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The role of taxonomy in species conservation

Georgina M. Mace

Institute of Zoology, Zoological Society of London, Regent's Park, London NW1 4RY, UK (*georgina.mace@ioz.ac.uk*)

Taxonomy and species conservation are often assumed to be completely interdependent activities. However, a shortage of taxonomic information and skills, and confusion over where the limits to 'species' should be set, both cause problems for conservationists. There is no simple solution because species lists used for conservation planning (e.g. threatened species, species richness estimates, species covered by legislation) are often also used to determine which units should be the focus of conservation actions; this despite the fact that the two processes have such different goals and information needs. Species conservation needs two kinds of taxonomic solution: (i) a set of practical rules to standardize the species units included on lists; and (ii) an approach to the units chosen for conservation recovery planning which recognizes the dynamic nature of natural systems and the differences from the units in listing processes that result. These solutions are well within our grasp but require a new kind of collaboration among conservation biologists, taxonomists and legislators, as well as an increased resource of taxonomists with relevant and high-quality skills.

Keywords: species; taxonomy; phylogeny; conservation planning

1. INTRODUCTION

Taxonomy and conservation go hand-in-hand. We cannot necessarily expect to conserve organisms that we cannot identify, and our attempts to understand the consequences of environmental change and degradation are compromised fatally if we cannot recognize and describe the interacting components of natural ecosystems. Several recent reviews have emphasized the fundamental role that taxonomy plays in conservation, and significant high-level science policy reports have additionally drawn attention to the funding and credibility gap faced by taxonomic and systematic science (NRC 1995; House of Lords 2002; The Royal Society 2003). The House of Lords' report on funding for systematic biology in the UK, for example, is entitled *What on Earth? The threat to the science underpinning conservation*, and in common with the others concludes broadly that effective conservation depends on a strong and well-funded science base in taxonomy and systematics.

All of these reports also emphasize the poor state of our knowledge of the world's species. Out of the estimated total of *ca*. 7–15 million species, we have described *ca*. 1.7 million (though, lacking any central inventory we do not even know this number exactly). As a consequence, high-profile campaigns have been launched in the name of biodiversity conservation to catalogue the entire set of species on Earth (Species 2000: www.species2000.org; AllSpecies: www.all-species.org)—by any estimate a major undertaking with a cost of more than US$$10^8$.

However, taxonomy and conservation clearly are not the same thing. Describing the world's species and their relationships is not equivalent to saving them. Completed species lists, regional taxonomies and guides on their own do nothing to conserve species. But neither is it going to be possible to develop the necessary plans and mechanisms for species conservation without adequate knowledge and description (Rojas 1992; Samper 2004). Both conservation and taxonomy face severe funding limitations. So, what is the relationship between them? What compromises can be drawn, where are the synergies between the two, and what kind of taxonomy do we need to achieve conservation goals?

In this paper, I consider these questions with particular reference to species conservation and the needs of conservation practitioners at global to local scales. A starting presumption is that while ecosystem- or landscape-scale conservation is essential to preserve significant environmental (e.g. biogeochemical cycles), ecological (e.g. nutrient cycling, community diversity) and evolutionary (e.g. adaptation, speciation) processes, species are a natural taxonomic rank to form the basis for both conservation assessments and for management. Hence, the focus on species is not intended to be exclusive, but to reflect the fact that species conservation is necessary, though certainly not sufficient, for wider conservation policy and practice. Conservation approaches at habitat or landscape scale expect the benefits at one scale to apply at others too, though the fit may not always be perfect (Kremen *et al.* 2000).

Whether we like it or not, the species rank has a special resonance with the public and with policy-makers. More fundamentally, the species rank is unique in the taxonomic hierarchy in that it has claim to objective reality, since gene flow is largely restricted within species (Hey 2000). Almost all of the many variants on a species definition agree at least that species are real and distinct entities in nature, understood to represent evolving lineages

One contribution of 19 to a Theme Issue 'Taxonomy for the twenty-first century'.

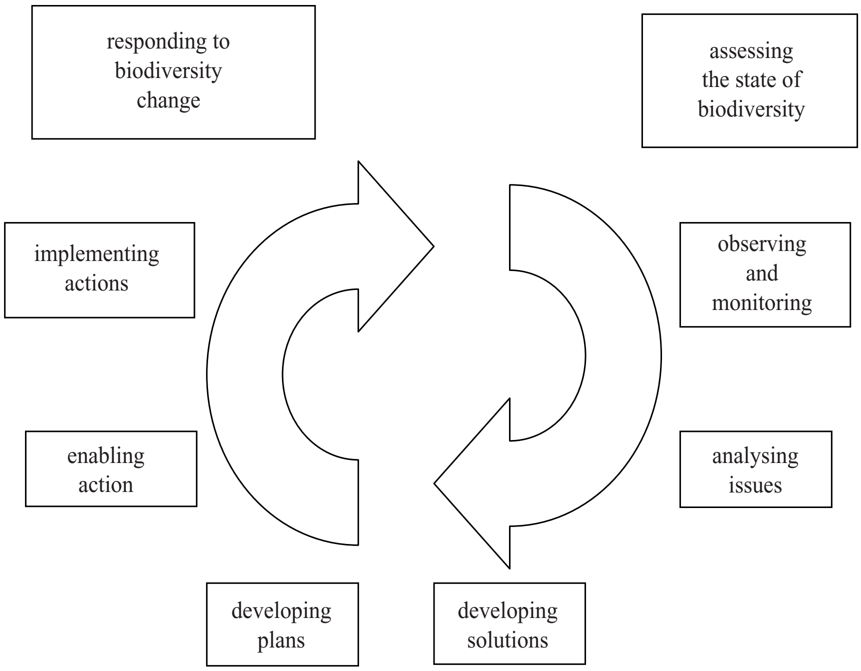

Figure 1. Cycle of activities involved in conservation assessment and planning.

within which the diversity that we see, and that we hope to conserve, is shaped (Hey 2001).

2. CONSERVATION PLANNING AND MANAGEMENT

To form a basis for considering the role of taxonomy in conservation, I use a simple representation of the cycle of conservation activities (figure 1). The starting point is the observations of the species or populations that indicate attention is needed. Ideally, these observations are formalized into some kind of systematic monitoring programme, but in fact much biodiversity assessment is opportunistic and sporadic (The Royal Society 2003). Depending on the context, the observations could be of the status of a single population or species, or could be of suites of species organized by locality, higher taxonomic grouping, biome, region, etc. At local scales, monitoring is likely to be through direct or indirect measures of population status, but at broader scales, the species level dominates most assessments. Once observations or monitoring indicate that there is a problem that needs addressing, the next step will involve an analysis of the factors involved, their relationships to one another and the conservation status of the species or population. At this stage, good experimental methods are needed to draw out causes and effects of rare or declining species, so as to best design strategies that will reverse the trend (Caughley 1994). This stage may take some time to complete but it should lead to the design and development of solutions.

There is an enormous range of possible solutions, which will vary according to their place in the causal chain and the degree to which they are local and practical versus distal and strategic. To take some extreme examples, the solutions for a declining population of a rare bird species might involve either or both of gazetting critical habitat and managing that habitat for its suitability for the species, to lobbying for the species to be added into lists that carry legal weight ensuring protection. On a broader level, analyses might indicate that species are especially threatened in certain habitats (e.g. coastal ecosystems; Jackson *et al.* 2001), or facing a particular threat (e.g. marine capture fisheries; Pauly *et al.* 1998), or belonging to particular taxa (e.g. amphibians; Houlahan *et al.* 2000). In this case an analysis of causation and of efficient conservation strategies is called for. The various prioritization schemes and strategies developed by conservation organizations and agencies are a response to these broader assessments of need, as well as the organization's particular focus or mandate. They may include species- or area-based priority-setting systems as well as responses that address the anthropogenic drivers of change (see Redford *et al.* (2003) for a review). The solutions then become embedded in a conservation plan for the species, taxon or region.

The existence of a plan is far from a guarantee that actions will follow. A series of alternative enabling activities, ranging from fund-raising, through raising awareness and lobbying, to drafting and implementing legislation are almost always necessary. At international levels this could include listing the species or population under one of the multilateral intergovernmental environmental agreements (e.g. CITES, Ramsar—the wetlands agreement, the Convention on Migratory Species, etc.) or international management agreements (e.g. fisheries agreements, trade agreements, International Whaling Commission). At national level, various countries have lists of species that are afforded protection (e.g. federal Endangered Species Acts in the USA and in Canada, the Biodiversity Action Plan species in the UK). At local levels the responses are most likely to involve direct action on the ground, for example habitat protection and management, but in very many instances the placing of the species on one of these important lists may be a prerequisite to effective direct actions to protect or restore the species. Over the past 20 years, largely as a consequence of influential national legislations such as the Endangered Species Act in the USA, there has been substantial work done on the design and implementation of species recovery plans, and general agreement that this level of analysis is required if actions are to be effective over the medium or long term (Tear *et al.* 1993, 1995).

Finally, once the plans are developed and implemented, observations and monitoring can again indicate status, and the cycle of analyses, finding solutions and developing and implementing plans can start again. Importantly, at this stage of the cycle revised plans can be informed by new information on both changes in biological status and their driving forces.

3. UNITS FOR LISTING VERSUS TARGETS FOR PLANNING AND ACTION

Considering this cycle of activities reveals two fundamentally different kinds of activity that conservationists undertake involving species. On the one hand species are units for listing whereas on the other they are the identifiable targets for conservation actions on the ground. Both these activities require that there is a valid and documented name, against which candidates for listing, protection and management can be tested. Hence, a valid taxonomy is essential at all points in the species conservation cycle. However, listing on the one hand, and designing and implementing practical conservation actions *in situ* on the other, are very different processes. Moreover, taxonomy is not an exact science. The precise criteria that need to be met before a set of more or less similar organisms are distinguished from other similar organisms as a distinct species are far from generally agreed. This is the 'species concept' problem on which much has been written by many authors (Hey 2000), which need not be repeated here. The relevant point is that these two major kinds of conservation activity, listing and *in situ* actions, have different purposes, constraints and requirements. It is just as unrealistic to expect a single species concept to meet the needs of conservationists as it is to expect it to meet the needs of other groups of modern biologists (Mallet 2001; Wheeler 2004). We do need a taxonomic approach for conservation, but its style and focus need clearer development towards the key tasks at hand. I outline the issues relating to the two activities in turn before returning to an overall assessment.

(a) *Taxonomic issues for listing species*

Lists here refer to all kinds of species lists including those that form the basis of national and international legislation, and those that are used in local and regional planning. There are many examples. CITES has lists of species that are covered by the Articles of the Convention—those species listed in appendix I are prohibited in international trade, whereas those listed in appendix II are controlled in trade. The IUCN produces a regular list of species most at risk of extinction in the short term—the Red List (Hilton-Taylor 2000), and changes in the length of the list are used to indicate changing patterns and intensity of threat over time, between higher taxa and among regions. Species richness and the proportion of species threatened with extinction can be calculated for countries (Groombridge & Jenkins 2002), ecoregions (Olson *et al.* 2001) and within countries (Stein 2000) and used for priority setting aimed at diverting conservation funds appropriately (Balmford *et al.* 2000). Regions of the world with exceptionally high species richness and evidence of threat are recorded as biodiversity hot spots, and extra conservation resources are focused on conservation in those areas (Myers *et al.* 2000). Among birds, significant conservation choices are made on the basis of areas where there are many sympatric species with restricted ranges (e.g. ICBP 1992; Bibby 1998). In some areas of the world (especially in Australia and South Africa) the choices over land areas to protect in reserves or parks are based on algorithms that systematically optimize areas of high complementarity or irreplaceability by comparing lists of species from different areas (Margules & Pressey 2000). Variations on all the same processes are played out within countries—there are lists of species protected in national legislation, lists of species recommended for protection, recovery planning and special protection. There are also national lists of rare and threatened species (Gardenfors *et al.* 2001). Without doubt, species need to be named and identified formally if they are to benefit from the conservationists' sets of legislative and planning tools.

Unfortunately, all lists of species, and species richness measures generally, are extremely vulnerable to changes in species definitions. As the species concept becomes narrower, or species are split for whatever reason, the length of the list increases. The units making up the list can also alter radically. Whether this is a problem or not depends on the role that entities in the list are expected to play. For example, conservationists concerned with mega-faunal diversity and the clear evidence that large bodied taxa are being lost at a disproportionately high rate are unlikely to be reassured that the list of large mammals is also growing as we add one or two more species of African elephants (Roca *et al.* 2001; Eggert *et al.* 2002), tigers (Cracraft *et al.* 1998) or gorilla (Taylor & Groves 2003). But at the same time, those seeking to conserve elephants, tigers and gorillas across their geographical and biological range may find it easier to achieve when there are more distinct units that have been given the rank of species. In reality, when the lists are lengthened by simply splitting previously recognized species, rather little diversity is added. To take another example, the list of species controlled in trade by CITES will grow longer as these new species are added, leading to some practical difficulties with implementation, but the impact of the Convention overall is unaffected because the set of organisms given protection is exactly the same.

The most serious problems arise where species lists are to be used in any attempt to compare conservation status across different groups of species, because the length of the list is then the informative metric. If species concepts, or variable interpretations about delimiting the boundaries of species, vary in any systematic way among the groups being compared, then the comparisons are seriously confounded and the results misleading.

Recent analyses of the proportion of species listed as threatened with extinction according to the IUCN (Hilton-Taylor 2000) show that 11% of birds versus almost 25% of mammals are threatened, whereas less complete data indicate that the comparable figure for freshwater fishes and amphibians will be 40–50%. These data could have a significant bearing on conservation resources distributed to birds versus other vertebrates. But

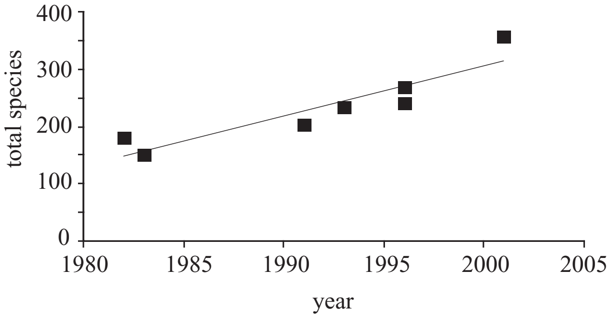

Figure 2. Species counts for the order Primates from taxonomic authorities over the past 20 years (N. Isaac, personal communication). Data from primate taxonomies used for conservation assessments (Honacki *et al.* 1982; Wolfheim 1983; Corbet & Hill 1991; Wilson & Reeder 1993; Rowe 1996; Baillie & Groombridge 1996; Groves 2001).

how confident can we be that the percentages are comparable? Among birds, conservation assessments are coordinated by BirdLife International, which also closely manages the lists of species to be included (Collar 1997). On the whole, BirdLife International is conservative about accepting new species until the evidence is very strong, and perhaps most importantly, they explicitly adopt a BSC, which will tend to be more inclusive than the main alternative the PSC (Collar 1997). By contrast, the IUCN assessments for mammals and amphibia and fishes are less closely managed, and for species distributed across patches of discrete habitat, such as the freshwater habitats of amphibia and fishes, the potential for taxonomic splitting is great. So, is it possible that to a degree the difference in threat levels among these higher taxa is explained by the adoption of different species concepts? A recent review comparing paired taxonomic assessments under phylogenetic and non-phylogenetic concepts showed species numbers roughly doubling under a PSC, with an associated decrease in species' population size and range, which will be likely to increase the assessment of extinction risk (Agapow *et al.* 2004).

A related problem arises as taxonomies undergo refinement and reassessment. In most cases, the number of species increases as new distinctive characteristics are uncovered. This is particularly likely to be the case with PSC where there is no privileged phylogenetic level that corresponds to a species other than 'the smallest aggregate' (Horvath 1997). This makes the degree of taxonomic resolution sensitive to sampling effort (Sites & Crandall 1997; Walsh 2000) and with more refined molecular and statistical tools the need for specific hypotheses and standards concerning species boundaries become compelling (Sites & Marshall 2003). However, the problem is not restricted to the PSC.

Over the past two decades the total number of primate species has increased progressively, and approximately doubled (figure 2). The growth in primate species is significantly greater than the level of taxonomic inflation characteristic of most well-studied groups, representing a linear increase of more than eight species per year (this is highly significant: $p < 0.01$; N. Isaac, personal communication). This has been caused by a number of factors. Several new species have been discovered but most of the increase is as a result of taxonomic revisions. In certain cases primate species were clearly over-aggregated in earlier taxonomies and this has been put to right; new studies and the application of new techniques (especially molecular genetics) have led to the recognition of many new species, especially among 'cryptic' taxa (e.g. galagos: Bearder 1999). Several more recent systematic reviews have raised what were once subspecies to the species level, and the increasing adoption of the PSC has also undoubtedly had an effect on species recognition. Finally, those responsible for the conservation assessments of primates have become increasingly concerned about the deteriorating status of several distinctive populations and subspecies. Elevating these to the rank of species has been justified by the degree of morphological and/or geographical distinctiveness, and guarantees additional conservation resources and legislative protection. However, the number of primate species added to the list by taxonomic revision is currently overwhelming changes in the list caused by real changes in conservation status. Because we know that the rules for delimiting species have changed over time, we cannot judge the real severity of the recent increase in the number of endangered primates, nor we can we compare this trend with other taxa within and outside the mammals.

Analyses of the turnover in extinct and endangered species reinforce the conclusion that these lists are confounded by the limited knowledge we have of most species and the extent of taxonomic uncertainty. For example, the number of vascular plant species presumed extinct in Australia progressively declined between 1988 and 2002, but almost entirely as a result of new knowledge and taxonomic revisions, whereas all the available evidence suggests that the real situation is worse in absolute terms compared with what the list suggests, and with a trend in the opposite direction (Burgman 2002). In revisions to the global lists of threatened birds between 1996 and 2000, 27% of the 295 changes were a result of taxonomic changes rather than actual changes in conservation status. It is not surprising then that the utility of such lists for reporting on the state of the environment is called into question (Possingham *et al.* 2002; Burgman 2002; Balmford *et al.* 2003). If such lists are to retain credibility there needs to be enforced stability of the units they report, so that real information relevant to conservation management is not overwhelmed by 'noise' caused by changing information and variable species concepts.

For their activities involved in listing and conservation assessment, conservationists need a taxonomic approach that is consistent (e.g. across taxa, time and regions), stable and relatively resistant to change, explicit (the methods used to delimit species should be clear so that new candidates can easily be assessed) and managed.

(b) *Units for conservation action*

The design and implementation of conservation actions on the ground is critically important for conservationists. All the legislative and policy work done to get species named and listed will be wasted unless the conservation and recovery plans developed as a result are well designed and implemented. So, ideally, once a species has been identified, its precarious conservation status determined, and its name included on lists that lead to actions to restore it, the real business of conservation can begin. Listing a species does no more than draw attention to it. Effective management now depends upon understanding the processes causing its decline, developing effective control and management strategies and implementing whatever actions are called for.

However, in practice a series of dilemmas lies at the interface between 'listing' and actions. First, as already discussed, the label 'species' can often determine whether or not conservation actions will be forthcoming. In national and international legislation, priorities are afforded to species over local populations or subspecies that are under threat. In scientific and popular discussions, the distinction between the species rank, and that of subspecies or local population is great, leading to a perceived association between the taxonomic rank of a taxon and the conservation priority afforded to it. Hence, there is a documented tendency to maintain species status for certain taxa in the absence of any scientific support for this status. Karl & Bowen (1999) document this phenomenon in the case of the black turtle (*Chelonia agassizii*) and suggest that this applies to other taxa too. This is not only a problem of failure to rectify outstanding errors; in recent decades several elevations to species rank among mammals have been motivated by the increased conservation attention they will thereby attract. I am not necessarily suggesting here that these are unwarranted elevations (though some certainly are dubious), but even if all were fully justified it remains the case that these elevations are not focused randomly but will inevitably be biased towards charismatic, large-bodied, rare and endangered forms that have the necessary scientific and conservation attention. Of course, this generally leads to increasingly lengthy lists. In addition, the variability within and between the entities on those lists can cause confusion and potentially a loss of credibility for the process, as well as for priority areas determined from the lists (Meijaard & Nijman 2003). What is needed is agreement on general principles from which methods could be drawn for determining which assemblages of individuals should from the units for conservation management and action.

This is a different problem to that of developing lists of species for planning purposes discussed in § 3a. Units for conservation action will almost always be populations or even individuals, and exactly how these should be defined, delimited and determined has been a focus of continuing debate among conservation biologists for the past 20 years (Ryder 1986; Moritz 1994; Vogler & DeSalle 1994; Waples 1995; Crandall *et al.* 2000; Fraser & Bernatchez 2001; Pearman 2001). The challenges posed by alternative species concepts and by the uncertain validity of subspecies were recognized early on, and ESUs were proposed as a way forward. However, the ESU is a concept that is also evolving with time. Originally, it was intended to distinguish between populations that represented significant adaptive variation, and the identification of ESUs was to be based on concordance between sets of data (genetic, ecological, behavioural) derived by different techniques (Ryder 1986). Waples (1991) redefined ESUs to be populations that are reproductively separate from other populations and that have unique or different adaptations. Both of these concepts have a degree of subjectivity which was addressed by a specifically genetic definition put forward by Moritz (1994), in what has been a very influential paper recommending specific methods for distinguishing ESUs. He defined ESUs as populations that are reciprocally monophyletic for mitochondrial DNA alleles, and that show significant divergence of allele frequencies at nuclear loci. More recently, Crandall *et al.* (2000) reviewed the implementation of both ESUs and species designations in conservation, and found highly divergent interpretations. Species may be designated as distinct according to very different criteria (ecological and genetic)—many of which do not correspond to the intentions of the ESU. It is clear that what was intended to be a concept that would sidestep the problems associated with designating species has fallen into much the same set of difficulties, and it is operationally hardly more standardized than are taxonomic methods used to delimit species boundaries.

Despite all this, there seems to be an emerging consensus from the species conservation–ESU debate about what the units for conservation action *should* represent (Hey *et al.* 2003). They should be chosen to maximize the potential for evolutionary success—and therefore to preserve adaptive diversity across the range of the taxon. Despite the difficulty in turning this general goal into standard operational methods, most biologists agree that conservation must focus on preserving evolving populations in which adaptive diversity and the potential for evolutionary change is maintained. Unfortunately, straightforward methods to identify these units are complicated by the fact that various different processes can result in a group of individuals evolving shared and distinctive adaptations. Both gene flow ('genetic exchangeability') and shared ecological niches ('demographic exchangeability') can lead to shared adaptations among individuals (Templeton 1989) and methods for assessing reproductive isolation or genetic distinctiveness revealed from molecular markers will not distinguish them simply (Crandall *et al.* 2000). Nevertheless, the goal is clear, there are abundant lines of evidence that can be used, and much fundamental work in ecology and evolution can be used to aid in the development of recovery plans (see also Nic Lughadha (2004)).

(c) *Distinguishing between processes*

The role of taxonomy in species conservation has become complicated by the fact that conservationists are confusing the two different processes of listing and priority setting, versus recovery planning and *in situ* conservation actions. Recognizing that these are distinct and have different demands will be necessary before we can determine what kind of taxonomy conservationists need. The general discussion in § 3a,b has outlined the issue but a specific case study illustrates this confusion.

The shiitake mushroom (*Lentinula edodes*) is a wild species with a broad natural distribution through East Asia to Tasmania and New Zealand, but it is under intense cultivation across Asia, expanding rapidly into other parts of the world (Hibbett & Donogue 1996). It is now the world's third largest mushroom industry. This industry is expanding in a way that may threaten the future of the wild species. Loss of natural habitats, harvesting of wild mushrooms at an unsustainable rate, and the introduction of non-native strains into cultivated areas are all increasing problems. Loss of genetic diversity is also occurring within the industry so the destinies of the wild and cultivated forms are closely interrelated.

The shiitake has been classified as a single species because there is reproductive compatibility among individuals from across the range, but both morphological and phylogenetic analyses suggest three or four distinct lineages may warrant species status. The geographical distributions of the morphologically and phylogenetically derived species are inconsistent, leading to an inevitable discussion about species concepts (see Hibbett & Donoghue 1996). However, whichever is used, the arguments for splitting are based on the importance of maintaining separately evolving lineages across the known range. In this case there are two distinct conservation-related issues.

(i) Is the (BSC-defined) species threatened, should it be listed under CITES and relevant regional and national legislation?
(ii) How could a conservation and management plan protect the significant range-wide variability and the genetic variability within and across that range?

By advocating four species reflecting the major phylogenetic lineages as being the only way to achieve within-species conservation, Hibbett & Donoghue (1996) confuse the two issues, and add to the inevitable taxonomic inflation that follows phylogenetic analysis in such cases.

If we could recognize the difference between units for listing and units for management, we could make progress on both fronts (legislation and listing, and effective *in situ* management) more easily.

4. WAYS FORWARD

Units for listing need to be consistent, change rarely and can be somewhat arbitrary. For political, scientific and other reasons the processes for developing and revising most of the significant conservation lists are complex and may take years to achieve. So their utility is undermined if the species they include are in a constant state of flux and turnover. Because of this various authors have criticized threatened and extinct species lists and questioned their value as monitoring and planning tools (Burgman 2002; Possingham *et al.* 2002; Balmford *et al.* 2003), but this problem lies largely with taxonomy, not with the assessment of threat or extinction (Lamoreux *et al.* 2003). If we could deal with this difficulty, the lists would provide useful information for planning and monitoring.

It is inevitable then that there will need to be some controls placed on the species included in these lists to ensure that they are relatively stable, consistent and explicit. This approach has already been developed by Helbig *et al.* (2002) who have published specific guidelines for the bird species that may be included on the BOU checklist, to maintain the stability of the list over time and to avoid confusion. There are two steps in their process. The first is a consideration of 'diagnosability'—whether one group of organisms can be distinguished from another. The guidelines of Helbig *et al.* (2002) define a taxon as diagnosable if at least one age/sex class can be distinguished by at least one qualitative difference (character), or if there is a complete discontinuity in at least one continuously variable character, or where discrimination can be achieved by statistical analysis of a combination of two or three (no more) functionally independent continuously varying characters. Second, once a taxon is shown to be diagnosably distinct according to these criteria, the determination of species rank follows from guidelines for each of the main categories of reproductive isolation: in sympatry, parapatry and hybrid zones, and allopatry. Helbig *et al.* (2002) argue that their system is clear and practical and will add to the value and credibility of the British List. As they state, the guidelines do not mean that there cannot be change, rather that changes are limited within the limits laid down by an explicit consideration of what entities the BOU wish their list to comprise. In their case, they aim for entities that are population lineages maintaining their integrity with respect to other lineages through time and space, and where it is reasonably certain that they will retain this integrity in the future.

The proposal made by Helbig *et al.* (2002) will face several difficulties. There will undoubtedly be problems raised with the implementation of this approach across the wide diversity of circumstances affecting character and range disjunctions, even among relatively well-studied organisms such as the birds. In addition, the adoption of specific criteria for this group may in fact add to the difficulties of comparisons between groups of organisms, though the reasons will at least be clear. Nevertheless it is a pragmatic approach which warrants further development and trialling.

The Helbig *et al.* (2002) system is designed for British birds and is not straightforward to generalize to other taxa and circumstances, but it provides a clear example of a practical approach from which more general principles could develop. Inevitably, the rules are somewhat arbitrary. Any more general system that will be developed seems likely to share this degree of arbitrariness, and is also likely to be based more firmly within BSCs than PSCs (Agapow *et al.* 2004). For conservation listing, the PSCs pose a series of fundamental problems, which may be overcome once phylogenetic knowledge is sufficiently complete that we can use phylogenies rather than arbitrary break points in the trees. But with our present state of knowledge it seems likely that we will make more progress with BSCs (Mace *et al.* 2003; Agapow *et al.* 2004). There are of course some intractable problems (e.g. related to widely dispersed but similar forms, hybrids, asexual species, etc.), but it is important to realize that these result from the real nature of species—they are not distinct entities, and any attempt to force them into an explicit structure will inevitably lead to contradictions. However, this is not a new problem for biologists or for society. In other areas of common endeavour we accept the need to divide graded or stepped, but continuous variation caused by incompletely understood processes, into distinct entities for the purposes of management. Examples are numerous: public examinations of the performance of school students; systems for determining extreme weather alerts, or publicized ranks reflecting the likelihood of extreme natural disasters (hurricanes, volcanoes, etc.) are all widely accepted, and do not undermine more sophisticated attempts at management once grading is completed. For the sake of having lists of species that are informative and useful, conservationists will need to adopt a pragmatic taxonomy and live with some of its biological inconsistencies.

The situation is very different in the case of the units to be targets for conservation action. Here, it is essential that the rules are not arbitrary or fixed. Instead the units need to be designed for the particular circumstances that pertain, they need to be able to change as the environment, the threats and the populations themselves change. The challenge here is to break the assumed link between the entities that are listed in conservation plans and those that need to benefit from direct conservation actions.

Resolving these two issues is going to be a challenge on several different fronts and will require a new kind of collaboration between taxonomists, conservation biologists and environmental planners and legislators. As a minimum, all the following steps will need to be accomplished before progress can be made.

(i) Lists of species should be designed, the units defined and the criteria for inclusion agreed with a specific role in mind. Many problems have arisen because a list developed for one purpose is applied to another problem (The Royal Society 2003). For example, adopting global lists of threatened species lists directly into national legislation, or placing such species automatically under protection in reserves or trade bans does not necessarily benefit them, and can be detrimental. As a specific example many countries, and some sub-national units, have straightforwardly adopted the IUCN red listed species into their legislation. But this can be inappropriate in several ways. First, the criteria in the IUCN list are specifically designed to identify the species that are most endangered at a global level. The thresholds for inclusion may therefore be too restrictive to pick up some species that need local protection. Alternatively, local circumstances may mean that listing a globally threatened species has negative conservation outcomes if its protection or local values are compromised as a result. Planners and legislators need to appreciate that there are many dimensions to threat and to protection.

(ii) The shortage of taxonomists is causing biases and under-representations in species lists compiled for monitoring and planning purposes. The needs are particularly critical in understudied habitats (e.g. marine; Mikkelsen & Cracraft 2001), invertebrates (Gaston & May 1992; Hopkins & Freckleton 2002), marine invertebrates (Dayton 2003), tropical flora (Knapp 2002) and in the developing world (The Royal Society 2003). A strong heritage of taxonomic expertise with shared standards and skills is essential to support conservation activities of all kinds (Valdecases & Camacho 2003).

(iii) Taxonomists and conservationists need to work together to design some explicit rules to delimit the units included as species for the purposes of conservation planning and assessment. The extent to which the two groups can continue to work together to implement these rules is debatable. The credibility and consistency of species units will be greater if they are determined by experts independent of those with particular interests in the outcome of the assessment of taxonomic boundaries.

(iv) Once a species is listed, and conservation resources are available to it, the intermediate stage of recovery planning should be used to develop appropriate strategies and tactics that apply to the circumstances at hand. There are unlikely to be many general rules here, though there are many general principles that will apply. Conservationists and evolutionary biologists need to work together to provide general guidance for this planning phase (Desmet *et al.* 2002; Moritz 2002).

(v) Legislators and politicians need to be educated about the difference between the units of monitoring and the units for conservation action. Although listing may determine that a recovery plan is needed for a species, it will not necessarily follow that all subunits of that species will require protection of the same kind. Nor will it be only subunits of listed species that require conservation actions. The lists compiled by conservationists are only part of the set of tools that regional planners will need to effectively conserve natural systems within a particular domain.

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REFERENCES

Agapow, P.-M., Bininda-Emonds, O. R. P., Crandall, K. A., Gittleman, J. L., Mace, G. M., Marshall, J. C. & Purvis, A. 2004 The impact of species concept on biodiversity studies. *Q. Rev. Biol.* **79**, 161–179.

Baillie, J. E. M. & Groombridge, B. 1996 *The 1996 IUCN red list of threatened animals*. Gland, Switzerland: International Union for the Conservation of Nature and Natural Resources.

Balmford, A., Gaston, K. J., Rodrigues, A. S. L. & James, A. 2000 Integrating costs of conservation into international priority-setting. *Conserv. Biol.* **14**, 597–605.

Balmford, A., Green, R. E. & Jenkins, M. D. 2003 Measuring the changing state of nature. *Trends Ecol. Evol.* **18**, 326–330.

Bearder, S. K. 1999 Physical and social diversity among nocturnal primates: a new view based on long term research. *Primates* **40**, 267–282.

Bibby, C. J. 1998 Selecting areas for conservation. In *Conservation science and action* (ed. W. J. Sutherland), pp. 176–201. Oxford: Blackwell Science.

Burgman, M. A. 2002 Are listed threatened plant species actually at risk? *Aust. J. Bot.* **50**, 1–13.

Caughley, G. 1994 Directions in conservation biology. *J. Anim. Ecol.* **63**, 215–244.

Collar, N. J. 1997 Taxonomy and conservation: chicken and egg. *Bull. Br. Ornithol. Club* **117**, 122–136.

Corbet, G. B. & Hill, J. E. 1991 *A world list of mammalian species*. London: Natural History Museum Publications.

Cracraft, J., Feinstein, J., Vaughn, J. & Helm-Bychowski, K. 1998 Sorting out tigers (*Panthera tigris*): mitochondrial sequences, nuclear inserts, systematics, and conservation genetics. *Anim. Conserv.* **1**, 139–150.

Crandall, K. A., Bininda-Emonds, O. R. P., Mace, G. M. & Wayne, R. K. 2000 Considering evolutionary processes in conservation biology. *Trends Ecol. Evol.* **15**, 290–295.

Dayton, P. K. 2003 The importance of the natural sciences to conservation. *Am. Nat.* **162**, 1–13.

Desmet, P. G., Cowling, R. M., Ellis, A. G. & Pressey, R. L. 2002 Integrating biosystematic data into conservation planning: perspectives from Southern Africa's Succulent Karoo. *System. Biol.* **51**, 317–330.

Eggert, L. S., Rasner, C. A. & Woodruff, D. S. 2002 The evolution and phylogeography of the African elephant inferred from mitochondrial DNA sequence and nuclear microsatellite markers. *Proc. R. Soc. Lond.* B **269**, 1993–2006. (DOI 10.1098/rspb.2002.2070.)

Fraser, D. J. & Bernatchez, L. 2001 Adaptive evolutionary conservation: towards a unified concept for defining conservation units. *Molec. Ecol.* **10**, 2741–2752.

Gardenfors, U., Hilton-Taylor, C., Mace, G. M. & Rodriguez, J. P. 2001 The application of IUCN Red List criteria at regional levels. *Conserv. Biol.* **15**, 1206–1212.

Gaston, K. J. & May, R. M. 1992 Taxonomy of taxonomists. *Nature* **356**, 281.

Groombridge, B. & Jenkins, M. D. 2002 *World atlas of biodiversity: Earth's living resources in the 21st century*. University of California Press.

Groves, C. P. *2001 Primate taxonomy*. Smithsonian Series in Comparative Evolutionary Biology. Washington, DC: Smithsonian Institution Press.

Helbig, A. J., Knox, A. G., Parkin, D. T., Sangster, G. & Collinson, N. 2002 Guidelines for assigning species rank. *Ibis* **144**, 518–525.

Hey, J. 2000 *Genes, categories and species: the evolutionary and cognitive causes of the species problem*. Oxford University Press.

Hey, J. 2001 The mind of the species problem. *Trends Ecol. Evol.* **16**, 326–329.

Hey, J., Waples, R. S., Arnold, M. L., Butlin, R. K. & Harrison, R. G. 2003 Understanding and confronting species uncertainty in biology and conservation. *Trends Ecol. Evol.* **18**, 597–603.

Hibbett, D. S. & Donoghue, M. J. 1996 Implications of phylogenetic studies for conservation of genetic diversity in shiitake mushrooms. *Conserv. Biol.* **10**, 1321–1327.

Hilton-Taylor, C. (ed.) 2000 *2000 IUCN Red List of threatened species*. Gland, Switzerland: IUCN.

Honacki, J. H., Kinmam, K. E. & Koeppl, J. W. (eds) 1982 *Mammal species of the World: a taxonomic and geographic reference*. Lawrence, KS: Allen Press, Inc. and Association of Systematic Collections.

Hopkins, G. W. & Freckleton, R. P. 2002 Declines in the numbers of amateur and professional taxonomists: implications for conservation. *Anim. Conserv.* **5**, 245–249.

Horvath, C. D. 1997 Discussion. Phylogenetic species concept: pluralism, monism, and history. *Biol. Phil.* **12**, 225–232.

Houlahan, J. E., Findlay, C. S., Schmidt, B. R., Meyer, A. H. & Kuzmin, S. L. 2000 Quantitative evidence for global amphibian population declines. *Nature* **404**, 752–755.

House of Lords 2002 *What on Earth? The threat to the science underpinning biodiversity conservation*. London: Select Committee on Science and Technology.

ICBP 1992 *Putting biodiversity on the map: priority areas for conservation*. Cambridge: International Council for Bird Preservation.

Jackson, J. B. C. (and 17 others) 2001 Historical overfishing and the collapse of coastal ecosystems. *Science* **293**, 629–638.

Karl, S. A. & Bowen, B. W. 1999 Evolutionary significant units versus geopolitical taxonomy: molecular systematics of an endangered sea turtle (genus *Chelonia*). *Conserv. Biol.* **13**, 990–999.

Knapp, S. 2002 Assessing patterns of plant endemism in neotropical uplands. *Bot. Rev.* **68**, 22–37.

Kremen, C., Niles, J. O., Dalton, M. G., Daily, G. C., Ehrlich, P. R., Fay, P. J., Grewal, D. & Guillery, R. P. 2000 Economic incentives for rain forest conservation across scales. *Science* **288**, 1828–1831.

Lamoreux, J. (and 15 others) 2003 Value of the IUCN Red List. *Trends Ecol. Evol.* **18**, 214–215.

Mace, G. M., Gittleman, J. L. & Purvis, A. 2003 Preserving the Tree of Life. *Science* **300**, 1707–1709.

Mallet, J. 2001 Species, concepts of. In *Encyclopaedia of biodiversity*, vol. 5 (ed. S. A. Levin), pp. 427–440. London: Academic.

Margules, C. R. & Pressey, R. L. 2000 Systematic conservation planning. *Nature* **405**, 243–253.

Meijaard, E. & Nijman, V. 2003 Primate hotspots on Borneo: predictive value for general biodiversity and the effects of taxonomy. *Conserv. Biol.* **17**, 725–732.

Mikkelsen, P. M. & Cracraft, J. 2001 Marine biodiversity and the need for systematic inventories. *Bull. Mar. Sci.* **69**, 525–534.

Moritz, C. 1994 Defining 'evolutionarily significant units' for conservation. *Trends Ecol. Evol.* **9**, 373–375.

Moritz, C. 2002 Strategies to protect biological diversity and the evolutionary processes that sustain it. *System. Biol.* **51**, 238–254.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B. & Kent, J. 2000 Biodiversity hotspots for conservation priorities. *Nature* **403**, 853–858.

Nic Lughadha, E. 2004 Towards a working list of all known plant species. *Phil. Trans. R. Soc. Lond.* B **359**, 681–687. (DOI 10.1098/rstb.2003.1446.)

NRC 1995 *Understanding marine biodiversity*. Washington, DC: National Academy Press.

Olson, D. M. (and 17 others) 2001 Terrrestrial ecoregions of the world: a new map of life on earth. *BioScience* **51**, 933–938.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. & Torres Jr, F. 1998 Fishing down marine food webs. *Science* **279**, 860–863.

Pearman, P. B. 2001 Conservation value of independently evolving units: sacred cow or testable hypothesis? *Conserv. Biol.* **15**, 780–783.

Possingham, H. P., Andelman, S. J., Burgman, M. A., Medellín, R. A., Master, L. L. & Keith, D. A. 2002 Limits to the use of threatened species lists. *Trends Ecol. Evol.* **17**, 503–507.

Redford, K. H. (and 13 others) 2003 Mapping the conservation landscape. *Conserv. Biol.* **17**, 116–131.

Roca, A. L., Georgiadis, N., Pecon-Slattery, J. & O'Brien, S. J. 2001 Genetic evidence for two species of elephant in Africa. *Science* **293**, 1473–1477.

Rojas, M. 1992 The species problem and conservation: what are we protecting? *Conserv. Biol.* **6**, 170–178.

Rowe, N. 1996 *Pictoral guide to the living primates*. New York: Pogonias Press.

Ryder, O. A. 1986 Species conservation and systematics: the dilemma of subspecies. *Trends Ecol. Evol.* **1**, 9–10.

Samper, C. 2004 Taxonomy and environmental policy. *Phil. Trans. R. Soc. Lond.* B **359**, 721–728. (DOI 10.1098/rstb.2004.1476.)

Sites, J. W. & Crandall, K. A. 1997 Testing species boundaries in biodiversity studies. *Conserv. Biol.* **11**, 1289–1297.

Sites, J. W. & Marshall, J. C. 2003 Delimiting species: a Renaissance issue in systematic biology. *Trends Ecol. Evol.* **18**, 462–470.

Stein, B. A. (ed.) 2000 *Precious heritage: the status of biodiversity in the United States*. Oxford University Press.

Taylor, A. B. & Groves, C. P. 2003 Patterns of mandibular variation in *Pan* and *Gorilla* and implications for African ape taxonomy. *J. Hum. Evol.* **44**, 529–561.
Tear, T. H., Scott, J. M., Hayward, P. H. & Griggith, B. 1993 Status and prospects for success of the Endangered Species Act: a look at recovery plans. *Science* **262**, 976–977.
Tear, T. H., Scott, J. M., Hayward, P. H. & Griffith, B. 1995 Recovery plans and the endangered-species-act—are criticisms supported by data. *Conserv. Biol.* **9**, 182–195.
Templeton, A. R. 1989 The meaning of species and speciation: a genetic perspective. In *Speciation and its consequences* (ed. D. Otte & J. A. Endler), pp. 3–27. Sunderland, MA: Sinauer.
The Royal Society 2003 *Measuring biodiversity for conservation*, p. 56. London: The Royal Society.
Valdecasas, A. G. & Camacho, A. I. 2003 Conservation to the rescue of taxonomy. *Biodiversity Conserv.* **12**, 1113–1117.
Vogler, A. P. & DeSalle, R. 1994 Diagnosing units of conservation management. *Conserv. Biol.* **8**, 354–363.
Walsh, P. D. 2000 Sample size for the diagnosis of conservation units. *Conserv. Biol.* **14**, 1533–1537.
Waples, R. S. 1991 Pacific salmon, *Onchorhynchus* sp. and the definition of species under the Endangered Species Act. *Mar. Fisheries Rev.* **53**, 11–22.
Waples, R. S. 1995 Evolutionarily significant units and the conservation of biodiversity under the Endangered Species Act. *Mar. Fisheries Soc. Symp.* **17**, 8–27.
Wheeler, Q. D. 2004 Taxonomic triage and the poverty of phylogeny. *Phil. Trans. R. Soc. Lond.* B **359**, 571–583. (DOI 10.1098/rstb.2003.1452.)
Wilson, D. E. & Reeder, D. M. (eds) 1993 *Mammal species of the world: a taxonomic and geographic reference*. Washington, DC: Smithsonian Institution Press.
Wolfheim, J. H. 1983 *Primates of the world: distribution, abundance and conservation*. Seattle, WA: University of Washington.

GLOSSARY

BOU: British Ornithologists' Union
BSC: biological species concept
CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora
ESU: evolutionarily significant unit
IUCN: World Conservation Union
PSC: phylogenetic species concept