BIODIVERSITY

A standard for species

Delimitation of species is especially taxing when populations of similar organisms occupy non-overlapping geographical ranges. A new quantitative framework offers a consistent approach for tackling the problem.

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In *The Diversity of Life*[1], E. O. Wilson memorably anoints the species as the "fundamental unit", the "grail of systematic biology", which, "though nicked and tarnished, is in our possession". Now, in a remarkable paper published in *Ibis*, Tobias *et al.*[2] aim to add lustre to the species unit by introducing practical guidelines for species delimitation.

Species have a central role in many branches of science, policy and practice: fields as diverse as agriculture, forestry, fisheries, pest management, forensics, drug discovery, macroecology and conservation depend on the accuracy and stability of species limits. Yet, over recent decades, this accuracy and stability has been eroded, deepening the nicks and tarnishes noted by Wilson. The problem is most acute where populations of similar organisms are widely separated, because some degree of divergence in genes or appearance is then likely but no test of interbreeding is available. Different biologists take different views as to what level of divergence between isolated populations constitutes a species. Worse, the trend has been towards recognition of progressively smaller levels of differentiation as evidence of species status. Just as monetary inflation can devalue a currency, this taxonomic inflation[3] can erode the usefulness of the species as a robust measure of the diversity of life.

In their paper, Tobias *et al.*[2] step beyond arguments over species concepts by standardizing criteria for distinguishing between subspecies and full species, especially to prevent trivial distinctions between populations from driving taxonomic inflation. Their proposal is to use the degree of differentiation between closely related bird species living in the same places without interbreeding (an accepted 'gold standard' for recognition as separate species) as a yardstick to determine species status between those living apart.

The idea itself is not novel — indeed, it has been central to taxonomy for a century or more[4]. Rather, Tobias and colleagues' innovation is to establish a rigorous, quantitative framework for comparing diverse phenotypic traits spanning morphology, pattern and colour, vocalization and behaviour. They calibrate thresholds for their proposed system using 58 species pairs from 29 families of birds. Testing these thresholds reveals that their yardstick agrees with the current classification of all but two of 23 pairs of geographically separated populations of well-known European birds considered to be the same species. However, the priority regions for comprehensive application of the authors' framework must surely be in the tropics (Fig. 1), where previous versions of the same criteria have revealed many more isolated populations deserving species status[5].

It is exciting to consider how Tobias and colleagues' method might be applied beyond birds. A strength of the method is that, given access to the organisms in the field and the museum, it can be implemented with minimal technology. In some cases — for example, in frogs and toads, cicadas or some mammals — the same phenotypic categories as used for birds could probably be applied. But with regard to birds, appearance and sound are very important; few other organisms are as easy to see and hear, at least for the human observer. Operational frameworks and thresholds would presumably need to be revised and recalibrated for different branches of the tree of life, incorporating phenotypic characteristics, such as teeth, genitalia or pheromones, that serve as proxies for reproductive isolation and ecological differentiation in other groups. This may well require modifications of the approach to incorporate distinctions in shape and in qualitative (non-continuous) and meristic (countable) morphological traits, but this should not be insurmountable.

Today, phylogenetic analysis of DNA sequence data is usually considered the most powerful tool in systematic biology. Tobias *et al.* note, however, that DNA analysis requires technology that is still beyond the reach of many taxonomists, and that DNA data remain scarce for many tropical organisms. They also point out that considering independently evolving traits across the phenotypic spectrum can yield a more incisive view of genomic differentiation than can analysis of relatively few mitochondrial- or nuclear-DNA coding regions, for example.

Still, for the framework to stand the test of time, the next step must be to accommodate genomic information, such as differences in chromosomal organization[6] and divergences across genomic loci that have multiple modes of inheritance[7], which have produced dramatic advances in studies of speciation. This will be especially crucial in groups that are morphologically conservative, and ever more so as the rapid evolution of sequencing technology makes genomic-scale data available faster and at lessening cost[8], even from degraded sources such as museum skins and bones[9]. Indeed, phenotypic and genomic information could be extracted from the same museum specimens, complementing field collection of vocalizations and ecological data.

Even with comprehensive

Figure 1 | Diversity delimited. The laughingthrushes, illustrated by H. Burn in the *Handbook of the Birds of the World*[11], encompass a great diversity of closely related forms living in different parts of Asia. Tobias and colleagues' framework[2] promises to shed light on species limits in such situations.

application of a consistent quantitative framework for species delimitation, numbers of known species will continue to grow — indisputably distinct species continue to be discovered at a remarkable rate, even in well-studied groups of organisms[10]. Indeed, the taxonomic challenge across most of the tree of life is not so much where to draw the line between species and subspecies, as it is in birds. Rather, it is that many, maybe most, species remain unnamed and undocumented, with too few hands on deck to help with this pressing task[1]. Nevertheless, consistent species delimitation within the best-known taxonomic groups will surely help to bring into focus patterns that may apply more broadly across the tree of life. We suspect that this approach[2] stands to ignite an operational revolution in taxonomy, tantamount to re-polishing the grail of the species as the fundamental unit of biology. ■

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NANOSCIENCE

Dark–hot resonances

The resonant behaviour of clusters of gold nanoparticles has been tuned by gradually bringing the particles together. The approach could have many applications, including chemical and biological sensing.

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Resonances are ubiquitous natural phenomena that occur on all spatial scales — from the largest distances in the Universe to the tiniest dimensions of elementary particles. They have great significance in both fundamental science and practical applications. Writing in *Nano Letters*, Hentschel *et al.*[1] describe the ability to switch a special type of resonance, termed Fano resonance[2], on and off in spectra of assemblies of nanometre-sized gold particles.

A resonant system, generically called an oscillator, undergoes an oscillatory motion that repeats in time with a certain frequency (or, correspondingly, period). When subjected to a periodically oscillating external force of nearly the same frequency as its own, an oscillator experiences resonance: with each new period, the oscillator gains some energy from the external force, which acts in unison with the oscillator's motion, and the amplitude of the motion increases. In atoms and molecules subjected to electromagnetic fields, resonances show up in spectra as narrow peaks of absorption, emission or scattering. (Other types of resonance exist that are caused by interactions with magnetic, nuclear and gravitational fields.) In certain cases of optical excitation, in which two quantum paths lead to the same final quantum state of the system, the resonance peaks have specific asymmetrical line shapes due to the interference of the paths' quantum amplitudes. Such resonances were first described by Ugo Fano in 1935 and are now widely called Fano resonances.

In the optical region of the electromagnetic spectrum, the strongest resonances are caused by surface plasmons — collective oscillations of electrons in nanometre-scale metallic systems (nanoparticles). When they interact with light, surface plasmons lead to highly enhanced, nanolocalized optical fields ('hot spots')[3] at the systems' metallic surfaces. Such nanoplasmonic resonances form the foundation for many of the remarkable applications of the rapidly developing field of plasmonics[4].

If the size of plasmonic nanoparticles — those composed of highly conducting metals — approaches or exceeds several tens of nanometres, they scatter light strongly. This is a beautiful phenomenon, and can be witnessed when sunlight obliquely strikes glass windows in churches and cathedrals (Fig. 1) — presumably, these contain gold, silver and copper nanoparticles. However, such light scattering causes broadening and dulling of the nanoplasmonic resonances, making them less significant in fundamental science and less suitable for applications. It would therefore be useful to use smaller nanoparticles, which do not suffer from such a drawback. But it is difficult to fabricate, assemble and tune them to specifications.

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Figure 1 | The magnificent glass window of La Sainte Chapelle in Paris. The window's deep yellow and red colours (bottom) — seen on exposure to oblique sunlight — are probably caused by the scattering of light from silver, gold and copper nanoparticles.