[Response to the HoL STC call for evidence: *Systematics and taxonomy*]

Memorandum submitted by the Systematics Association

1. Executive Summary

1.1. The Systematics Association is convinced that previous attempts to remedy the decline of systematics in general, and taxonomy in particular, in the UK have (a) been insufficiently ambitious and (b) have not taken adequate account of the interconnectivity of related disciplines. We emphasise that many of the chronic problems besetting taxonomy reflect several recent changes in the academic environment that have together conspired to damage all research disciplines that are inherently long term. This realisation raises the broader question of whether the UK's present strategies for research policy and funding are competent to maintain the research programmes that underpin not only biodiversity assessment but also monitoring of environmental changes and climatic shifts – all fundamentally long-term goals.

1.2. After reviewing the challenges that presently face systematic biology in the UK, the Association concludes that the following actions are of highest priority (they are presented in logical rather than priority order):

(1) Establish a new independent body to coordinate UK systematics activities.

(2) Conduct a thorough and inclusive survey of the current status of the UK systematics community and the requirements of its user communities.

(3) Undertake a detailed consultation with all current and potential substantial funders of systematics and biodiversity research.

(4) Agree a prioritised list of goals for the UK systematics community, and agree the best methods of achieving those goals.

(5) Recognising the global success of 'Genbank', agree a prioritised list of databases and a set of inducements to encourage systematists to routinely deposit other categories of relevant information in those preferred databases.

(6) Develop a mixed economy for funding that spans the full possible range from small, short-term awards to very large, long-term programmes.

(7) Coordinate funds from multiple sources in order to guarantee funding for prioritised long-term research goals over unusually long time-scales.

(8) Establish a new national Institute of Biodiversity Research, requiring a substantial number of permanent salaried taxonomic positions to be inaugurated within several pre-existing systematics institutes, biodiversity monitoring institutes and research universities.

(9) Assign the majority of these new taxonomic posts to the university sector.

(10) Apply to these new university appointees a set of RAE-style assessment criteria specifically optimised for performance in the taxonomic field.

(11) Introduce more organismal biology into the national curriculum, and restore previous levels of laboratory experimentation and field excursions in schools and universities.

(12) Provide increased resources and improved coordination for organisations that encourage the acquisition and constructive use of taxonomic skills by amateur natural historians.

1.3. The Association believes that the above challenges can be met only by bringing genuinely new resources into systematic biology. The series of HoL reports has, until now, relied largely upon recommendations that redeployed existing resources. It is sometimes stated that such practices are akin to rearranging the deckchairs on the Titanic. However, given the level of resources currently available to systematic biology, it would be more accurate to describe many of the recently suggested remedies as repositioning the cushions in the lifeboats.

2. The nature and aims of the Systematics Association

2.1. The Systematics Association and Linnean Society together represent the primary independent bodies responsible for the UK's contribution to systematic biology and biodiversity studies. Although pursuing a broad remit of evolutionary biology, these organisations place particular emphasis on describing, identifying, comparing and understanding organisms using a broad spectrum of analytical techniques.

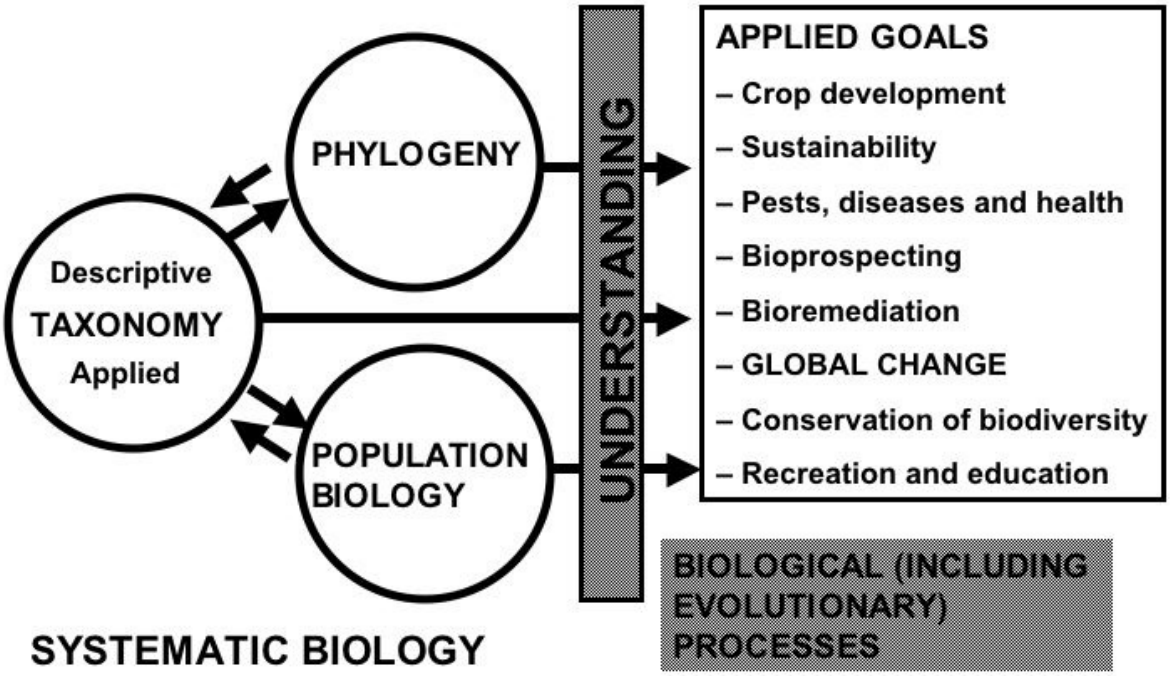
2.2. The Systematics Association separated from the Linnean Society in 1937, in order to become a fast-moving, forward-looking, relatively youthful organisation able to represent active professional systematic biologists at both the national and international scales. It aims to maximise its impact on the international systematics community within the constraint of its limited financial resources. This strategy has precluded acquisition of paid staff or dedicated accommodation but has permitted the Association to take the lead in initiating two modestly funded but highly subscribed grants schemes (Systematics Research Fund and CoSyst). The primary role of the Association is to coordinate, and publish the proceedings of, professional conferences targeted on specific topics (the next such meeting will be held in Dublin and will address the topic of *Systematic Biology and Climate Change*). In recent years the Association has become more deeply involved in science policy, both indirectly and indirectly, via the Biosciences Federation. Working together with four other systematics associations representing other western European countries, we recently co-founded the lobby group BioSyst EU. Thus, the next international biennial conference of the Association will be held in the Netherlands, under the auspices of BioSyst.

3. The nature of systematics: terminology used in this submission

3.1. The core sister-disciplines within **systematic (comparative) biology** are **taxonomy** and **phylogenetics** (see **Figure**). Taxonomy concerns the delimitation, description, and identification of all species and other taxa, both extant and extinct. This has traditionally been pursued via global treatments of a relatively narrow range of species (monographs) or regional treatments of a much wider range of species (inventories leading to floras/ faunas), typically based primarily on reference collections of specimens. Taxonomy it is increasingly integrating information from various nucleic acid-based approaches such as population genetics and "DNA bar-coding". Phylogenetics explores the evolutionary relationships among the species and other taxa that have been generated by taxonomists, using various comparative approaches to explore both morphological and DNA-based information. Its ultimate aim is to reconstruct and interpret the "tree of life". Both taxonomy and phylogenetics are integrated into the naming of taxa and their organisation into hierarchical systems of classification.

3.2. It is commonly (and correctly) stated that taxonomy provides the essential framework for any biological study, by providing the formal classifications and names, and also the standardised terminology, to reference, describe and identify the organisms that constitute the Earth's biota. It can justly be argued that any biological study, and certainly any comparative biological study, is rooted in taxonomy. Taxonomic activities can usefully be categorised in two subdisciplines (see Figure). **Descriptive taxonomy** is comparatively creative and proactive, inevitably requiring specialist knowledge and involving the formal (indeed, highly prescriptive) description of new taxa, followed by their redescription as further relevant data are gathered. **Applied taxonomy** is generally more reactive, encompassing the subsequent use of those classifications to identify organisms, and the dissemination of the resulting data on species recognition and distribution. Recent attempts have been made to reduce the level of specialist knowledge needed to identify organisms. Applied taxonomy generates information that is fed back into descriptive taxonomy in a positive feedback loop, either directly or through other more obviously charismatic disciplines encompassed by systematic biology, notably evolutionary comparison of species (phylogenetics) and populations (see Figure). This mutual support among systematic disciplines is critical to the success of systematic biology; positive or negative impacts on one discipline have corresponding effects on the remaining disciplines.

3.3. Taxonomy and phylogenetics are intellectual challenges sufficiently rigorous to be justifiable on their own merit. However, in recent years they have been justified primarily on the grounds that they feed directly into a wide range of other biological disciplines; they are essential to our understanding of evolution and speciation, biogeography, ecology (including sustainability and environmental issues), conservation, agriculture s.l. (including horticulture, forestry and fisheries), biomedicine and biotechnology (unfortunately, the inter-dependency of these disciplines is still not immediately obvious to non-systematists). Systematics also underpins more general interests in natural history and social phenomena such as education and leisure. In addition to generating such data, much recent discussion has focused on improving methods of disseminating systematic information, notably via networked databases. It is widely accepted (not least by the 2002 House of Lords review) that it is taxonomy rather than phylogenetics that has suffered the most serious decline during the last two decades (phylogenetics was especially strongly promoted by the 1992 House of Lords review). However, it is important to recognise that any future prescription aiming to benefit taxonomy should also consider the likely downstream



impacts of such recommendations on phylogenetics, and on the many user groups exploiting taxonomic and phylogenetic information.

3.4. A joint Systematics Association/Linnean Society working group sought to identify the key priorities for these organisations, and in March 2005 recommended that we:
(1) Increase the resourcing and impact of systematic biology in its broadest sense.
(2) Achieve a better balance between, and better integration of, whole-organism and molecular science.
(3) Promote systematics as a discipline that is both scholarly and socially relevant, primarily through meetings and a diversity of publications.
(4) Improve access of actual and potential users to scientific information and publications.
(5) Restore routine teaching of organismal biology and the "informal apprenticeship" that ultimately generates professional systematists.
(6) Facilitate the substantial contributions to natural history of student, retired and amateur researchers.
(7) Translate accumulating scientific knowledge into high-level policy, notably via research and education strategies.
Further strategic planning is ongoing within the Association's council.

4. Association's view of the 2002 Lords review *What in Earth?*

4.1. The Systematics Association gave *What on Earth* a broadly positive reception upon its publication in 2002, and we remain supportive, while recognising that the environment in which we operate has change substantially during the subsequent six years. We considered the 2002 report to be well-informed and each of its recommendations to have merit. However, we found it disappointingly conservative in several respects: the number of recommendations was small (9) and their content unduly modest. Few of the recommendations required significantly increased investment from government, instead focusing on reallocating within the UK the limited resources then available to systematic biologists and/or suggesting actions to be taken by (generally reluctant) intermediate organisations.

4.2. We assumed that the modest number and negligible cost to government of the Lord's proposals was intended to encourage the government to enact those proposals rapidly and effectively. We were

therefore especially shocked by the dismissive tone and minimal content of the government's formal response (Anon. 2002). Although a minority of the recommendations were implemented rapidly, wholly or in part, at least one relatively simple recommendation was only enacted four years later (Recommendation 5, BBSRC analogue status for the Royal Botanic Gardens). Moreover, other recommendations were ignored, and at least one resulted in withdrawal of funding (Recommendation 9, arguing for increased spending by Defra on the Darwin Initiative, was initially followed but funding of the Initiative was suspended of the grounds of fiscal expediency in 2007/8). Primarily due to inaction on the part of various supposedly interested parties, the 2002 Lord's review had negligible impact on the UK's systematics base, and had appreciably less impact than the 1992 Lord's review.

5. Does facilitation or long-termism lie at the core of taxonomy?

5.1. The Association suspects that one of the main reasons that there have been two full reviews (1992, 2002) and two interim reviews (1997, 2008) of the UK's systematic biology base by the House of Lords is the continued argument that systematics in general, and taxonomy in particular, is a "special case" and therefore merits equally special treatment.

5.2. The many unusual features of taxonomic research were summarised in HoL 2002 as being those characteristic of an "enabling" (facilitating, foundation) science. Although we do not deny this commonly expressed perspective, in our view taxonomy differs from the majority of disciplines primarily in being a science that requires long-term stability of activity and funding. Taxonomic skills take a long time to acquire. The outputs (floras/floras and monographs) remain scientifically highly relevant for a long time but equally they take a long time to produce; they may be better accumulated gradually through time in an electronic environment. Such databases take a long time to fill with sufficient data to become sufficiently useful to justify the investment. Also, the most important applications of the resulting data, such as monitoring climate change, ecosystem dynamics and population-level evolution, require a substantially longer time-scale to address than is typically accommodated by funding bodies (or by particular government policies).

5.3. The majority of the issues raised by the decline of British taxonomy therefore present a broader challenge to policy-makers and funders – specifically, whether the UK is sufficiently committed to the more general category of long-term scientific research. The laudable leadership recently shown by the British government in publicising and addressing global climate change – the archetypal long-term challenge – should provide an unparalleled impetus for all relevant bodies to collaborate in solving the crucial general issue of how to reliably maintain long-term research programmes. However, we note that, as one corollary to long-termism, many of the potential remedies will inevitably take a long time to yield their full benefits.

6. Preliminary comments regarding the present Lords questionnaire

6.1. As with the original House of Lords report, the Association has some reservations regarding whether the present set of questions posed by the Select Committee encompass the entire range of crucial challenges currently facing systematic biology. Thus, although we have, as requested, used the Committee's questions as the framework of our response, we have subsequently summarised some additional issues and principles that we believe are of particular importance, as well as recommending a small number of key actions that we believe would most effectively remedy current deficiencies in the discipline. We recognise that this document is unusually long for a parliamentary response. In our defence, we note that (a) this enquiry strikes to the heart of the Association's raison d'etre and (b) that we have in effect been set 30 questions to answer, as well as wishing to raise a few additional key issues that we believe have been overlooked by the Select Committee.

6.2. The Association should also state at the outset that it regrets that the majority of its responses to the following questions are often based on anecdotal evidence. The Association has argued since before the 2002 Lords review that a comprehensive survey of the UK's systematics base is urgently needed, to compare with that conducted by the UK Systematics Forum in 1994/5 and published in 1996. The most recent relevant post-1996 output is the UK Taxonomic Needs Assessment prepared by the Natural History Museum on behalf of the Global Taxonomy Initiative in February 2006, but

this survey involved a limited sampling of both producers and users of systematic information, and considered only taxonomy rather than the full breadth of systematic biology.

The (present) state of systematics and taxonomy research

7. Q1. (a) What is the state of systematics research and taxonomy in the UK? (b) What are the current research priorities? (c) What are the barriers, if any, to delivering these priorities*?*

7.1. We cannot give a definitive account to Q1A because of the lack of strong current baseline data. The answer should consider four main areas of activity; morphological and molecular approaches, respectively, to phylogeny reconstruction, and taxonomic description and identification. Current evidence suggests that molecular phylogenetics is the best supported and thus most rapidly expanding discipline, in part because it is being widely pursued in the university sector as well as in the major institutions. Surprisingly, molecular taxonomy ("bar-coding"), which is rapidly expanding in some other countries, has found relatively little favour with the major funding bodies in the UK, despite our strong initial contributions and continued enthusiasm among practitioners (see Q6). Morphological phylogenetics appears to be diminishing, having been replaced in some programmes by molecular phylogenetics. The area of greatest concern continues to be classical morphological taxonomy, where both the number of the practitioners (especially professionals), and the average amount of time spent on practical taxonomy by each remaining practitioner, continue to decline.

7.2. With regard to Q1B, although the Association can (and has) developed its own prioritisation of major research areas, and has highlighted a few of the most relevant in this document, it cannot justly claim to speak for the discipline as a whole. In general, there have been far too many systematics-related initiatives during the last decade at every scale (national, European, global), thereby diluting effort, slowing progress and eventually prompting ingrained cynicism. And the systematics community has itself been surprisingly slow in reacting to changes of emphasis at the policy level that directly affect its applied user groups, most notably the scientific enthusiasm for climate change studies that preceded the Stern report and the political enthusiasm that followed it.

7.3. In addition, systematists have continually found difficulty in agreeing the criteria for prioritisation among projects. Relevant issues that are still widely debated include (a) is it necessary to address specific scientific hypotheses, (b) if so, which kinds of hypotheses are most important, and (c) should those hypotheses be selected proactively by the systematics community to satisfy its own needs or reactively, in response to expressed needs of the many user-communities? We must also decide (d) which are the most appropriate taxonomic groups for addressing those hypotheses, and (e) which are the most appropriate methods for analysing those groups to yield the necessary data?

7.4. These issues are discussed most acutely in taxonomy, where there is a strategic dichotomy between two schools of thought that could be termed encyclopaedists and integrationists. Encyclopaedists believe that priority should be given to beginning to fill the many vast gaps in our current taxonomic knowledge. They are inspired by frequent statements that estimates of the number of species on Earth generally exceed 10 million, whereas only approximately 1.7 million species have so far been described, and that at the current rate of description it will take 200–500 years to complete these descriptions). This school of thought is driven by the urgency instilled by the biodiversity crisis, and more specifically by the belief (most likely correct) that species are currently becoming extinct more rapidly than they are being described. Moreover, the questions addressed are so broad and simple (i.e. does a particular species exist, and how many species presently occur on Earth?) that some observers will not accept them as bona fide scientific hypotheses. The integrationist viewpoint gives greater emphasis to more specific hypothesis-testing and to the requirements of our user-groups. It recognises that although taxonomic description is an essential first step to any biological study, robust recommendations regarding practical issues such as conservation, ecosystem services and climate change monitoring and remediation cannot be made until a great deal more is known about a particular species than its name. Key criteria include its appearance, anatomy, mode of reproduction, behaviour, genetics, habitat preferences, distribution, evolutionary relationships with other related species and ecological relationships with other, generally unrelated, species. The integrationist mind-set implies a closer relationship between taxonomy and other related disciplines, and a belief that a

considerable depth of knowledge is a necessary pre-requisite for effective human intervention in complex biological systems.

7.5. Question 1C is best addressed by questioning why taxonomy in particular has all but disappeared from the UK university sector. British universities have been impressively (and destructively) homogenised during the last two decades by the Research Assessment Exercise (RAE) – specifically, by its emphasis of a small number of arbitrary targets. The present route to success for an academic relies heavily on just two criteria – the ability to publish just one paper a year in a journal of high impact factor (ideally, *Nature* or *Science*) and the accumulation on behalf of their host institution a large amount of overhead that now accompanies most research grants. In addition, in order to reduce administration costs and to encourage more integrated science through team building, most major funding bodies have adopted a Big Science strategy. They allocate smaller numbers of larger grants, though these remain typically three years in duration and never more than five; moreover, grants are most readily made large by proposing expensive, high-tech approaches to particular problems, irrespective of whether the question could be solved using a lower-tech solution. The target-based approach to managing the UK's science has had profound negative effects across throughout the science base, encouraging low productivity from individual grants and the mutual back-scratching inherent in publishing cartels. However, the most serious damage of holding all researchers to the same few assessment criteria is the inevitable homogeneity of their response when chasing these arbitrary targets. The ability of the UK's science base to support disciplines that do not readily fit the prescribed mould has inevitably collapsed.

7.6. Sadly, few if any disciplines fit the mould as poorly as does taxonomy. With the arguable exception of pilot schemes in DNA bar-coding and automated identification (see Q6), taxonomy is a low-tech activity. The greatest actual cost is the salary of the taxonomist, and the greatest hidden cost is the considerable period of time needed for that taxonomist to reach the desired levels of skill and knowledge. Further (and generally hidden) costs, often resented by university administrators, are likely to be incurred if the taxonomist's collections require curation. At present, the typical outputs of taxonomy are either geographically restricted faunas/floras or taxonomically restricted monographs. Each such output takes far longer to produce than a single grant from an existing scheme would permit. These are produced either as infrequently generated books or as series of frequently generated shorter articles in journals that are of low impact and rarely cited (though, unlike most science, they can remain valid and current for centuries). Such kinds of output are effectively invisible to the RAE. A more modern approach to disseminating taxonomic information, adopted with enthusiasm by the 2002 HoL report, seeks to largely replace these traditional outputs with electronic equivalents. At present, these kinds of output are equally invisible to the RAE. In addition, there remains a widespread perception (one that is increasingly inaccurate) that taxonomists are too individualistic to make good team members. Moreover, some grant-awarding bodies hold rather parochial views of teams, considering them to operate within single organisations and thus effectively ignoring the fact that electronic communication has permitted researchers world-wide to become strongly networked. In summary, taxonomy is cheap science that offers good value for money, traits that mean it is heavily penalised by the tyranny of the RAE. We had hoped that the succeeding Research Excellence Framework (REF) would prove more amenable, but its current draft form suggests an equally damaging obsession with short-term citation.

8. Q2. (a) What is the role of systematics and taxonomy and, in particular, in what way do they contribute to research areas such as biodiversity conservation, ecosystem services and climate change? (b) How important is this contribution and how is it recognised in the funding process? (c) How is systematics integrated in other areas of research?

8.1. Terminological rigour is especially crucial in answering Q2A, which depends on understanding the interrelationships between several research disciplines (see **Figure**). After establishing the framework of systematic biology in Section 3, and before considering below the broader applications of systematic data, we emphasise here that systematic biology is an intellectually rigorous discipline in its own right, and that its success should not therefore be wholly dependent on its immediate applications. In particular, comparative biology is the source of most of our knowledge on evolutionary patterns and processes. Nonetheless, we recognise that the interests of the present enquiry are likely to be applications in general and climate-change issues in particular. We also wish

to emphasise that the user communities still inevitably make occasional unreasonable demands on existing taxonomic knowledge. One of the most common fallacies is to prefer classifications that are (a) fixed and/or (b) built upon relatively flat hierarchies (e.g. focus on species at the expense of infraspecific taxa). Such static approaches remove the scientific element of taxonomy by discouraging further evolution of classification in response to an increasing range and quantity of relevant data.

8.2. It is difficult to conceive how high-priority applied disciplines such as biodiversity assessment/ conservation, ecosystem services/ sustainability, and monitoring/ remediation of climate change could even be discussed in the absence of the framework provided by the formal names and ranks inherent in taxonomic classifications. As is widely stated, taxonomy is, in this sense, an "enabling" science. However, when passed through the interpretative filters of other disciplines, both within systematics (e.g. phylogenetics, evolutionary biology) and immediately adjacent to systematics (e.g. ecology), it becomes an interpretative science that is competent to offer constructive advice on these high-profile, socially engaged issues. Thus, maintaining effective communicative and collaborative links among these disciplines is crucial to making effective practical use of systematics data.

8.3. Many initiatives at different hierarchical scales have been established in attempts to improve communication and collaboration. They have achieved varying degrees of success, but overall, there have been too many such initiatives and they have failed to garner sufficiently widespread or committed support. Such initiatives are still badly needed, but it is important that lessons are learned from past mistakes, and that the relevant government(s) offer sufficient inducements to encourage stronger commitment from systematists, researchers in related disciplines and more applied user groups.

8.4. While there has been a superfluity of schemes designed to improve networking, the number of institutions operating within the UK that are capable of generating taxonomic data has fallen, most notably in the university sector. At the same time, the number of institutions that applied these data to practical problems such as biodiversity monitoring has also declined (e.g. the recent rationalisation of NERC's Centre for Ecology and Hydrology). Arguably the best way to monitor climate change would be to closely link taxonomically competent institutes to ecologically competent institutes, yet in recent years the UK has suffered severe reductions in both constituencies.

8.5. Linkage between producers and users of taxonomic information is especially important because, in the current highly competitive funding environment, it is rare that funds are awarded to activities that affect the desired practical outcomes indirectly rather than directly. Partly for this reason, phylogenetics and population genetics are currently substantially better funded than taxonomy. Moreover, within taxonomy, it is currently easier to fund dissemination of existing knowledge than generation of new knowledge. Reversing the long-term decline of descriptive taxonomy will require radical actions, including: ensuring better representation of systematists (especially taxonomists) on grant-awarding panels; better integration of taxonomic work into hypothesis-testing projects; assessment systems that give appropriate credit for the outputs of descriptive taxonomy (monographs and floras/faunas) in both the traditional printed and modern electronic forms; establishing a stable funding basis for long-term research in critical policy-related areas.

8.6. Lastly, we note that Q2A implicitly under-estimates the number of key users of taxonomic information. In addition to conservation, ecosystem services and climate change, taxonomic research feeds critical information into attempts to remediate the effects of damaging organisms such as invasive species and pathogens of humans, domestic animals (including fisheries) and crops.

9. Q3. (a) Does the way in which systematics research is organised and co-ordinated best meet the needs of the user community? (b) What progress has been made in setting up a body to lead on this? (c) What contribution do the leading systematics research institutions make, both nationally and internationally?

9.1. At present, the organisation and coordination of the UK's systematics research base is far from optimal, reflecting both the unwillingness of any particular body to take responsibility for, and fund, a coordinatory body (Q3B) and the large number and recalcitrant nature of the challenges faced. The community is strongly influenced by several government departments and collectively has many

funding bodies; all are poorly communicative and have goals that at best only partially overlap. The systematics base is divided between dominantly professional and dominantly amateur organisations, and active research is conducted at every conceivable scale, from major institutes through regional centres to local societies. It is our impression that these organisations have actually become less well coordinated in recent years, as regional and local governments have set their own (often conflicting) priorities and organisations that were formed specifically to provide cohesion, such as the Joint Nature Conservation Committee and National Biodiversity Network, have been consistently under-funded.

9.2. Defra have failed to respond in any meaningful way to the 2002 Lord's review requirement that they show leadership to Britain's systematics community. Six years later, no action has been taken toward the Lord's 2002 recommendation that "Defra takes the lead in setting up a body with the express purpose of bringing together representatives from government departments, ecologists and conservationists and the systematic biology community" to guide the UK's biodiversity and conservation efforts. When challenged by the Institute of Biology and Linnean Society in 2006 to justify their chronic inactivity, Defra cancelled a previously agreed discussion meeting and announced that "as a result of the tight financial position in Defra, prioritisation of our objectives and strategic outcomes has resulted in progress in systematics falling below the threshold to command the necessary resources." A similarly defensive reply was given to a query from the Biosciences Federation and the Systematics Association a year later. Given these responses, we can only reach the extraordinary conclusion that Defra have failed to perceive the crucial connection between the outputs of systematic biology and the critical areas of government policy for which they are at least partly responsible, such as agrarian diseases (and epidemics), remediation of environmental degradation and, of course, climate change.

9.3. Despite the apparent lack of interest from any relevant government department, the UK systematics community could still have taken actions independently to improve coordination and prioritisation of tasks. However, in the absence of government guidance, the systematics community failed to organise itself sufficiently well to establish priorities that reached beyond individual organisations. None of the major research institutes has shown strong interest in achieving this goal, and those discussions that have taken place since HoL 2002 have been by no means inclusive; smaller and/or dominantly amateur organisations, which play a proportionately increasing role in taxonomy in particular, are rarely included. The ideal coordinatory body would be led, or at least chaired, by a broadly based independent organisation. The Systematics Association is certainly willing in principle to take on this task, but it would require funds to supplement its present meagre resources.

9.4. The overall trend of the last two decades has been for taxonomy to gradually diminish in the universities and the user-groups of such information (e.g. the NERC institutes), and to become relatively concentrated in the major systematics institutes and the 'amateur' sector. Phylogenetics has, in contrast, spread from the major institutions into the university sector, encouraged by its proven effectiveness and by the funding priorities of the research councils. This in turn has understandably encouraged greater emphasis on evolutionary biology in the major systematics institutes, thereby effectively reducing the emphasis on taxonomy. With the exception of the diminution of taxonomy in the university sector, these trends have not necessarily had effects that were negative overall. Nonetheless, it seems likely that the bulk of the UK's taxonomic research is now conducted in just three institutions: the Natural History Museum, and Royal Botanic Gardens of Kew and Edinburgh.

9.5. This apparent centralisation of taxonomy offers considerable advantages to coordinating and prioritising work internally, but less effort has been made in recent years to achieve these goals between the major institutes. In addition, there has been diminishing encouragement of staff in these institutes to show leadership to the many 'amateur'-dominated societies who now in practice generate the vast majority of the biodiversity data produced for the UK. The Association is not convinced that the many national and international schemes designed to improve networking and data flow among systematists, and between systematists and their many user-groups, have come close to achieving their potential. We need to critically assess, and then select among, such schemes, preferentially resourcing those of greatest potential. The major institutes have a clear role to play in this strategic process, but they need to take full account of the broader requirements of the taxonomic community.

10. Q4. (a) What level of funding would be needed to meet the need for taxonomic information now and in the future? (b) Who should be providing this funding?

10.1. There is no straightforward answer to Q4A. Several recent statements have suggested that it will take at least 200 years at the present rate to give basic descriptions of most of the species on Earth. One might therefore conclude that the UK's contribution to this global endeavour could double its speed if its funding base were to be doubled. Such an analysis would actually be grossly simplistic, since the depth of knowledge on species is important, and there is understandably increasing emphasis on encouraging taxonomists to be better networked and more interactive.

10.2. Much of the evidence offered to the House of Lords review in 2002 singled out the UK research councils (especially NERC and BBSRC) for particular criticism. The Association believes that this widely held view was simplistic; the research councils are inevitably held accountable to policies set by relevant government departments, and ultimately to the Treasury. We also sympathise with the belief long held by the research councils that research funded through normal channels should be genuinely hypothesis testing. Nonetheless, there have been very limited gains in the enthusiasm shown by the Research Councils toward systematics in general and taxonomy in particular. The Association, supported by the Linnean Society, successfully initiated and now administers CoSyst, a pump-priming small-grants scheme that received total funding of £225k over three years (2007–9) from BBSRC and moral support from NERC. The intention is that the successful CoSyst proposals will ultimately lead to full responsive mode proposals to the research councils, and the initial application rates have been unexpectedly high (only 5.5 of 48 applications could be funded in 2007, and a further 36 applications were received in 2008). However, full responsive mode systematics applications have long fallen down the cracks that separate the supposedly overlapping remits of the research councils, and in practice they continue to bounce like footballs between councils. Proposals containing more than a modest amount of taxonomy still do not receive funding, and the councils still appoint very few systematists, and no classical taxonomists, in their grant-awarding panels. It also remains difficult to gain funding from most likely sources for the cost of curating and/or databasing materials used for taxonomic studies. The Systematics Association and Linnean Society together address a further funding gap by offering small grants of up to £1500 toward a wide range small-scale systematics projects (in 2007, the total available spend of £36,000 funded 37 of 98 applications; in 2008, applications have risen yet again, to 140, yet the previous annual contribution of £5,000 from NERC has been withdrawn). Thus, there remain substantive issues that the research councils should address urgently.

10.3. If we are disappointed by inaction in the funding area by the research councils, we are even more disappointed by certain actions that *have* been taken. In particular, both NERC and BBSRC have pursued long-term rationalisation programmes of the research institutes for which they provide substantial core funding. The relatively recent rationalisation of NERC's Centre for Ecology and Hydrology (including the closure of research institutes such as Monks Wood and Windermere) inevitably reduced the effectiveness with which taxonomic data is deployed to monitor and, where possible remedy, environmental change. The systematics community is constantly encouraged to disseminate its information to key users, but this laudable goal is made far more challenging when critical users of that information are eliminated.

10.4. The Association has long noted that the British systematics community relies on funding from an exceptional diversity of sources. The three largest systematics institutes in the country (in order of decreasing size the Natural History Museum, Royal Botanic Gardens Kew and Royal Botanic Garden Edinburgh) each still gains at least half of its recurrent funding from a different government department (DCMS, Defra, and the Scottish Executive's RERAD, respectively). This diversity offers some buffering against the vicissitudes of allocations to these departments by the Treasury, as few external phenomena can affect all three organisations simultaneously. However, it complicates any attempt to develop stable joint initiatives among these institutes, and leaves each at the mercy of often radically contrasting policy priorities that must be met if even modest levels of core funding are to continue.

10.5. The Association is especially disappointed with the performance of Defra in recent years, over and above their inaction with regard to establishing a new coordinatory body for UK systematics

(Q3B). We recognise that Defra has been obliged to respond rapidly to a series of resource-sapping, agriculturally-related crises, some caused by epidemics and others by suboptimal administration. However, Defra do not appear to have perceived the link between these epidemics and our ability to identify, predict and remedy their causes – activities that rely heavily on information and techniques that are central to systematic biology. They have significantly reduced core funding of the one major research institute for which they hold direct responsibility, RBG Kew. They suspended payment the funds promised for the current round of Darwin Initiative grants, thus undermining a globally respected initiative designed to allow British researchers to provide practical assistance on biodiversity and human welfare issues, targeted especially at communities in developing countries. They have reduced funding to organisations that help to translate systematic data into practical outcomes within the UK, notably JNCC and the Environment Agency. Such decisions make it far more difficult for systematists to deploy their outputs as components of practical, socially applicable programmes.

10.6. If, as we have argued, reliable long-term funding is the single most critical need for improving the UK's taxonomic base, substantial changes need to be made in the way that funding is apportioned. At present, typical funding periods from both government funders (e.g. the research councils) and independent charity funders (e.g. the Wellcome and Leverhulme Trusts) is three years. There have been welcome signs that five-year funding may be considered more seriously in future (the most encouraging being the development of substantial five-year 'Lola' grants by BBSRC). In our view, both the fundamental taxonomic enterprise itself, and the uses that feed off that fundamental data (e.g. monitoring biodiversity to assess the effects of climate change), need guaranteed core funding for periods measured in decades rather than years. We therefore recommend that research funders and relevant government departments convene a novel body to develop an initiative that will guarantee such funding, by pooling resources from multiple sources toward a mutually agreed set of biodiversity-related goals. Any such initiative should distinguish clearly between (a) conducting creative taxonomy, (b) disseminating existing taxonomic information (including identification), and (c) more applied uses of systematic information.

11. Q5. (a) How does funding in other countries compare? (b) Could there be more international collaboration? (c) If so, what form should this collaboration take and how might it be achieved?

11.1. During the 19th century and first half of the 20th century, the global centre of gravity for systematics research lay firmly in Europe. In the second part of the 20th century, the phylogenetics revolution was primarily driven by Europe and North America (focused on the Natural History Museum, London and the American Museum of Natural History, New York). However, in the last decade in particular, the USA has invested far more heavily in its general systematics base (as assessed on both absolute and per capita measures) than have European countries. In particular, the American National Science Foundation invited a series of systematists to work for them for several years to establish a complementary suite of programmes covering phylogenetics (Assembling the Tree of Life: AToL), species descriptions, biodiversity inventories and collections enhancement (Planetary Biodiversity Inventory: PBI), and training young taxonomists (Partnerships in Enhancing Expertise in Taxonomy: PEET). These schemes have benefited, both directly and indirectly, collaborators in other countries, including the UK. The Australian Biological Resources Study (ABRS) also attracts substantial government funding. The EU-funded European Distributed Institute for Taxonomy (EDIT), a relatively recent innovation, is built on far more modest basis than its broader US and Antipodean equivalents. Other countries have chosen to focus their investments on specific activities, such as DNA bar-coding in Canada and bacterial systematics in South Korea.

11.2. Major international collaborations such as the Global Biodiversity Information Facility (GBIF) tend to be handicapped by the expectation (possibly the necessity) that one country (or one organisation within that country) should take the lead role in that initiative. The commitment to that initiative of the other subordinate countries tends to be reduced, often ultimately leading to that country developing a similar initiative that it can then claim to lead.

11.3. Thus, although developing international collaborations remains an important goal, improving international communication among systematists is a more straightforward goal. This is the simple

way to avoid duplication of effort and to improve complementarity among research projects across the globe. Such communication has also brought considerable benefits in the area of standards – for example, data spectrum and quantity, database platforms, collection curatorial standards, shared analytical protocols, common conceptual frameworks. And such international networking belies frequent statements, fuelled by a now ubiquitous Big Science ethos, that critical masses of researchers (and curators) within specific institutes are essential, such that the traditional concept of individualistic taxonomists should be superseded in the modern research environment. Rather, the modern research environment, increasingly dominated by the mixed blessing of electronic communication, means that no systematists need operate in isolation, irrespective of their physical location. The opportunity exists to make successful on a long-term basis one or more integrated, yet flexible, international networks in systematic biology. This goal requires comparative assessment followed by prioritisation.

12. Q6. (a) What impact have developments in DNA sequencing, genomics and other new technologies had on systematics research? (b) In what way has systematics embraced new technologies and how can these research areas interact successfully and efficiently?

12.1. This question is best answered by distinguishing between molecular and morphological approaches. Within the DNA sequencing realm, two main categories of technology are being explored. The first, for long forecast by several distinguished proponents (not least Lord May), is the pocket-sized sequencer. The American military recently demonstrated to the Association at its Biennial Conference that they have already effectively achieved this goal, having produced a portable field device that can sequence a chosen region of the genome for about 100 specimens within a ten minutes. At present the device is the size of a laptop computer and requires the stability of an environment such as the back of a vehicle, but it is predicted to shrink to genuinely pocket size within a year. It should soon be possible for field surveyors to analyse a significant number of samples in the field and use satellite technology to compare the resulting DNA sequences with databases such as Genbank, and thus to obtain probability statements regarding the identification of the organisms while still in the field. We note that these techniques can readily be applied to juvenile, senescent or otherwise non-reproductive organisms that fail to show crucial diagnostic characters of their morphology, or to the many organisms (most relatively primitive) that show little morphological differentiation at any stage in their life histories (on the negative side, higher animals tend to evade field sampling). In short, field-based DNA identification is within reach. The question is less whether the technology exists than when it will become available (a) to non-military researchers and (b) to field surveyors at an affordable price (past experiences with GPS technology suggest that it could occur within five years).

12.2. However, exaggerated claims have been made regarding the efficacy of DNA bar-coding/ DNA taxonomy, which is liable to be constrained less by the sequencing technology than by the nature of the data held in the databases. Although Genbank is by far the best-populated and best-maintained database relevant to systematic biology, it remains deficient in both quantity and quality of data. Even most described species remain wholly unrepresented in the molecular databases, and a significant proportion of the sequences that have been entered into the database have been misidentified, often because the relevant taxonomic expertise was unavailable or otherwise not consulted when sampling took place. In addition, thus far there has been insufficient exploration of the range of genetic variation exhibited within species, to determine how likely a novel sequence is likely to represent a novel species. In our view, DNA taxonomy has revolutionised systematic studies of organisms that truly show little if any morphology, but for the remainder of the Earth's biota, it is the combination of morphological and DNA data obtained from the same organisms that permits genuine understanding and explanation.

12.3. Parallel improvements in sequencing protocols and robotics, driven in part by the human genome project, have combined to permit an exponential increase in the number and diversity of sequences available to systematists. These have proven especially influential in the fields of population genetics and molecular phylogenetics. An important debate is currently gaining momentum within molecular phylogenetics circles between proponents of an analytical strategy that analyses a modest but well-chosen range of genes for a large number of species and approaches that analyse entire genomes (in eukaryotes this is the nucleus, inherited from both parents, or more often

the plastids or mitochondria, usually inherited from only one parent), inevitably encompassing a much smaller range of species. As sequencing technology advances further, this debate will become less polarised. The main challenges will become (a) dealing statistically with the massive volumes of data generated, and (b) understanding better the biological implications of these genetic data, not least their mode of expression within organisms (thus linking genomics to another rapidly expanding biological field, proteomics).

12.4. Some current research projects are attempting to emulate the increasing automation of DNA-based systematics in morphology-based systematics, using automated image-recognition systems. These have shown promise thus far, albeit within relatively narrow taxonomic ranges (e.g. comparing the wing patterns of mosquitoes). Informed opinion is currently divided regarding how much further promise such systems hold for taxonomy. A more pragmatic approach has been developed that uses imaging technology to interface with taxonomic experts. A problematic organism, such as a parasite, can be imaged in 2D or even pseudo-3D in the field and then the image sent electronically to a specialist to aid in identification. Similarly, a critical type specimen in a museum collection can be imaged and sent to the field worker for comparison. However, such approaches are labour-intensive, and tie up the taxonomist in relatively low-level identification procedures – in other words, in using taxonomies rather than creating and improving them. The American military has simplified such a system, by providing field-based para-taxonomists with organism identification guides that can be projected onto the interior of a sophisticated visor, allowing them to compare electronic images with the problematic organisms placed literally under their noses.

12.5. Overall, the Association believes that the systematics community has maintained a sensibly pragmatic attitude to technological innovation. This is a considerable achievement, because recent debates could easily have become polarised between (a) enthusiastic advocates of technological fixes who exaggerate the potential of any new technique before it has been adequately explored, and (b) the views still expressed by many sceptics within the systematics (and especially the taxonomic) community that only conventional approaches yield data that will stand the test of time. However, the Association believes that the UK had the opportunity to show stronger global leadership in initiating and developing such innovations, but that progress has been avoidably slow due to the reluctance of funding bodies to endorse sufficiently ambitious pilot studies to determine the all-important boundaries inherent to these novel approaches. Greater commitment to technological innovation is therefore recommended (as strongly advocated in DUIS policy), along with better coordination among organisations so that several smaller pilot projects can more often be superseded by a single networked project.

Data collection, management, maintenance and dissemination

13. Q7. (a) Does the way in which taxonomic data is collected, managed and maintained best meet the needs of the user community? (b) What is the state of local and national recording schemes?

13.1. As a generalisation, databases are of limited value until they have been populated with the bulk of the information that they are intended to contain. It is therefore especially unfortunate that it has long been, and remains, relatively easy to obtain external funding for the establishment of a new database (especially a meta-database intended to give greater cohesion and/or user-friendliness to several existing specialist databases) but in contrast it is extremely difficult to fund the costs of populating those databases to the point where they become cost-effective. It has also proven feasible to fund the establishment of databases at several different levels (institutional, local, national, European, global). The net result has been a proliferation of databases that often overlap considerably in objectives and/or content. Attempts to coordinate or unify content, presentation, platform, or other crucial properties have been handicapped by the proliferation of the databases and the lack of carrots or sticks sufficient to strongly encourage adherence to such standards. The number and diversity of databases mean that ease of access to data can be problematic for any user-group, including systematists themselves, unless they have prior knowledge of the range of databases available and are asking very specific questions.

13.2. In many cases, the justifications put forward for developing meta-databases have been undesirably weak. Perhaps the most important factor is whether any particular database can be accessed via the Internet. If so, it can usually be located reasonably easily by intelligent use of a search engine such as Google. There is no doubt that meta-databases can greatly enhance ease of access to the relevant data, but this can be achieved most effectively by applying standards and standardisation both to the databases, thereby improving their interconnectivity, and to the data themselves, thereby improving their quality and reliability. In other words, a widely recognised validation procedure is highly desirable. Overall, improving the quantity and quality of data available in the Internet is arguably at least as important as improving its user-friendliness.

13.3. As noted under 12.2, by far the most influential database currently available that underpins systematics (and many other disciplines) is Genbank. This has befitted from many years of evolution and data-population, though even here the reliability of the data is mediocre. But the main secret of its success has been the decision by most relevant journal editors to make submission of DNA sequence data to Genbank a pre-requisite for publication of the resulting research papers. It is this compulsion that has allowed both standardisation of, and rapid population with, data. Attempts to establish similar systems for various kinds of morphological systematic data (e.g. Morphobank, Morphbank) have been far less successful, because (a) fewer such data are now generated, (b) the journals that publish such data are less influential, and (c) very few of those journals have made deposition of the underlying data compulsory. Britain could show a lead in this area by identifying a suitable international morphological database for further development as the preferred repository, ensuring that appropriate standards of data content and validation are established and that UK-based journals identify that database as the preferred repository.

13.4. Bacterial systematists have taken the radical step of identifying a single journal as the outlet for all new taxonomic descriptions of their organisms. This centralisation permits easy detection of trends in bacterial taxonomy (notably the rapid rise of South Korea at the expense of the UK, which now contributes only 3% of the world's new bacterial descriptions), though we believe that it would be impossible to impose such a restriction on the larger volume and greater diversity of taxonomic works encompassing groups of more complex organisms. However, a more pragmatic suggested change is increasingly debated within taxonomic circles – specifically, whether a single centralised repository should be identified for all newly described taxa, and whether registration of new taxa in that repository should be made compulsory. The weight of opinion within the systematics community appears to be shifting toward this idea. Again, the UK systematics community could lead the international community in identifying a suitable repository for Linnean names and making their registration a firm requirement.

13.5. Each major group of organisms (e.g. animals, plants, bacteria) has long had its own legalistic code dictating how those organisms are classified and named. Each of these codes has evolved to suit that particular group of organisms, but now there is an understandable desire to unify (or at least bring closer together) the content of those codes, and to modernise them to better accommodate more recent data sources such as DNA sequences, and to be made fully compatible will electronic publication of taxonomic data. UK-based systematists have long had a strong influence over the content of these codes. Thus, development of a unified view within the UK regarding the most appropriate route to unification would have a good chance of influencing the (often conservative) international bodies that regulate the codes.

13.6. With regard to Q7B, Britain's biodiversity is better known than that of any other country. Most local and national recording schemes for biodiversity data are run increasingly by amateur (or retired professional) systematists. Even where actively employed systematists are directly involved, in most cases their contribution is made in their own time, without encouragement or recognition from their employer. Most of these schemes are poorly resourced, and many are experiencing increasing difficulties obtaining funding at a time when demands for data are increasingly rapidly. It does not help that the government department most closely associated with the majority of the schemes (Defra) has proven especially unpredictable in its resource allocations, due in part to its vulnerability major spends in response to various environmental/ agricultural crises. This has undermined the activities of organisations such as Joint Nature Conservation Committee and the Environment Agency. The recent

rationalisation and reduced resourcing of NERC's research institutes constituting the Centre for Ecology and Hydrology has also negatively affected national recoding schemes.

13.7. At the local level, the UK gradually built up a network of County Biological Records Centres during the latter part of the 20th century, feeding into (and funded primarily by) local government. Many of these CBRCs became highly effective, but for reasons that the Association does not fully understand, the network has been in decline for several years, and several CBRCs have become moribund. This has placed even more reliance for national biodiversity recording on the many specialist societies, which play critical roles in biodiversity recording and assessment. They are most commonly populated by highly skilled and experienced but ageing amateurs, acting voluntarily. Such groups cannot (and should not) have their priorities dictated externally, either by government or by umbrella organisations such as the National Biodiversity Network. Sensitivity is required in several areas. At a practical level, new technologies such as electronic recording systems should be introduced carefully, after being rendered maximally user-friendly. At the political level, these increasingly rare generators of primary data (as opposed to synthesisers of other people's data) need to be given full credit for their efforts; credit (and resources) rarely pass unmolested from the top down, through increasingly complex recording networks, to the shop floor. And where professional systematists are involved in such schemes, they are unlikely to receive credit from their employers, especially where those employers are universities held in thrall to the RAE. In short, greater political and practical emphasis needs to be given to individuals and schemes that focus more on generating new systematic data than on recycling old data.

14. Q8. (a) What is the role of the major regional museums and collections? (b) How are taxonomic collections curated and funded?

14.1. The multiplicity of roles fulfilled by the larger regional museums possessing natural history collections (and botanic gardens/zoos possessing living and preserved collections) makes them especially difficult organisations to manage. Together with other biological records centres they provide a vital focus for local, regional and national natural history organisations, and thus for biodiversity recording and monitoring. Clearly, they play a vital role in education, from interested members of the public through to at least undergraduate level. Higher education roles are particularly important in cases where associations have been forged with universities – universities that today are unlikely to employ taxonomists, and so increasingly rely on museum staff for expert advice and/or tuition. As noted above (Q5B, C), the argument requiring a local "critical mass" of taxonomists does not withstand close inspection; it is extremely important that students in biology and related disciplines are exposed to systematics and taxonomic concepts, but far less important which particular taxonomic group is pursued by that particular researcher in that particular post.

14.2. One can also argue that there is even greater reason to digitise smaller research collections than larger, because (a) it is a more tractable task and (b) they are likely to attract fewer physical visits. However, in this context, digitisation is a double-edged sword, because collections in general, and regional collections in particular, rely heavily on physical visits by specialists to modernise that naming and arrangement of their collections – in other words, for the most creative aspects of curation. In addition, as the staffs in regional institutions diminish in number, dominantly reactive educational and identification roles often detrimentally displace more proactive research initiatives that would increase the academic profile of the institute, particularly where the majority of departments in the institute are not required to pursue academic research.

14.3. In this context, programmes that fund physical visits from international researchers for research and/or skills acquisition have been well-subscribed and successful in their aims, even though inevitably they have preferentially benefited institutions holding the largest collections. The concomitant influx of expertise and modest finances into an organisation, such as that achieved through the long-running (but near-ended), EU-funded SyntheSys programme, can have a disproportionately beneficial impact on the organisations concerned. Such programmes merit continuation beyond SyntheSys, which has received its maximum number of renewals and must now end.

14.4. Just as the larger systematics organisations have primary relationships with different government departments, the smaller organisations rely on a great diversity of sources for their (usually modest) funding. Few of those sources are wholly reliable long-term. Local and regional government often give relatively low priority to such institutes, annually allocating resources that are effectively residual, determined after funding for most other areas of activity has already been decided. And externally funded grants require much effort to obtain, are often relatively small, and are never long-term. It is not surprising that maintaining such organisations and associated collection has proven so challenging over the last two decades, and has led to many casualties.

14.5. However, it is instructive to see what has happened when organisations have made conscious decisions to attempt to revitalise their collections-based research. For example, both Oxford and Cambridge Universities considered donating at least some of their natural history collections to other, even larger collection holders. Instead, decisions were ultimately made to enhance the housing of these collections and to encourage greater activity associated with those collections. In the case of Cambridge, one outcome is the current construction of an ambitious and well-funded plant diversity research institute within the botanic garden. Similarly positive decisions need to be encouraged in other organisations that have less ready access to substantial resources.

15. Q9. (a) What progress has been made in developing a web-based taxonomy? (b) How do such initiatives fit in with meeting demand for systematics and taxonomy information? (c) How do UK-led initiatives fit in with international initiatives and is there sufficient collaboration?

15.1. In many ways, the issues facing web-based taxonomy mirror those facing web-based systematics databases in general. Consequently, several of our more detailed answers to Q7A also apply to Q9 and Q10. With regard to Q9A and Q9C, the enthusiasm shown in the 2002 Lords report for web-based taxonomy helped to accelerate an already expanding debate among systematists and their user-groups regarding how best to pursue taxonomy on the web. Several pilot projects have been developed under the auspices of the Planetary Biodiversity Inventory (PBI) in the US and in Europe the Distributed Institute for Taxonomy (EDIT: see 11.1). Once again, the main project operating within the UK is far more modestly funded (by NERC): Creating an e-Taxonomy (CATE). And once again, the corresponding global initiative (in this case, the Encyclopedia of Life: EoL) is experiencing difficulties in attracting sufficient resources and the necessary political momentum.

15.2. Over the last five years, discussions have led to better understanding of the relative usefulness of different categories of data and the standards needed to ensure quality of data. There have also been significant technological advances in how such data are stored and electronically distributed. Static texts, images and keys can readily be mounted, though more interactive systems (e.g. interactive keys or Wikipedia-style modifiable classifications) remain technically challenging. However, we how now reached a state where theory is arguably stronger than practice. Those standards and prioritisations should be more widely applied, and the taxonomic databases adequately populated. The internationally binding nomenclatural codes need to be revised and brought closer together in order to better accommodate electronic descriptions, and a very small number of web-based initiatives need to be identified as primary repositories, ideally on a global rather than a national scale. UK initiatives have paid much greater attention to (and often informed) European and global programmes, suggesting that international collaboration is indeed improving (Q9C). It is achieving international agreement that remains the greatest challenge to genuinely global web-based taxonomy.

15.3. Similarly, it is important to recognise the constraints on web-based taxonomy and identification. Although web-based taxonomy can be a boon to utilising taxonomies (notably to rapid identification), its benefits to creating taxonomies (i.e. description and revision) and curating reference collections are less clear-cut. For example, digitised images of specimens act as a valuable catalogue, informing a remote user which specimens are available in which collections worldwide, but all of the detail needed for rigorous taxonomic revisions is unlikely to be visible; the specimen needs to be physically examined and perhaps sampled (e.g. for microscopic characters or DNA analyses). The serendipitous finds of relevant specimens in collections, and the improved curation of those collections (e.g. improved identifications), that result from the physical visit of a specialist to a collection are less readily achieved remotely. Also, interaction among specialists is most effective when they are present in the same room. In short, physical visits and exchanges among taxonomic

specialists will continue to remain important; they can be enhanced, but not replaced, by electronic consultation and dissemination.

15.4. The needs of the user communities for systematics data remain largely anecdotal; a thorough survey remains highly desirable. The most up-to-date data were gathered in 2004, in a survey coordinated by the Natural History Museum on behalf of the Global Taxonomy Initiative. The results were undesirable narrow, since (a) they focus on taxonomy rather than the broader discipline of systematics and (b) they consider primarily the need for information to inform biodiversity conservation within the UK. The resulting priorities surprised many systematists, because all of the most commonly reported priorities focused on geographical distribution and/or habitat preference (i.e. on the composition of particular ecosystems) rather than on taxonomic identification, which appeared relatively low on the prioritised list. This reflects the fact that the British biota is the best understood and best surveyed of any in the world, due to a combination of many factors (small country, relatively low biodiversity due to temperate location and recent glaciations, dense population, unusually large proportion of amateur natural historians, unusually large number of natural history societies). Consequently, identification is less of a barrier to conservation in the UK than inadequate understanding of the species and the ecosystems that they form (here termed the "ecological impediment"). In other words, there is more of a systematic and ecological impediment than a taxonomic impediment in the (arguably unusual) case of the UK. Of course, the taxonomic impediment will become more severe as the number of skilled taxonomists in the UK continues to decline. The taxonomic impediment remains more severe in developing countries, leading to what might be termed the "ecological impediment" to achieving effective social improvement schemes.

16. Q10. (a) What needs to be done to ensure that web-based taxonomy information is of high quality, reliable and user-friendly?

16.1. There is only one credible answer to this question: experienced taxonomists need to first set and then monitor, via authoritative peer review, standards for the quality of the data in those databases identified by systematists and user-groups as being most useful. This is in some ways unfortunate because, like identification, monitoring of data quality diverts taxonomists away from actively pursuing the more creative aspects of taxonomy for which they are uniquely qualified, specifically establishing and revising classifications. It emphasises the need for a greater number of experienced taxonomists.

16.2. It has recently been argued that DNA taxonomy (including DNA "bar-coding") can free taxonomy from the need for much of the specialist knowledge inherent in morphological taxonomy. However, apart from paucity of comparative data, the greatest weakness of the databases that underpin DNA-based identification is sequences attributed to the wrong name, because the analyst lacked the skill and/or the determination needed to identify the "yardstick organism" correctly. In many cases, the organisms in question are not deposited in reference collections, precluding other researchers with greater taxonomic knowledge from subsequently checking, and then correcting, the erroneous original identification. Thus, for all but the most primitive groups of organisms (which exhibit comparatively little morphological variation), cross-referencing between morphology-based and DNA-based taxonomies will remain critical. DNA-based taxonomy can only supplement morphology-based taxonomy; it cannot realistically replace it.

17. Q11. (a) How does the taxonomic community engage with the non-taxonomic community? (b) What role do field studies play?

17.1. Due in part to the restrictive definition we have employed, the majority of professional systematic biologists currently operating in the UK are not primarily taxonomists. Thus, in our view, taxonomists are most likely to interact with non-taxonomic systematists, notably phylogeneticists, and then with the related academic disciplines of evolutionary biology and ecology. However, we suspect that the motivation behind this question is primarily to explore how much progress has been made ensuring that taxonomic products reach the users of taxonomy, particularly those addressing increasingly high-priority environmental questions.

17.2. In this context, we would argue that there is still considerable room for improvement in how taxonomic data are fed into more applied disciplines. As previously discussed, provision of raw taxonomic data to applied user communities is unlikely to constitute effective delivery. Rather, the significance of the information is likely to require explanation. Thus, in some circumstances, feeding data through other disciplines (phylogenetics, evolutionary biology, ecology) makes good academic use of the data and also adds meaning to the data, thereby presenting the applied user with a more rounded and intelligible understanding. However, placing applied users more in control of their own destiny is likely to accelerate the rate of progress of projects such as climate-change monitoring. The more effort that users make to understand both the concepts and terminology that underlie taxonomy, the more successful collaborations with taxonomists are likely to be, and the more readily information will pass from "producer" to "consumer". Nonetheless, despite the existence of several promising pilot projects, we have noted a relative reluctance on behalf of both producers and consumers to expend much time addressing these issues.

17.3. We now turn to Q11B. Anecdotal evidence suggests that a remarkably high proportion of the current cadre of systematic biologists entered the discipline as a result of a series of connected positive experiences – most commonly, inspiration from particular teachers/lecturers or media popularisers such as David Attenborough, combined with increasing exposure to natural habitats, together with living collections maintained in zoos and/or botanic gardens and non-living collections in natural history museums. Also, the relatively high proportion of amateur natural historians within the UK, who often enter the field as activists in their more mature years but nonetheless make important contributions to biodiversity monitoring (e.g. via specialist societies to the National Biodiversity Network), also generally gain interest through field experiences. The two groups then constructively interact when professionals volunteer to act as mentors, helping to develop the skills of the amateurs. Field experience is vital across a far wider range of natural history disciplines than systematic biology, including ecology, conservation and various environmental topics. It also helps researchers to comprehend the importance of rigorous experimental design.

17.4. In addition, as was recently noted in a policy paper issued by the Biosciences Federation, laboratory studies of whole organisms (such as dissections and behavioural studies) have suffered reductions of similar magnitude to field studies, and remain equally important if students are to develop an adequate understanding of organismal biology and natural history.

17.5. The Association is convinced that the radical reduction over the past 25 years in fieldwork (in its broadest sense) and in organismally-oriented laboratory studies, particularly in schools (GCSE/A-level) and undergraduate courses, does not reflect reduction in the inherent interest shown by students in these activities. Rather, it reflects a combination of their systematic elimination for curricula and the increasing unwillingness of teachers/ lecturers to invest time in such enterprises in the face of the cost implications and increasingly constraining health and safety regulations. These practical constraints would most likely be overridden if field studies figured more prominently in the relevant curricula, which would also assist the surviving field studies centres.

Skills base

18. Q12. (a) What are the numbers and ages of trained taxonomists working in UK universities and other organisations?

18.1. Again, precise figures are badly needed in order to give definitive answers to this and similar questions. However, the anecdotal evidence is sufficiently strong to give a clear overview. We are confident that the number of researcher (and curator) hours being devoted to taxonomic activity have declined greatly throughout the last half-century, and this decline is ongoing. This is partly because of the number of practising taxonomists in the UK has steadily fallen, but also for a reason that is rarely discussed – the remaining taxonomists (particularly those in employment) are obliged to spend decreasing amounts of their time actively engaged in taxonomic research. Over the last half-century we have seen the focus of the UK's professional taxonomic activity shift first from the universities and wide range of national and local-government-sponsored institutes to a small number of government-sponsored institutes (notably the Natural History Museum and the Royal Botanic Gardens of Kew and Edinburgh). Even here, overall taxonomic effort has declined (see evidence

presented by the Linnean Society). At present, the relative role of researchers not in paid employment is increasing, as the dwindling number of remaining taxonomists age and retire (admittedly, in many cases they remain active long after retirement).

18.2. The experiences of recently retired taxonomists help to illustrate the second cause of the reduction of overall taxonomic activity in the UK. Very often, the productivity of taxonomists substantially *increases* upon their retirement. This reflects the diversion of skilled taxonomists time away from taxonomic description and revision towards a host of other activities. Decreases in curatorial staff mean that taxonomists generally have inadequate staff support and must curate their own specimens. They are often responsible for various dissemination initiatives such as specimen digitising and data-basing. The electronic age mean that they are far more likely to spend large amounts of time reacting to identification enquiries (identification is an important activity, but it does not in itself directly progress the science of taxonomy). If they are fortunate they may still be able to contribute to initiatives designed to train taxonomists. The acquisition and subsequent utilisation of specimens have been rendered far more bureaucratic by a raft of national and especially international legislation, diverting yet more time away from hands-on research. A dedicated researcher is likely to be spending increasing amounts of time preparing funding proposals, and to be interacting far more directly and deeply with key user groups. He or she is also likely to be spending more time writing reports, summaries and overviews to assist those user groups – an important task, but yet another diversion of time of the skilled taxonomist away from conducting primary research. Mirroring a trend common in modern life, the relationship between manufacturing and retailing (in this case, of taxonomic information) has become seriously imbalanced in favour of the latter, which is where the easy profits (and kudos) presently lie.

18.3. In summary, the Association believes that the single most informative key measure of taxonomic activity in the UK should be the cumulative number of person hours spent directly pursuing taxonomic description and revision. We are confident that this figure, if correctly assessed, would be shockingly low. There are two obvious remedial measures to the current situation: (a) return the remaining taxonomists to full-time research activity by appointing a new generation of interstitial staff members whose job is to translate the outputs of the taxonomy for the various user-groups or (b) to accept that the role of a modern taxonomist now includes all of these additional "epi-taxonomic" activities and thus add to the present taxonomic cadre a new generation of more rounded and integrated taxonomists, specifically directed to interact with other systematists and with the various user groups. The Association believes that this second solution would be more effective, but emphasises that this new generation of taxonomists must be an additional resource, rather than falling into the trap of previous remedies by simply reallocating existing resources to fill perceived short-term needs. It is essential that any solution should be based on stable, long-term increases in resources available to systematic biology.

19. Q13. (a) What is the state of training and education in systematics and taxonomy? (b) Are there any gaps in capacity? (c) Is the number of taxonomists in post, and those that are being trained, sufficient to meet current and future needs across all taxonomic subject areas?

19.1. Over the past two decades, systematic biology has almost been eliminated from schools and undergraduate curricula in the UK (despite a recent marginal increase in the natural history content of the national curriculum). This has been part of a broader decline in the educational status of organismal biology and natural history in general, which has also strongly negatively affected previously popular topics such as ecology and evolutionary biology. Broadening consideration even more, it is also consistent with a move of undergraduates away from traditional subjects such as biology, zoology, botany, microbiology and ecology towards "softer" interdisciplinary degrees such as sports science and food science. Concerns regarding costs (increasingly passed onto the students rather than borne by the school) and health and safety constraints have together greatly reduced the exposure of both school and undergraduate students to laboratory based organismal practicals (e.g. dissection and behavioural studies) and to excursions for both fieldwork in natural habitats and visits to natural history collections in museums and botanic gardens – experiences that began the careers of many of the present cadre of systematists. Also, in the rare cases where some systematics is made available at the schools or undergraduate level, it is likely to be taught by someone with little knowledge or experience of the discipline. These declines seem bizarre in the light of the enthusiasm for natural history still clearly shown

by the UK population for natural history, typically inspired primarily by media figures such as David Attenborough.

19.2. A more positive account can be given of the availability in the UK of Masters-level training in systematics, where several well-respected courses are available. However, the level of research council support for these courses is limited, and most of these courses currently rely heavily on students who originate from outside the UK. Also, the paucity of previous exposure of the students to systematic biology means that an undesirably large portion of these typically one-year courses must be spent teaching basic knowledge that previously the students would already have possessed. The situation worsens again at the doctoral level, where positions are uncommon for both stand-alone doctoral grants and those linked to larger-scale research grants. In particular, for many years there have been exceptionally few doctoral students pursuing projects that are primarily taxonomic. This situation extends to the postdoctoral level, where we suspect that the few systematics-oriented researchers experience a larger percentage of researchers either transferring to other research fields or leaving science altogether than most other research disciplines. The near-elimination of taxonomy from the university sector means that it is extremely difficult to find the required university supervisor for any erstwhile doctoral student. We also suspect that, for the lucky few who eventually obtain "permanent" positions, the period between obtaining their doctorate and their first permanent job is unusually long.

19.3. We also note that other, more "vocational" routes into a systematics career, passing though a phase of employment as a technician or curator, have become less effective. This has occurred partly because there are fewer professional technicians and curators and partly because employment hierarchies within organisations have become more rigid, permitting far less fluidity of movement between these roles and research positions as individuals gain skills and maturity.

19.4. We are confident that there is already a profound taxonomic skills deficit in the UK. However, because of the long periods of time required to generate a skilled systematist via the "informal apprenticeship" (school for inspiration > undergraduate for background knowledge > masters for specialist knowledge > doctorate for research experience), the effects of the deleterious trends listed above will take a long time to become fully apparent. However, we also note that any attempts to remedy the decline will similarly require long periods to take effect.

19.5. Fortunately, tuition in systematics in general and taxonomy in particular is much stronger in many other countries, so that the UK's "gaps in capacity" can usually be filled, albeit not always satisfactorily. The majority of postdoctoral and permanent research posts in systematic biology advertised in the UK are now being filled by applicants who have been trained abroad (e.g. North America, Australasia, Scandinavia, and increasingly eastern Europe). This outcome is not intrinsically problematic, though some applicants lack the conceptual rigour desired by many employers (and collaborators), and others are sufficiently shocked by the disparity between the cost of living and academic salaries in the UK that they either reject the initial offer or accept but remain in post for a disappointingly short period.

19.6. Given the above observations, the Association believes that it is highly desirable that Britain generates a stronger pool of systematics researchers, capitalising on the globally recognised strength of its research universities, and on the exceptional expertise and collections available in its major systematics institutes. Specifically, we strongly advocate rebuilding the UK's "informal apprenticeship" in systematics and biodiversity, preferably from the bottom up: (a) Organismal biology and systematics need to be enhanced in secondary schools, preferably via modifications to the national curriculum. (b) Increased use of field studies by schools should be strongly encouraged, deploying not only knowledge-based arguments but also criteria favoured by the current government, such as remedying social exclusion. (c) Increased exposure to systematics in schools should lead to increased demand for specialist undergraduate courses in at least some higher education institutes (ideally, systematics should be made a core element of all biological bachelors degrees). (d) This undergraduate demand would in turn require restoration of some of the lectureships in systematics that have been lost over the last two decades – a goal that merits especially high priority. (e) Government should encourage selected research universities to specialise in systematics and biodiversity. At least some universities should operate in partnership with the major research institutes and/or possess their own actively curated natural history collections. (f) Organisations such as the Systematics Association and Linnean Society should work alongside the

universities and research institutes to develop up-to-date teaching materials and to initiate summer schools and/or workshops for individuals who wish to enhance their systematics knowledge.

19.7. We suspect that reinvigorating systematics teaching would have a beneficial effect in related areas currently under-subscribed by students, such as ecology and evolutionary biology. This outcome is especially desirable if, as we believe, significantly increased numbers of skilled researchers are going to be required to address high-profile, long-term challenges such as sustainability and climate change.

20. Overarching recommendations

20.1. **Recommendation 1: Establish a new independent body to coordinate UK systematics activities. —** Neither the UK government nor the systematics community has made significant efforts to respond positively to Recommendation 8 – that Defra should coordinate the establishment of a body to give leadership to the UK's systematics community, identifying weaknesses and priorities, and campaigning for increased resourcing. In theory this remains a highly relevant and desirable recommendation. However, such a body, named the *UK Systematics Forum*, existed from 1990 to 1998 (led by a past-President of the Association, Prof. Stephen Blackmore). The Forum became defunct as a result of a lack of bipartite support in general and of funds in particular. Steps would therefore need to be taken to ensure that such a fate did not befall any future replacement body. This would require inducements (ideally, both carrots and sticks) to encourage the major systematics institutes and organisations, and the major user-groups of systematic information, to take the initiative seriously by genuinely committing to the goal of developing a shared strategy. It would be important that this body was seen to be balanced and objective, which suggests that an informed, yet neutral, coordinator is required. The Association would be willing to play that role, provided that (a) adequate, long-term resources were made available to manage the steering group, and (b) the steering group had considerable influence over the allocation of resources, and the establishment of high-level policy, within the UK systematics community.

20.2. **Recommendation 2: Conduct a thorough and inclusive survey of the current status of the UK systematics community and the requirements of its user communities**. — One of the first priorities for this new coordinatory body should be to rapidly but thoroughly survey the UK systematics base, so that reviews such as the present HoL inquiry need no longer rely largely on anecdotal evidence to underpin their deliberations. An appropriate level of detail would be required, including breakdowns on time spent by each systematist on different activities and the resources used in undertaking those activities.

20.3. The systematics community could have shown more prescience and proactivity in responding to policy-driven priorities of the UK government. Although we continue to believe that the UK systematics community should have ultimate control of its own destiny, it would equally be inappropriate for it to set its own priorities without consideration of (a) the priorities of potential sources of substantial funding and (b) the needs of its many major user groups. Improved dialogues are highly desirable, as many systematists remain ignorant of the needs of their user groups, and user groups often fail to understand the constraints on systematics research, consequently making unreasonable demands on systematists. In addition, some funding bodies and policy makers have failed to make the direct connection between systematics research and environmental monitoring. Until resourcing improves, there is limited motivation for pursuing recommendations 4–7:

20.4. **Recommendation 3: Undertake a detailed consultation with all current and potential substantial funders of systematics and biodiversity research.**

20.5. **Recommendation 4: Agree a prioritised list of goals for the UK systematics community, and agree the best methods of achieving those goals.**

20.6. **Recommendation 5: Recognising the global success of 'Genbank', agree a prioritised list of databases and a set of inducements to encourage systematists to routinely deposit other categories of relevant information in those preferred databases. —** The UK should better capitalise on the lead it has previously shown in establishing international agreements for data

standards, and for strongly encouraging deposition of relevant data in a very limited range of internationally accessible databases, mirroring Genbank. It could also show leadership in modernising nomenclatural practises and registration, and the fact that many professional journals are based in the UK could help to incentivise researchers to populate favoured databases. However, our global influence in these areas has declined as a consequence of the apparent unwillingness of UK-based funding bodies to elevate successful pilot schemes into fully-fledged, long-term programmes.

20.7. The most obvious funding trend in the UK in recent years has been to concentrate resources in a smaller number of larger research grants. Until recently, there has been no sign that these grants could be awarded for unusually long periods. It has become abundantly clear to us that systematic biology needs a mixed economy of funding. The Small and "fairly small" grants schemes run jointly by the Systematics Association and the Linnean Society are extraordinarily strongly subscribed with high-quality proposals. Moreover, 12 years experience of the Small Grants scheme strongly suggests that it has been cost-effective. We would therefore like to see funding bodies take such schemes more seriously. In theory, there is no corresponding problem with the availability of medium to large-sized grants, since these have become standard. The problem here for systematists in general, ands taxonomists in particular, is acquiring such grants. Perhaps the most important battle-ground is at the most expensive end of the spectrum. Rather than see large grants awarded to consortia of many researchers over short periods, we would like to see large grants awarded to a smaller number of researchers over a longer time-scale – one more compatible with both taxonomic description and practical applications such as climate-change monitoring.

20.8 Recognising the ongoing reluctance of major funding bodies to allocate resources for periods of more than five years hence, we suggest that the government should encourage "joined-up funding", where multiple funding bodies each take partial responsibility for maintaining key long-term research programmes.

20.9. **Recommendation 6: Develop a mixed economy for funding that spans the full possible range from small, short-term awards to very large, long-term programmes.**

20.10. **Recommendation 7: Coordinate funds from multiple sources in order to guarantee funding for prioritised long-term research goals over unusually long time-scales.**

20.11. The Association supports the consensus view that, within the UK's systematic biology community, the most serious damage sustained over the period of the four HoL reviews has been to taxonomy. This reflects three main causes: (a) The RAE-mediated near-elimination of taxonomists from the university sector in the UK, due to low overhead potential and producing outputs of limited immediate impact. (b) The reduction in other long-term users of taxonomic data for identification purposes in the public sector, as a result of over-emphasis in addressing narrowly focused, tractable questions through short-term funding. (c) The diversion of time among the few remaining qualified taxonomists away from descriptive taxonomy towards a rapidly expanding range of other responsibilities (e.g. identification and education/PUS, together with increased bureaucratic burdens imposed by international agreements such as CBD/CITES and the Freedom of Information Act) or the movement of taxonomists wholly into other, more lucrative research fields. The pyramid of activity appears to have become inverted, with fewer researchers generating novel data than recycling existing data. These observations lead to a further series of recommendations (8–10), which are a logical sequence that collectively is designed to redress all three of these negative effects on taxonomy:

20.12. **Recommendation 8: Establish a new national Institute of Biodiversity Research, requiring a substantial number of permanent salaried taxonomic positions to be inaugurated within several pre-existing systematics institutes, biodiversity monitoring institutes and research universities.** — Appointees would pursue previously prioritised, and interrelated, research programmes, some providing the descriptive taxonomy "pull" and others the applied taxonomy "pull", and with input from collaborators in other disciplines through the establishment of "taxonomic colleges". Ideally, this scheme would be funded by the Department of Universities, Innovation and Skills (DUIS) and administered by joint research councils (NERC, BBSRC and perhaps EPSRC). Much of the initial focus would most likely be long-term monitoring, particularly of climate change. It would require careful prioritisation of appropriate habitats and taxonomic groups. We note that

experience suggests that this scheme would not be cost-effective if only short-term or medium-term funding was provided.

20.13. **Recommendation 9: Assign the majority of these new taxonomic posts to the university sector.** — Admittedly, this guideline is hardly a unanimous view of the Association's council. However, university positions should have maximum positive effect because they will reinvigorate university undergraduate teaching in systematics, and will provide: essential university-based supervisors for postgraduates studying taxonomy (thus revitalising the "informal apprenticeship" in taxonomy); university-based co-applicants for inter-institutional funding proposals in systematics; foci for local/regional natural history societies and, where still in existence, for natural history collections.

20.14. **Recommendation 10: Apply to these new university appointees a set of RAE-style assessment criteria specifically optimised for performance in the taxonomic field.** — Protect these taxonomic researchers from the profoundly negative effect of the RAE (or, more accurately, its successor, the REF) by either (a) placing the relevant academics wholly outside the auspices of the REF or (b) greatly diversifying the criteria required by the REF such that the standard outputs of a descriptive taxonomist (long-lived and most likely increasingly electronic) would allow systematists to be put forward for the REF while benefiting, rather than prejudicing the well-being of, their host department. In other words, the REF need to be revised to be more flexible, and in particular to better fit the needs of long-term research.

20.13. Lastly, we offer two recommendations (11, 12) designed to better channel the ongoing enthusiasm shown for organismal biology by schoolchildren, retired and other 'amateur' natural historians:

20.14. **Recommendation 11. Introduce more organismal biology into the national curriculum, and restore previous levels of laboratory experimentation and field excursions in schools and universities**. — The interests of both the country and its citizens will be best served by relieving some of the fiscal and bureaucratic pressures that have, in practice by stealth, systematically suppressed the innate love of Britons for the study of their natural history. This will in turn revitalise the flow of natural historians through the UK's educational infrastructure, eventually (after a considerable lag period) restoring the 'informal apprenticeship' that once generated the world's best taxonomists. Achieving this goal would require only modest increases in funding for school-based science and a pragmatic reappraisal of the relevant Health and Safety regulations.

20.15. **Recommendation 12. Provide increased resources and improved coordination for organisations that encourage the acquisition and constructive use of taxonomic skills by amateur natural historians. —** Although organisations dominated by amateur natural historians are now responsible for the bulk of biodiversity recording conducted in the British Isles, professionals play key roles in providing training (e.g. through specialist workshops) and, on occasion, leadership. However, the combination of increased workloads and decreased credit for such work from most employers means that it is becoming increasingly difficult for employed researchers to fill these key roles; clearer recognition is badly needed. Nationwide recording and data-dissemination schemes, notably the National Biodiversity Network (NBN), have long been chronically under-funded, as have most of the specialist societies that generously supply NBN with original data. Papers and articles generated by amateurs (and by poorly funded professionals) require subsidies against, or preferably absolution from, the substantial costs of the rapidly expanding "author-pays" open-access concept of publishing. An even greater contribution from government would be to properly acknowledge the major contributions made by amateurs to biodiversity assessment, by (a) formally recognising those who have acquired appropriate vocational qualifications as para-taxonomists and (b) providing a central fund to cover their travel and subsistence.

20.16. Most importantly, none of the above recommendations should be implemented by reallocating the meagre resources already vouchsafed to the systematics community.

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February 3rd 2008 (drafted by R M Bateman)