biological Association; Sir Alister Hardy Foundation for Ocean Science; Plymouth Marine Laboratory; Queen Mary University London, River Laboratory; National Oceanographic Centre, Southampton; Network Stratigraphic Consultancy Ltd.; National Museum Wales; National Museum Scotland; Reading University; Queen Mary University; Imperial College London; University of Southampton; Glasgow University; FERA laboratory (York); BP; National Institute of Agricultural Botany; Institute of Food Research; Royal Horticultural Society.

Interviews varied in length between ~30 and ~90 minutes, depending on the amount of information volunteered. Not every question was applicable to each interviewee, so the number of responses in the analysis does not always equal 160. At many institutions it was not possible to randomly select staff; we were typically dependent upon staff who volunteered to participate in the survey.

## 3. Community Consultations

A consultation document was prepared and circulated throughout the stakeholder communities. Written responses were received via the Review's website ([www.uktaxonomy.co.uk](http://www.uktaxonomy.co.uk)) and the document formed the basis for the community consultation workshop.

The Community Consultation Workshop was held on 23<sup>rd</sup> April 2010 at UCL, London and allowed us to engage with the spectrum of taxonomy and systematics user communities. It was a free of charge all-day event sponsored by NERC and BBSRC. Interested individuals attended from all sectors, including academia, the voluntary sector, learned societies, and industry. We had a strong representation from three different sectors of industry – consultancy companies engaged in environmental impact assessments, biostratigraphy companies working for the oil industry, and companies active in agricultural pest control research. In addition we targeted representatives from conservation agencies, biological recording, museums (local to national), and field studies (see Appendix 3 for list of attendees). The day comprised a series of break-out discussions with rapporteurs, and there was a great deal of interesting discussion. The key points to emerge from this highly successful event form a major component of the assessment of user needs in this report.

A consultation event was also held in Scotland on 12<sup>th</sup> March 2010, hosted by the Royal Botanic Gardens, Edinburgh, and attended in addition by representatives from Scottish Natural Heritage, the National Museum Scotland and the University of Edinburgh.

### **Appendix 3: Community Consultations**

#### **1. Participants in Community Consultation held at UCL on April 23<sup>rd</sup> 2010**

Michael Akam	Expert Working Group
Mark Bailey	Expert Working Group
Peter Barry	Fugro Survey Ltd
Mark Blaxter	Expert Working Group
Lynne Boddy	British Mycological Society / Cardiff School of Biosciences
Olaf Booy	Non-native Species Secretariat, Defra
Paul Bown	University College London (UCL)
Geoff Boxshall	Review team leader
Juliet Brodie	Systematics Association
Mark Chase	Expert Working Group
Jonathan Clark	University of Surrey
Alastair Culham	Reading University, Centre for Plant Diversity & Systematics
Matthew Curtis	CEFAS
David Cutler	The Linnean Society of London
John David	Royal Horticulture Society Garden, Wisley
Ian Denholm	Rothamsted Research
Jamie Dyson	Fugro Survey Ltd
Dan Finucane	BP Exploration Operating Co. Ltd.
Anthony Flemming	Syngenta
Richard Fortey	Expert Working Group
Nick Fraser	National Museums Scotland
Ron Fraser	Society for General Microbiology
Mary Gibby	Royal Botanic Gardens, Edinburgh
Charles Godfray	Expert Working Group
Lisa Grubb	Marine Ecological Surveys Ltd
Geoffrey Hancock	Hunterian Museum, University of Glasgow
Julie Hawkins	Reading University
David Hawksworth	British Lichenology Society
Alice Hiley	Environment Agency
Mark Hill	CEH Biological Records Centre, Wallingford
Stephen Hopper	Royal Botanic Gardens, Kew
Tammy Horton	National Oceanography Centre, Southampton
Johnathan Hunt	ERT (Scotland) Ltd.
Andrew Impey	NERC
Mark Irvine	ERM Consultancy
Tony Irwin	Norfolk Museums Service
John Jackson	Natural History Museum
Trevor James	National Federation for Biological Recording
Tanya Jones	Sir Alister Hardy Foundation for Ocean Science (SAHFOS)
Matt Longshaw	CEFAS
Lara Lopez	independent
Ian McLean	Expert Working Group
Darren Mann	Oxford University Museum; British Entomological & Natural History Society
Nigel Marley	University of Plymouth
Kryisia Mazik	Institute of Estuarine & Coastal Sciences, University of Hull
Ellinor Michel	International Commission on Zoological Nomenclature (ICZN)
David Middleton	Royal Botanic Gardens, Edinburgh
Colin Miles	BBSRC
Mike Morris	Royal Entomological Society
Jim Munford	National Biodiversity Network (NBN)
Andy Musgrove	British Trust for Ornithology (BTO)
Eimear Nic Lughadha	Royal Botanic Gardens, Kew
Clare Nixon	BBSRC (Strategies & Policy)
Graham Oliver	National Museum of Wales
Rod Page	University of Glasgow
Alan Paton	Royal Botanic Gardens, Kew

Jane Pottas	British Phycological Society
Jim Prosser	University of Aberdeen
Robert Quest	Heathrow Animal Reception Centre
Christine Salmon Percival	House of Lords, Clerk to S & T Select Committee
Amanda Read	BBSRC
Fred Rumsey	Botanical Society of the British Isles
Chester Sands	British Antarctic Survey
Malcolm Scoble	Natural History Museum
Robert Scotland	University of Oxford (Plant Sciences)
Lindsay Jane Seiderer	Marine Ecological Surveys Ltd
Matt Shardlow	Buglife
David Simpson	Royal Botanic Gardens, Kew
Colin Smith	Edgehill University
Vince Smith	Natural History Museum
Vaughan Southgate	The Linnean Society of London
Mark Spencer	Angela Marmont Centre for UK Biodiversity, NHM
Ruth Temple	The Linnean Society of London
Steve Tilling	Field Studies Council
Sue Townsend	Field Studies Council
John Waland Ismay	Dipterists Forum
Bob Wingate	Heathrow Animal Reception Centre
Tom Worsfold	Unicomarine Ltd.
Fiona Young	independent

*Review Team in attendance:*

Martin Stemp, David Self, Kristina Duffin, Lucy Reeve, Marie Rose

## **2. Participants in consultation held at Royal Botanic Gardens, Edinburgh on 12<sup>th</sup> March 2010.**

Ian Bainbridge	Head of Science, Scottish Natural Heritage
Stephen Blackmore	Regius Keeper, Royal Botanic Gardens, Edinburgh
Mark Blaxter	University of Edinburgh, Expert Working Group
Geoff Boxshall	Review Team leader
Mary Gibby	Director of Science, Royal Botanic Gardens, Edinburgh
Charles Godfray	Expert Working Group (Chair)
Andrew Kitchener	National Museum of Scotland
Sandy Knapp	Expert Working Group
Ian Strachan	Scottish Natural Heritage

*Review Team in attendance:*

Martin Stemp	Contract Manager
David Self	Review Researcher

## **3. Discussion Meeting held at Linnean Society on 21<sup>st</sup> October 2010**

A well attended evening discussion meeting was held at the Linnean Society on 21<sup>st</sup> October 2010 at which the key results of the UK taxonomy and systematics survey were presented by Prof Boxshall and a draft of the strategic recommendations was presented by Prof Godfray. There was considerable discussion of the draft recommendations and substantial feedback from the community.

## **4. Additional Feedback on draft Recommendations**

Draft recommendations were also sent to the directors and/or directors of science at the Natural History Museum, RBG Kew and RBG Edinburgh, all of whom provided valuable feedback.

**Appendix 4: Sources of grants over £10k, received in past 5 years by 160 taxonomists interviewed by in-depth survey.**

NERC (18)  
Darwin Initiative (18)  
European Union (14)  
Defra (11)  
Leverhulme Trust (9)  
BBSRC (7)  
National Science Foundation (NSF) (7)  
Royal Society (5)  
CoSyst (5)  
National Geographic (4)  
Esmée Fairbairn Foundation (3)  
Gordon and Betty Moore Foundation (3)  
Deutsche Forschungsgemeinschaft (DFG) (3)  
Marie Curie Trust (2)  
Andrew W. Mellon Foundation (2)  
Environment Agency (2)  
National Research Foundation (S. Africa) (2)  
Carlsberg Foundation (2)  
Jumelles (2)  
Spanish Ministry of Science (CSIC) (2)  
British Potato Council (2)  
Aggregate Levy Sustainability Fund (2)  
Rio Tinto (2)  
Alfred P. Sloan Foundation (1)  
Alcoa (1)  
ALSF (1)  
American Petroleum Research Fund (1)  
Axa Research Fund (1)  
Bentham-Moxon Trust (1)  
BIS (1)  
Boots (1)  
British American Tobacco (1)  
British Council (1)  
CEPF (1)  
Census of Marine Life (1)  
Chulalongkorn University (1)  
Crown Estate (1)  
Cyclamen Society (1)  
Darwin Trust of Edinburgh University (1)  
Declining Amphibian Population Taskforce (1)  
Department of Energy & Climate Change (1)  
DFID (1)  
East Indian Company of Denmark (1)  
Environment Agency, Northern Ireland (1)  
EPSRC (1)  
Fundação para a Ciência e a Tecnologia (1)  
FWO (Flanders Research Council) (1)  
GBIF (1)  
Government of South Georgia (1)  
Government of Thailand (1)  
Government of Portugal (1)  
GSK (1)  
INTAS (1)  
International Association of Plant Taxonomists (1)  
IUCN (1)  
Japan Society for the Promotion of Science (1)  
John Spedan Lewis Trust (1)  
Kraft Food (1)  
Leatherhead Food Research (1)  
Levy Boards (1)  
National Trust (1)  
Natural England (1)  
Região Autónoma dos Açores (1)  
Royal Horticultural Society (1)  
SEPA (1)  
SNH (1)  
South African Research Foundation (1)  
SRK (1)  
Sultan of Oman (1)  
Syngenta (1)  
SynTax (1)  
Tobu Fund (1)  
UK Industrial (1)  
Wellcome Trust (1)