

Developing a National Strategy in Taxonomy & Systematics

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Executive Summary

This document is the report of a Committee set up by NERC to address whether there should be a national strategy for taxonomy and systematics in the UK and if so how it should be developed. It affirms, and treats as a basis for action, the conclusion of the 2008 House of Lords Science and Technology Committee report that stressed the importance and cost-effectiveness of taxonomy and systematics in modern biology and environmental sciences. The report considers all aspects of taxonomy and systematics except teaching at school and undergraduate level.

The report concludes that taxonomy and systematics is a science with a series of unique features that make the explicit development of a national strategy very advantageous. These include the role of collections, the great importance of the non-university sector, the very disparate sources through which the subject is funded and the importance of volunteer scientists. In addition the subject, one of the oldest branches of biology, is currently undergoing a period of major transformational change that will determine its future role and structure.

The report recommends that a UK Taxonomy Co-ordination Committee (TCC) is set up to develop the national strategy. The TCC will add value by independently linking together the very disparate organisations involved in taxonomy and systematics throughout the UK in a coalition of the willing to provide leadership and co-ordination that would be difficult or impossible for the individual bodies that fund or practice taxonomy. It should be small and lean, with a minimal secretariat, and we recommend be sponsored by the Department of Business, Innovation and Skills.

The report defines the UK's *national capability* in taxonomy and systematics to include the care of national collections and the country's contribution to the global taxonomic enterprise. It recommends that statistics are collected to allow investment in national capability to be monitored. The disposition of collections amongst UK institutions should be examined to ensure they match current needs, and the use of modern information and communication technology to facilitate access to resources should be accelerated. The report highlights the state of taxonomic collections in universities which lack a stable funding model and calls for HEFCE to explicitly address this issue.

The classification and study of life on earth requires a co-ordinated international effort and the UK through its major taxonomic organisations should build on its fine track record of leadership and the opportunities afforded by modern technology to help bring this about.

Taxonomy and systematics is critical for UK environmental sciences and the TCC should co-ordinate the development of a costed road map to provide appropriate identification tools for all UK organisms.

NERC should continue to support PhD training in taxonomy and systematics. Evidence from the private sector identifies gaps in postgraduate training, particularly in micropaleontology and identification skills, which the research councils have a role in addressing.

Taxonomy and systematics is unusual in that volunteer scientists are able to contribute significantly to the development of the subject. Moves to facilitate these contributions should be supported and extended.

The TCC should bring together the UK taxonomic community to list and prioritise time-limited major research programmes or “grand challenges” that would advance UK taxonomy and systematics. The TCC should also act to help bring together consortia of funders. Cutting-edge research in taxonomy and systematics should be eligible for funding through Research Council responsive mode schemes and the Research Councils should ensure the relevant committees have appropriate expertise in this area.

Consolidated list of recommendations

1. A national strategy in taxonomy and systematics should be developed
2. A UK Taxonomy Co-ordination Committee (TCC) should be set up to develop and review the National Strategy in Taxonomy and Systematics
3. Science spend in taxonomy should be categorised as *National Capability, Research Programme* or *Responsive Mode*
4. Investment in national capability in taxonomy and systematics by different bodies should be recognised as such and its levels monitored
5. A study should be undertaken to determine whether the distribution of the UK’s taxonomic collections is the most efficient for today’s needs
6. There is no viable funding model for collections in universities and HEFCE should work with HEIs to resolve this situation (which may involve collection consolidation and transfer)
7. Moves to collection digitisation should continue with investment concentrated on priority resources
8. As part of a co-ordinated global programme major taxonomic organisations should take the responsibility for leading the provision of resources for particular taxa
9. For most groups molecular and morphological taxonomic approaches should advance together though for certain microorganisms concentration on molecular approaches (as has happened with bacteria) will be most efficient
10. The TCC should co-ordinate the development of a costed road map to provide appropriate identification tools for all UK organisms
11. Taxonomy in support of conservation in the Overseas’ Territories should be considered a priority

12. NERC should continue to support PhD training in taxonomy and assess the consequences of its recent decision to stop supporting taught masters
13. NERC should take the lead in addressing a deficit in training in taxonomy for micropalaeontology which is of great concern to the private sector
14. NERC should explore whether lack of training opportunities is the reason for the difficulty in recruiting trained taxonomists by environmental consultancies
15. All organisations receiving funding for national capability in taxonomy should include in their remit the facilitation of volunteer scientists
16. Provision of small grants for volunteer scientists and recognition of their contributions by learned societies and other bodies should be encouraged
17. The TCC should bring together the UK taxonomic community to list and prioritise time-limited major research programmes or “grand challenges” that would advance UK taxonomy and systematics
18. The Research Councils should continue to provide competitive funding to support excellent science involving taxonomy that comes within their remits and ensure their committees contain the appropriate expertise
19. NERC and BBSRC (and where relevant MRC) should ensure their support of taxonomy is coordinated and complementary

1. Introduction

Defining Taxonomy & Systematics

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

Purpose and Scope of Report

- 1.2. The 2008 House of Lords Science and Technology Committee report (henceforth HoL report) on the state of taxonomy and systematics highlighted a series of concerns about the health of the discipline in the UK and its ability to support the needs of its user communities. They concluded that “*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.*” In response NERC, acting on behalf of all research funders in this area, set up a review with three tasks:
 - i. To assess the current status of and trends in UK taxonomy and systematics, including the nature of current funding and the size of the workforce.
 - ii. To assess the current and anticipated future needs for the outputs of taxonomy and systematics by the full range of its user communities.
 - iii. To produce recommendations for a future UK Taxonomy & Systematics Strategy.
- 1.3. This document is the report of the Committee set up to address the third goal, to produce recommendations for a national strategy in taxonomy and systematics. The first two tasks were carried out by the Natural History Museum (NHM) acting as consultants. Their findings are reported separately (UK Systematics & Taxonomy review – henceforth UKST) but have been used in drawing up our recommendations. The Committee was supported by the NHM, who arranged the community consultation, and was composed of taxonomists and other scientists acting as individuals rather than institutional representatives. The membership of the Committee is given in Annex 1.
- 1.4. The HoL report described the importance of taxonomy and systematics and its critical role in underpinning research in many other areas of biology and the environmental sciences, as well as in addressing some of the most important policy areas affecting both wealth creation and quality of life. Our committee strongly agrees with these conclusions, and with the importance the HoL report accorded to providing the resources to maintain a healthy and vibrant taxonomy and systematics research community. However, this report does not consider the absolute levels of support required but rather explores how a given spend can be used most effectively to maintain the science base and to address the needs of the users of taxonomy and systematics.

- 1.5. In considering recommendations for a national strategy we examined all aspects of the subject including research, training and the application of taxonomy. It takes into account living and fossil organisms, and microorganisms as well as larger plants and animals. We believe it important that elements of taxonomy and systematics are included in both school and undergraduate curricula, but further exploration of this topic is outside the scope of our report.
- 1.6. We went about our task by publishing a consultation document and inviting input and comments (and made use of the published evidence submitted to the HoL report). We held a public meeting on April 23rd 2010 at University College which was attended by 85 people. We took into account a review of taxonomy and systematics in the UK undertaken by the Linnean Society of London that focused on organism-based learned societies and equivalent organisations. Further details of community consultations are given in Appendix 3 of the UKST.

2. A National Strategy in Taxonomy and Systematics

The Need for a Strategy

- 2.1. The science of Taxonomy and Systematics has a number of special features discussed in this section that makes it distinct from other scientific disciplines. It is because of this that the HoL has unusually published three reports on this area over the last twenty years, and it is also the reason why we recommend that a National Strategy is developed.
- 2.2. Many sciences require substantial infrastructure, and in the case of taxonomy and systematics this is the collections of organisms and associated resources largely found in museums and herbaria. Unlike other science infrastructure that has a fixed lifespan, taxonomic collections by their very nature remain valuable indefinitely and indeed increase in importance as they grow and are worked on. These collections have also always had great importance for education and for public exhibitions concerning biodiversity. A National Strategy must take into account the unique status of the taxonomic science infrastructure.
- 2.3. Largely as the result of the role of collections, the funding base of taxonomy and systematics is both very diverse and difficult to quantify. Considering only public spending on taxonomy an unusually large numbers of government Departments are involved. The largest institutes conducting systematic biology research in the UK are the Natural History Museum (NHM) and the Royal Botanic Gardens, Kew (henceforth abbreviated to Kew) which are currently core funded by the Department of Culture, Media and Sport (DCMS) and the Department of Environment, Food and Rural Affairs (Defra) respectively. The Department for Business, Innovation and Skills (BIS) supports taxonomy indirectly through funding to universities and through the Research Councils. Significant collections exist in Scotland, Wales and Northern Ireland supported by the Devolved Administrations; for example The Royal Botanic

Garden Edinburgh (henceforth RBGE) is part funded by the Scottish Government's Rural and Environmental Research and Analysis Directorate (RERAD). Regional and county museums in England are supported ultimately by the Department of Communities and Local Government (DCLG) with additional funding from DCMS. Other government departments, for example Health and International Development, have smaller, targeted spends in this area. There are advantages and disadvantages of a broad funding base, but a National Strategy will help maximise the efficiencies and synergies. Another field with a different but equally broad funding base is space science which has benefitted from the recent development of a national strategy

- 2.4. There is a further unusual feature of the collections infrastructure underpinning UK taxonomy and systematics. Because of the legacy of empire and the historical strength of UK taxonomy there is a very large concentration of international material in UK museums and herbaria, on a par with the United States. The UK thus has a critical role in global collection stewardship and in facilitating research in other nations, particularly low-income countries. It is important that this is part of the National Strategy.
- 2.5. It is very difficult today for individual citizens without extensive technical training to contribute meaningfully to scientific advances. One of the few exceptions is biodiversity science and in particular taxonomy and systematics. In this report we shall use the term *volunteer scientist* to describe people who make significant unpaid contributions to the field. Volunteer scientists can never replace the core funding for the subject but, if suitably facilitated, can increase the volume and efficiency of the science in this area that the UK produces. Development of a National Strategy will help ensure this happens. We note also that this is a concrete example of the current government's concept of the "Big Society" linking efforts in the public and volunteer sectors.
- 2.6. Taxonomy and systematics is one of the oldest branches of biology and the Linnaean system of classification that is still used today dates back to the 1750s. Throughout its history taxonomy has continuously reinvented itself, but today the science is experiencing an unprecedented rate of change. This is largely due to (i) the continuing pace of advance of molecular biology and in particular DNA sequencing that is providing radical new opportunities for the field and (ii) the opportunities afforded by the web and related information and communication technologies to disseminate taxonomic and systematic information as well as to help the community work together more effectively. A National Strategy can help the UK community adapt to and exploit these exciting opportunities by setting priorities and bringing together consortia to develop new resources.
- 2.7. The outputs of research in taxonomy and systematics have always had a broad range of end-users. A major constituency has been environmental scientists. Over the last two decades there have been large changes in the way environmental scientists seek

to understand and protect the natural world. The Convention on Biological Diversity was signed at the Earth Summit in 1992 and was reframed in 2010. National and international targets to protect biodiversity have been instituted, many including statutory obligations. Over the same time period, and in particular spurred by the Millennium Ecosystem Assessment, new thinking based around the concept of ecosystem services has come to the fore. Taxonomy is also important in different areas of industry, in particular for stratigraphy in the mining and oil sectors. It is essential that the field of taxonomy and systematics recognises and adjusts to the changing needs of its user communities, and a National Strategy will help bring this about.

Recommendation that a Strategy is developed

- 2.8. **Recommendation 1.** Our committee was asked to consider the need for a National Strategy in Taxonomy and Systematics. Based on the arguments in this section we believe there is a compelling case that the effectiveness, efficiency and usefulness of this area of science will be enhanced by developing a National Strategy. In the rest of this report we make further recommendations for how this might be achieved.
- 2.9. However, for a number of reasons we do not think a Strategy is something that can be specified immediately, and then left in place without modification. First, the broader review of which this report is part has highlighted gaps in our understanding of the state of taxonomy and systematics in the UK, particular how it is funded (see Section 3). The development of the Strategy should involve the resolution of these issues, and their feedback into its further development. Second, the Strategy needs to be adaptive, responding to changes in the funding landscape, the science itself, and the needs of taxonomists and their user communities. Third, the Strategy needs to be developed in consultation with the taxonomic community, especially the three largest institutions (NHM, Kew and the RBGE), and the main users of taxonomy.

UK Taxonomy Co-ordination Committee

- 2.10. **Recommendation 2.** We recommend that a UK Taxonomy Co-ordination Committee (TCC) be set up to develop and maintain the National Strategy in Taxonomy and Systematics. The TCC would have three main roles: (i) to monitor UK investment in this area of science and to publish regular summaries; (ii) to develop the National Strategy to help guide the individual funders of science in this area; (iii) to work with the UK's dispersed taxonomic community to increase co-ordination, maximise returns on scientific investment, and avoid duplication both nationally and internationally.
- 2.11. The TCC will add value by independently linking together the very disparate organisations involved in taxonomy and systematics throughout the UK (including the Devolved Administrations) in a coalition of the willing to provide leadership and co-ordination that would difficult or impossible for the individual bodies that fund or practice taxonomy. It would not hold funds nor exercise authority over organisations

doing taxonomy, for example the major independent museums and herbaria that are governed by their own Boards of Trustees. The successful development of a National Strategy in taxonomy and systematics will require the enthusiasm and engagement of funders, practitioners and users and the TCC, though independent of any particular organisation, must work in close contact with all.

- 2.12. The HoL report recommended (HoL 7.26) that BIS (then the Department for Innovation, Universities and Skills) should take on the role of lead Government Department for systematic biology. This recommendation was rejected in 2009 by the then Government. We recommend that as a middle way BIS should be the sponsoring organisation for the TCC, appointing its members
- 2.13. We are keenly aware that we are recommending the creation of a new committee at a time when all areas of government are seeking to reduce and rationalise the complexity and costs of government. We do so only because we think that a National Strategy cannot be developed in its absence. We argue that the TCC should be small and lean, with a minimal secretariat. The latter might be provided by one of the major taxonomic institutions as part of its role in fostering taxonomy and systematics in the UK.
- 2.14. The TCC should not see its role as an advocate of taxonomy or as the body that lobbies government or other organisations for increased funding for the subject. We note that the Linnean Society of London has recently set up a Taxonomy Support Committee which we hope will act as a focus for the subject to argue the case for the discipline. Other learned societies also have an important role in championing the subject.

3. Understanding Public Funding of Taxonomy and Systematics in the UK

- 3.1. Because of the complex funding arrangements for taxonomy and systematics in the UK it is very difficult to assess national investment in this area, and how this money is allocated to different aspects of the subject. We believe this lack of clarity is detrimental to the subject in the UK.
- 3.2. **Recommendation 3.** We recommend that the categorisation used by NERC to classify its science spend is adopted by all public funders of taxonomy and systematics in the UK. The categories are National Capability; Research Programmes and Responsive Mode. These are defined with special reference to taxonomy and systematics in the next three paragraphs. In addition, individual Departments and other bodies may commission specific research to address particular evidence needs not included in this categorisation.
- 3.3. National capability. Resources invested in the core long-term funding of the field including

- i. The maintenance and care of collections and other resources which are accessible to all researchers.
 - ii. The UK's contribution to the global taxonomic enterprise – collections-based research on the taxonomy, systematics and identification of the world's biota
 - iii. Taxonomy to support UK environmental and other science
 - iv. Training of the next generation of taxonomists
 - v. Facilitating volunteer scientists
- 3.4. Research programmes. Time – limited major programmes to address strategic research and infrastructure priorities requiring funding above baseline
- 3.5. *Responsive mode*. Research projects instigated by individual principal investigators (PIs) where science innovation and excellence are the major criteria for funding.
- 3.6. **Recommendation 4.** We ask the funders of the major taxonomic institutions, Defra, DCMS and the Devolved Administrations, formally to recognise their role as supporting national capability in taxonomy and systematics research (as some implicitly or explicitly already do). The funding and funded organizations should work together to publish through the TCC statistics on investment in this area. The statistics should be disaggregated into the different categories of National Capability listed in para 3.3. We recognise that not all public funds allocated to the major institutions are used for science, nor that all the science that is core funded at these institutions comes from public money as opposed to revenue generation. We also realise that some core support is used for collection-based research that is not itself taxonomic (and hence should not be classified as taxonomic national capability). The situation is thus complex but unless funders and funded organisations are clear about what is spent on taxonomic and systematic research it will be impossible to have a discussion about trends in public support for the subject or about the efficiency with which scarce resources are deployed.
- 3.7. The policy of the Research Councils is that they fund Responsive Mode taxonomic research, may fund or contribute to Research Programmes, and have a role in the training of the next generation of taxonomists (see discussions below). Within NERC's national capability portfolio a limited amount of taxonomy and systematics is carried out in its Centres and Surveys and we recommend that statistics on this are also captured by the TCC. Research Council policy is coherent and well-defined though it has contributed to the near extinction of basic taxonomic research in Higher Education Institutions (HEI) (see 10.2).
- 3.8. The Higher Education Funding Council for England (HEFCE), its equivalent bodies in the devolved administrations, and local government, all provide support for collections and some other aspects of national capability. That these funds support national capability in taxonomy is not acknowledged and we return to the special issues involved with university and local museum collections in 4.4 & 4.5 below.

- 3.9. Taxonomists in the UK have been very successful in attracting international funding that is not included in this classification. The UKST found the European Community to be the third largest funder of taxonomy in the UK (though much of this is for setting up networks rather than basic research) while foreign research councils, NGOs and foundations have funded many projects in the UK. This foreign investment in the science base reflects both the importance of the collections held in the UK and the excellence of the taxonomy carried out there.

4. National Capability: Collections and Related Infrastructure

- 4.1. The collections in the UK's major taxonomic institutions constitute a resource of huge global importance. Surveys in the 1980s recorded 254 institutions holding biological collections and 283 with geological collections and the UKST review estimates the numbers today are only a little less. In both cases about 20% of collections hold type specimens¹ (though unrecognised types probably exist in some of the others), an indicator of global taxonomic importance.
- 4.2. Ensuring the safe preservation of UK collections and their accessibility to researchers should be a major national science priority. Recent investment in the two phases of the Darwin Centre at the NHM and the Herbarium Extension & Jodrell Laboratory Extension (holding the fungi collection) at Kew, which involved both public and private funding, has been very important in ensuring this. Decisions about major investment in buildings by the large taxonomic organisations will remain the responsibility of their Trustees but we suggest that the TCC should have a role in identifying independently the major priorities for large capital investment in taxonomy infrastructure at the national level.
- 4.3. **Recommendation 5.** The disposition of collections amongst the major UK institutions reflects a degree of historical contingency and there may be overlap and opportunities for increased efficiency and reduced running costs. We recommend that a study is undertaken to determine whether this distribution is the most efficient for today's needs, and to make recommendations for any rationalisation. It is important to stress that any re-organization would require short-term investment and a sustainable long-term funding model.
- 4.4. **Recommendation 6.** After the major national taxonomic institutions, the most significant taxonomic collections in the UK are housed in university museums and herbaria. These are supported by HEFCE but we have grave concerns about the sustainability of the current funding model. We recommend that HEFCE publishes a strategy for the future of taxonomic collections held by universities. We believe that HEFCE, assisted by the TCC, should identify the most important collections and work

¹ Type specimens are the basis for describing each species, currently acting as the essential reference point for defining each species when over time knowledge increases and further new species are described

with the relevant universities to develop a funding model that both maintains the collections and provides for national capability taxonomic research to be carried out at these institutions. We do not think it sustainable for collections to be maintained without taxonomists and there is at present no feasible way to fund basic taxonomic research at universities (see 10.2). HEFCE support in this area should be concentrated in a limited number of universities with internationally important collections and research groups. Where university collections of taxonomic importance are deemed unsupportable resources should be found to transfer the most significant material to other institutions. A recent example of this has been the transfer of part of the Leicester University herbarium to the NHM, the potato collection held at the University of Birmingham to Kew and the remainder of their collection of Solanaceae (the potato and tobacco family) to Nijmegen, a botanic garden interested in research on these plants. Similarly, paleontological collections in Scotland have been amalgamated at one site. Note, some universities maintain collections for use primarily in undergraduate teaching; in our view these should be supported through the HEI's teaching budget.

- 4.5. Outside the major taxonomic institutions and universities, some significant collections are held in country or local museums. Quite often a museum will contain material associated with the region, but also wider material donated by an authority who happened to live locally. For example, Norfolk Museums and Archaeology Service holds local collections of international importance for the study of Quaternary fauna in the UK, while the Great North Museum (now incorporating the Hancock Museum) houses the types of some 200 species of micro-crustaceans described by G.S. Brady, including many from the Southern Ocean. The Renaissance programme of the MLA (Museums, Libraries & Archives) has established a system of regional hubs collating important data on local natural history collections. Some of these collections are maintained to very high standard, while others lack resources or specialist curators. However, NatSCA, the Natural Sciences Collections Association, have created a professional support network which promotes sharing of skills, resources and knowledge in the sector. We recommend that the TCC works with NatSCA to maintain a register of nationally and internationally important collections held in smaller museums, and reports on their preservation and access. As a last resort, the TCC should recommend collections be moved if there is a significant chance of their deterioration or loss.
- 4.6. **Recommendation 7.** Modern information and communication technology offers numerous opportunities to make access to specimens, collection information and other resources easier and available to a much greater number of people. UK taxonomic institutions, often funded by grants from foundations, are leaders in digitising this type of material. To digitise all resources in UK collections is impossible in the foreseeable future, and would not be the best use of resources. We recommend the TCC takes a role in fostering links between taxonomists and their user communities to help define digitisation and web priorities for UK taxonomy, and

to ensure the maximum interoperability amongst UK and international initiatives. Priorities might include (i) collections which are most in demand and impossible to replace if lost or destroyed, (ii) other collections with high levels of demand, especially economically and ecologically significant groups and (iii) collections bearing information which could inform and support the delivery of conservation action.

- 4.7. Taxonomic literature differs from other scientific literature in that it typically remains relevant for a much longer period of time. Making this large information resource widely accessible is a major challenge. The Biodiversity Heritage Library (BHL) is an international project that has been set up to digitise and make available this literature on the web. If it succeeds it will facilitate the rationalisation of holdings and reduce the infrastructure overheads of doing taxonomy outside the major institutions. Progress with the BHL and other digitisation projects, and their priority for UK investment, should be considered in the development of the National Strategy
- 4.8. A special case of collections infrastructure is culture collections, collections of live microbial organisms. Culture collections are used for taxonomy, but also for many other biological purposes. Decisions about their importance will be strongly influenced by non-taxonomic considerations. The UKST lists the main collections that comprise the UK National Culture Collection (UKNCC), 73,000 cultures in total. 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). The UKNCC model demonstrates how integrated access can be provided to the benefit of a wide range of public and commercial users. Care of live collections is relatively expensive and we recommend that the taxonomic value of these resources is considered in planning the future of the UKNCC.

5. National Capability: Contribution to Global Taxonomy

- 5.1. At the core of taxonomy is (i) the naming, description and classification of organisms, sometimes called alpha taxonomy and (ii) the determination of the evolutionary relationships between organisms – phylogenetics. Both activities in their modern incarnation involve the creation and testing of hypotheses, for example about species limits or evolutionary relationships. In the past, morphological characters were largely used in taxonomy, but today for living organisms these are increasingly being supplemented by molecular data. In addition to carrying out descriptive and phylogenetic work, most taxonomists use their detailed understanding of particular groups to contribute to broader questions in areas such as ecology, evolutionary biology, environmental science and conservation, and geology.
- 5.2. The global taxonomic enterprise is the international effort to understand the diversity and evolutionary relationships of life on earth. The UK has made an important

historical contribution to this enterprise because of the strengths of its collections and expertise and continues today to be a very significant actor in this field of science.

- 5.3. We believe that the UK should continue to play its part in advancing the global taxonomic agenda because of its importance in understanding and protecting biodiversity and ecosystem functions. This support of core taxonomy should be considered part of the UK's national capability in science.
- 5.4. We think that the UK should continue and expand its leadership role in global taxonomy. There are insufficient global resources for even the major science powers to work on the taxonomy of all groups, and we believe a more formal division of labour would increase the efficiency of investment in taxonomy. Modern information and communication technologies also offer major new opportunities for consortia of taxonomic institutions to be developed linking together institutions in high-, middle- and low-income countries. Organisations in the UK should play a major role in facilitating taxonomic and systematic research in countries that lack major collections and other infrastructure. The Foreign and Commonwealth Office and the Department for International Development should be engaged in this cultural and scientific diplomacy.
- 5.5. **Recommendation 8.** There are no international mechanisms at present to decide on a division of labour and instead we believe the UK should lead by example. We recommend that Kew, RBGE & the NHM, and possibly other organisations within the UK (separately or in partnership with the above) specify as part of their science strategies major taxa on which they will at least in the medium term take a global leadership role (this will often be in partnership with other major organisations abroad). This would involve
 - i. The declaration of a long-term commitment to remain a centre for the alpha taxonomy and phylogenetics of particular taxa (provisional on sufficient national capability funding).
 - ii. The development of digital collection infrastructure and web-based resources to allow scientists working at other institutions, both in the UK and abroad, to contribute to this work.
 - iii. The setting of clear, costed targets and goals, and definitions of metrics of achievement.

This recommendation would not of course apply to all of an institution's activities allowing it to retain flexibility and the ability to respond to new opportunities and challenges. It also reflects what to a certain extent happens already where a museum or herbarium has had a long-term track record in the taxonomy of one particular group.

- 5.6. The choice of taxa should be decided by the institutions involved, though because this will become a major part of the National Strategy in Taxonomy and Systematics the

opinion and advice of the TCC should be sought. Not all the core taxonomic research conducted by the major organisations will be in these selected taxa, and there is already a *de facto* commitment to concentrating long-term research on priority groups. Nevertheless, we see a clearer long-term strategic commitment to be important in increasing returns on science investment, and in mobilising more efficiently the global taxonomic workforce.

- 5.7. **Recommendation 9.** Molecular methods are used in addition to morphological methods in all areas of modern taxonomy (except of most fossil organisms). For bacteria, taxonomy is almost completely based on molecular techniques. Recently, some have argued that the whole of taxonomy should be exclusively molecular. We reject this pure-molecular argument for the majority of plants and animals because access to molecular techniques is currently restricted and is likely to remain so for the foreseeable future. Nevertheless, there are some groups, particular single-celled and very small eukaryotes, where we see expenditure on morphological taxonomy to be poor value for money compared to a molecular approach. Detailed recommendations about which groups this should apply to could be made by the TCC working together with other interested bodies.

6. National Capability: Supporting UK Environmental Science

- 6.1. Provision of paper-based, web-based and molecular resources for identifying animals, plants and micro-organisms in the UK is patchy and uncoordinated. Different museums, herbaria and societies have taken *de facto* responsibility for some taxa, but there is no long term strategy to provide a complete set of identification tools.
- 6.2. **Recommendation 10.** We recommend that the TCC be tasked to work with all relevant bodies to develop a costed road map to provide identification tools for all UK organisms. Identification tools using morphological characters would be developed for most macroscopic species while tools based on molecular methods (including “DNA barcoding”) would ultimately be available for all groups. The tools would be made available on the web (and where demand exists in print as well) and they would be developed in conjunction with checklists and the assignment of unique digital identifiers to facilitate the incorporation of biodiversity knowledge into biodiversity informatics programmes such as the National Biodiversity Network.
- 6.3. The TCC should facilitate co-ordination amongst museums, herbaria and societies to undertake to maintain and update the identification resources once developed (there are excellent models where this happens at present). It should identify taxa for which no taxonomic expertise is available in the UK, and advise policy makers if this is harming national capability.
- 6.4. We recognise that the rate of progress in achieving the road map’s goal is contingent on funding being available.

- 6.5. Further taxonomic resources for the UK environmental community could be considered beyond identification tools, for example phylogenetic information about important taxa, geospatial data for specimens held in collections, and linkages to further data resources. The TCC should organise a dialogue between users and providers of these data and advise on priorities for investment (see also Section 9).
- 6.6. **Recommendation 11.** The UK's Overseas' Territories contain biodiversity that in some ways is more significant than that in the metropolitan UK because of their high levels of endemism and greater risks of global extinction. We recommend that taxonomy in support of conservation in the Overseas' Territories be considered a priority.

7. National Capability: Training Future Taxonomists

- 7.1. The UKST review identified approximately 700 taxonomists in the UK and estimated the true figure to be about 1100. One third (31%) worked in the major taxonomic research organisations and 10% in HEIs, with others chiefly involved in diagnostics and identification in the public (20%) and private sectors (25%). The relative high number of taxonomists in the private sector (around 270) had previously been unrecognised.
- 7.2. The UKST estimated that about 40% of UK taxonomists were primarily engaged in descriptive, delimiting or revisionary work, 10% in phylogenetics and 50% in identification for monitoring or survey work.
- 7.3. The UKST found that the age distribution of taxonomists in major research organisation to be typical of the general scientific community. In parts of the public sector the age distribution was skewed to younger age classes which appeared to reflect difficulties of retention, perhaps related to remuneration.
- 7.4. Though major taxonomic organisations contain relative large numbers of PhD students, relatively few are pursuing research in descriptive taxonomy; the UKST review concluded less than 20 a year.
- 7.5. Public funding for training taxonomists to degree level is largely provided by NERC though many masters students are self-funded and some doctoral students are supported by different Research Council and other bodies including museums and herbaria.
- 7.6. Expertise in taxonomy and systematics was identified as a critical skills gap in the environmental sector in a recent report by the ERFF (Environment Research Funders' Forum; <http://www.lwec.org.uk/sites/default/files/Post-grad%20Skills%20Needs%20Report%20web%20v%20Jan%202011.pdf>). The specific needs identified included identification skills, particular for biological monitoring and environmental impact assessments. There is substantial demand from

the private sector for taxonomic expertise and the UK is in danger of being put at a competitive disadvantage as this gap is filled by our competitors, especially Germany which has maintained active training in taxonomy. There is a danger that national skills sets including training expertise will be lost through retirement.

- 7.7. **Recommendation 12.** NERC has recently reviewed its training and skills portfolio and has announced the withdrawal of support for taught masters. We recommend continued NERC support for doctoral students in taxonomy as important for the future health of the subject in the UK, and that it should look critically at the consequences of its decision on taught masters.
- 7.8. **Recommendation 13.** Micropalaeontology is the study of microscopic fossils and is a particularly important part of stratigraphy which is used widely in the extractive (oil and mining) industries. Until recently five universities (Aberystwyth, Hull, Sheffield, Southampton and UCL) provided masters training in this subject, but all courses have now closed. We believe there is a significant deficit in training in taxonomy for micropalaeontology and recommend that NERC takes the lead in addressing this problem.
- 7.9. **Recommendation 14.** We received several representations about the difficulty environmental consultancies had in recruiting trained taxonomists (terrestrial, freshwater and marine). There are masters courses in general taxonomy, but these do not seem to be addressing this constituency's needs. We recommend that NERC conducts a brief, targeted and more detailed study of this problem to ascertain whether the problem is lack of suitably trained staff (as opposed, for example, to the attractiveness and remuneration of positions in consultancies) and if so whether this is best met by masters level training or by the provision of specialist identification courses. The consultation should explore the possibility of joint ventures between NERC and industry.
- 7.10. There are a number of non-degree schemes for training taxonomists. A good example is the apprenticeships in lichen taxonomy run by the Royal Botanic Gardens Edinburgh which is targeted to provide the skilled workforce required for Scottish Natural Heritage biodiversity monitoring programme. The Linnean Society of London through its Taxonomy Support committee might consider acting as a clearing house for recognising novel training methodologies in taxonomy, and ensuring that best practice is shared throughout the community.

8. National Capability: Facilitating Volunteer Scientists

- 8.1. Taxonomy and associated areas of biodiversity science are one of the few areas of modern science where "citizen scientists" can make genuinely valuable and novel contributions. Indeed, considering the diversity and number of species involved their role is critical in advancing the subject. The UKST quotes evidence that unpaid

taxonomists (including retirees) described 60% of the European species new to science between 1998 and 2007.

- 8.2. The UK is particularly rich in people with often advanced biodiversity knowledge and identification skills. A database lists over 1000 British natural history and related societies of which around 30 are significant national organisations that participated in the recent Linnean Society review. There are 75 national separate recording schemes for different taxa.
- 8.3. Volunteer taxonomists are served by a broad range of specialist societies and other bodies. In recent decades the NHM, Kew, RBGE, and other core taxonomic institutions have increasingly seen helping support volunteer taxonomists as part of their brief, a move we strongly support. For example, the new Angela Marmont Centre at the NHM has six FTE posts attached to it, a substantial commitment, and Kew has led on innovative projects working with volunteer mycological (fungi) community.
- 8.4. **Recommendation 15.** We recommend that all organisations receiving funding for national capability in taxonomy should include in their remit the facilitation of volunteer scientists. This might be done by providing taxonomic resources on the web (especially literature), offering training courses or through opportunities to use collections, use specialist libraries and meet taxonomists (as at the Angela Marmont Centre). The TCC terms of reference should include a brief to report on the degree to which this is successfully occurring.
- 8.5. **Recommendation 16.** Different societies and NGOs provide small grants for equipment and other resources for volunteer scientists, as well as recognizing major contributions with a range of prestigious prizes and awards. We believe this an excellent use of resources by the non-governmental sector and recommend where resources allow that it is expanded and given a higher profile.
- 8.6. Training in identification skills is provided by taxonomic organisations and societies using many different models. For example the British Entomological and Natural History Society and its affiliated bodies provide basic to advanced training in identification skills, while the Field Studies Council and Wildlife Trusts run a variety of different identification courses, some in partnership with HEIs. Taxonomic research institutes and HEIs should where possible encourage and facilitate these largely self-funded programmes.

9. Research Programmes

- 9.1. We use the NERC definition of a Research Programme as a time-limited directed investment in an area of science to address a major scientific need. Research Programmes may be funded by a single body or involve contributions from a number of funders. A recent example of the latter is the Pollinator Initiative which included support from the BBSRC, NERC, the Wellcome Trust & Defra. There is a model in

other countries of scientific communities coming together to decide major research programmes as well as to rank them in order of priority.

- 9.2. Examples of what a major taxonomic research programme might be (without prejudice to their importance) are
- i. Major digitisation campaigns
 - ii. Establishment of web-based taxonomies of significant taxa
 - iii. Completion of significant taxonomic resources (such as identification guides) for the UK
 - iv. Assembling key branches (phylogenies) of the Tree of Life
 - v. Bar-coding campaigns
 - vi. Taxonomic inventories of selected UK Overseas Territories
 - vii. Major micropalaeontological resources to reconstruct climate change
- 9.3. **Recommendation 17.** We recommend that the TCC brings together the UK taxonomic community to list and prioritise time-limited major research programmes that would advance UK taxonomy and systematics. The TCC would also act to help bring together consortia of funders. Of course each funding body would tension such requests against competing projects and priorities. These taxonomic “grand challenges” may also attract support from non-standard funders
- 9.4. Many Research Programmes will produce resources requiring maintenance and upkeep, typically by our major taxonomic institutions. This may have funding implications extending many years into the future and it is imperative that the organisations that will take on this responsibility are involved from the outset. The existence of a credible medium to long-term business plan should be a major criterion in determining the relative priority of different research projects.

10. Responsive Mode Research

- 10.1. Responsive mode funding refers to support for research projects awarded competitively where science excellence is the primary criterion for funding. Funding can be awarded for specific research projects, or to individuals as fellowships or “programme grants”.
- 10.2. In some countries such as the USA there is significant responsive mode funding for taxonomy and several responses to our call for input have urged that taxonomy funding should be ring-fenced in the UK. Apart from increasing the total investment in taxonomy, the main argument is that it would provide a funding stream for taxonomists in universities and other organisations outside the main museums and herbaria. This is a difficult issue but we do not recommend ring-fenced funding for taxonomy through the Research Councils. Under current funding arrangements for responsive mode science we do not see a strong argument why science-excellent taxonomic research should be treated separately from that in other fields: it should be tensioned fairly (see 10.3) against the best research proposals from different subjects.

We also believe that it would be unacceptable to the UK science community for money currently allocated as competitive responsive mode to be redefined as competitive national capability administered by the Research Councils. An alternative would be to move a fraction of current national capability funding to competitive schemes administered by the Research Councils. In effect this would move resources from museums and herbaria to universities and related institutions. Considering the importance of maintaining national capability in taxonomy and the critical role of museums and herbaria we believe this would damage the field in the UK. We acknowledge the disappearance of descriptive taxonomy from HEIs (see 4.4) though within the current funding envelope do not see ring fencing taxonomic funding as a feasible solution.

- 10.3. **Recommendation 18.** The Research Councils should continue to provide competitive funding to support excellent science involving taxonomy that comes within their remits. We recommend that Research Councils ensure their grant committees contain the expertise required to recognise excellence in taxonomy.
- 10.4. **Recommendation 19.** NERC and BBSRC (and where relevant MRC) should ensure their support of taxonomy through Research Programmes is coordinated and complementary. This has not always been the case. We acknowledge the success and innovation of the small “Syntax” programme to link taxonomy with other areas of their research portfolio and hope this pilot scheme continues and succeeds in enabling more cross-disciplinary projects including taxonomy being funded via responsive mode.

Annex 1. Membership of Expert Working Group with affiliations and declared interests

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