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HOW TO CONDUCT LARGE-SCALE TAXONOMIC REVISIONS IN FORMICIDAE

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ABSTRACT

An essay is presented that illustrates the author's personal system, developed and expanded over many years, for the production of taxonomic revisionary work in Formicidae starting from first principles. It indicates what revisionary taxonomy means, stresses the main points essential to good taxonomic procedure, indicates the snares and pitfalls that may be encountered when conducting such work, and shows how to avoid commonly committed errors. Emphasis is laid on features such as general procedure, production of good keys, gradual accumulation of relevant data and proper layout and reproducibility of results in all stages of the work from initiation to final publication.

Key words: Hymenoptera, Formicidae, taxonomy, revisions, methodology.

INTRODUCTION

The purpose of this contribution is to outline a functional procedure for the production of large-scale taxonomic revisions in the ants. The term "large-scale" is of course subjective and open to various interpretations. For instance, a student undertaking his or her first attempt at such a project may consider 5 - 6 species to be quite a major undertaking, whereas an experienced student would pitch the number of taxa involved considerably higher. Some would not consider the task to be large-scale if under 50 species were involved. So the methodology outlined here must satisfy all the conditions necessary to carry out a revisionary survey where more than a mere two or three taxa are involved.

What follows is written in the form of an essay, rather than a formal publication. The main reason for adopting this procedure is that its various sections attempt to point out good techniques but also to illustrate poor methodology together with errors of omission and commission. The sections of the essay are written in a sequence which implies a smoothly continuous process from first considerations to completion of the task. In reality, of course, things never go that regularly or that smoothly. Factors over which the researcher has no control mean that the treatment of some taxa will progress at a different rate from that of others. For instance, some institutions will respond to requests for loans much more quickly than others, some journals may be difficult to obtain, and resolving the taxonomy of some species will always be more difficult than others. There is no quick cure for these complaints, but if the taxonomic work is structured as laid out here they should not impede the overall progress of the study. Each problem, as it is resolved, can be slotted into its appropriate place in the sequence without causing disruption to the work as a whole.

Finally, because this is a personal system, presented as an informal essay rather than a standard scientific publication, there are no formal references given in the text. In part this is to save the blushes of good taxonomists who make the odd mistake (we have all done it) who would thus find themselves thrown into the company of serial incompetents. This is not to say that the work exists in a vacuum; much of the basis of the taxonomic work discussed below can be found in: Mayr, E. and Ashlock, P.D. 1991. *Principles of Systematic Zoology* (second edition): 475 pp. McGraw-Hill.

The aims of this essay

What I hope to set out and explain is a methodology for conducting a taxonomic study or revision; in particular:

i how to set about studying numbers of related species, some of which are probably or certainly already described and some of which are probably or certainly undescribed, and the establishment of the unique identity of each,

ii how to build up a formal taxonomic study or revision of a given group, regardless of its size or rank,

iii how to present the findings in such a way that others can understand the taxonomy and use it to identify their own specimens.

What the essay is not concerned with is piecemeal alpha-taxonomy. Taxonomy of this nature is basically concerned with the detection, discrimination, description and publication of isolated new taxa (species, genera, etc.). Each taxon is known or assumed to be new to science and is known or assumed to be undescribed. The author therefore issues a description and names the taxon. This may be described as the "one by one" technique and is usually acceptable in groups that are very well known (birds, primates, butterflies), but in most insect groups the numbers of undescribed species are vast and this "one by one" technique only serves to increase bafflement and frustration among those wishing to identify taxa; and this applies to other taxonomists as well as non-taxonomic biologists.

The main problem with the "one by one" approach is that anyone faced with the task of identifying a species is confronted by numerous descriptions of single species with no way of knowing where to begin. The specimen must be compared with each description in turn, in the hope that eventually a match will be found. This is an incredibly frustrating and extremely time-consuming exercise. The frustration is often compounded because exponents of the "one by one" technique frequently fail to draw attention to uniquely diagnostic characters and fail to provide any notes by which the new species may be compared with those that are already known. There are even cases where piecemeal alpha-taxonomic authors have described new species in well known genera, where keys to species already exist, and have failed to indicate where the new species fit into the key or how they modify the pre-existing system. This is inexcusable: it is not just poor taxonomic procedure, it is bad scientific methodology.

Finally, there are people who, with the best will in the world, cannot fulfil the four factors listed below, try as they may. Their discriminatory faculties seem insufficient to cope with the huge numbers of characters available, or they are unable to sort or categorize the observed characters in any meaningful way. There are others who cynically disregard the basic factors in a rush to have their names associated with supposedly new taxa, as if such a trivial aim was important. Such people should avoid descriptive taxonomy and comparative morphology as their efforts, whether unfortunately inept or cynically divisive, only add to the problems rather than contribute to solutions.

Good taxonomy ultimately relies upon:

i the detection of unique characters that diagnose a taxon,
ii the comparison of characters that differentiate related taxa,
iii the recognition of characters that unite related taxa,
iv the description and ordering of those characters in such a way that each taxon can be recognized by other workers

In short: *the function of taxonomy is to establish identity.*

INITIATION PHASE OF THE PROJECT

Select a group to study

Choice of a study group may depend upon:

i economic importance,
ii value in biodiversity work,
iii understanding evolution,
iv fixing identities to investigate phylogeny,
v interpreting zoogeography,
vi interest in morphological adaptations,
vii establishing patterns of speciation,
viii forming a basis for ecological or ethological studies,
ix attempting to establish a natural classification,
x learning more about the inhabitants of the planet,
xi your supervisor says this is what you are going to do.

Depending on circumstances of time or funds available, and the degree of experience and determination of the researcher, the group selected for study may consist of a species group, a genus, a defined group of several genera, or a higher taxon such as a tribe or subfamily.

Ideally the area covered by a revision should encompass the entire range of the group in question, or at least the species of a group from an entire Zoogeographical Region if the group is of very wide distribution. However, political or financial considerations often restrict taxonomic surveys to a single country, usually the one providing the finances and facilities. The danger here is that instead of solving taxonomic problems a survey of a relatively small area, especially if the area is treated as isolated, may add confusion. There is a real risk of the unwitting creation of junior synonyms or homonyms because the researcher is insufficiently acquainted with the extralimital fauna. Thus, if circumstances dictate that a project has to be restricted to a relatively small area it is important that the researcher obtains a working knowledge of the entire group. It is useful to remember that insect species do not recognize red lines on political maps, despite the fact that bureaucrats tend to think they should.

Preliminaries

Once a group for study has been decided upon the next step is to acquire material so that work can commence. For most researchers a small to moderate collection will usually be available in the institution where the work is taking place. Additional material can be obtained from:

i museums and other state or local institutions,
ii private collections,
iii universities,
iv field collecting.

Collections held in categories i - iii can usually be borrowed through the mail but sometimes it is necessary to visit the appropriate institution. Material held in these collections sometimes includes types or other specimens of historical importance, and is always useful for obtaining data on distribution and variation of the species concerned. Always treat borrowed material with respect and return it in good condition within the terms of the loan agreement. When returning specimens through the mail always remember to pack them safely; protect the specimens against mechanical damage as most postal services are unaware that insects tend to be fragile.

Field collecting is the best way to obtain fresh specimens and to get to know the appearance and behaviour of the group in its natural habitat. Take time to discover the best method(s) for collecting, transporting and storing specimens of the group in question. If unaware of the techniques involved then consult with other people who have experience in the same or related fields and ask their opinion; they are usually very happy to advise. There are also some museum publications that deal with the acquisition and storage of entomological specimens. When fresh material is obtained always ensure that it is properly mounted and safely stored and has appropriate data labels. When collecting abroad, always ensure that the correct permission to do so has been obtained. Many countries now have strict regulations concerning the collecting of insects, especially the larger and showier groups, and they tend to become irate if their regulations are flouted.

Note that the acquisition of material and preliminary work on it precedes searching the literature for names, precedes amassing and reading vast photocopied files of original descriptions, and precedes the examination of type-material.

This approach is important because at this stage the critical aspect is to have a reasonable representation of the group from its entire range and to develop a personal insight into its morphology and variation that is not unduly influenced by what has previously been published.

Initial dependence on previous publications has a strong tendency to restrict the scope of a new investigation. There is real psychological pressure for the researcher to make an unwarranted

assumption that previous authors have already investigated all the useful characters. This is especially true in groups where there are many isolated descriptions of single species, carried out by multiple authors from several countries, over many years. In fact, what has usually happened in such cases is that an initial author has described, say, the first species in a genus. He has stressed certain characters that he considers most important, out of the enormous number available, merely because a description must have a finite length. A second author, a few years later, adds a couple more species to the genus. To contrast his species from the original he stresses differences from those characters cited by the first author, especially if he has not bothered to see the original author's type-specimens. The third worker in the chair then reads these two works. He either again concentrates on variation in the same characters, because he has no inkling of the state of characters that have not already been mentioned; or he inserts characters that have not been discussed previously, assuming that because they were not mentioned they were not present. You can see what is happening - the descriptions, despite becoming less trustworthy, are assuming more importance than the specimens they purport to represent. This procedure unfortunately becomes self-perpetuating and as it continues the descriptions become more and more trivial and have less and less value. As a corollary, as the number of supposedly different species, really just differing descriptions, increases, the ease with which a serious taxonomist can compare all the type-material decreases.

Contrary to what many seem to believe, the objective of a taxonomic revision is to establish the unique identities of the species involved and to transmit that information to a reader in a reasonably compact, concise manner. It is not, and should not be reduced to, a mere review of previous type-material with the express aim of finding new species that can be described.

The discovery and description of new species is incidental, it is not the prime objective of the exercise.

The first thing that needs to be achieved when commencing work on a group is a reasonable understanding of the limits of all the species that constitute the group, in a way that is not unduly influenced by the opinions of earlier workers. It is therefore best to leave the examination of the type-material of previously described species until a later stage, after a good understanding of the characters and relationships of all the species has been independently acquired.

All students of taxonomy should be acquainted with the *International Code of Zoological Nomenclature* (Fourth Edition, 1999) before embarking on a project. This volume sets out the rules and regulations that govern the naming of animal taxa. It should be born in mind that the rules of nomenclature are tools for ordering and understanding taxonomy and classification; nomenclature should not be regarded as an end in itself.

Before undertaking a taxonomic revision all students should become familiar with, and understand the function of, the type-concept in taxonomy, the rules governing synonymy and homonymy, and those governing the status and availability of names; these aspects are not discussed here.

Initiation of taxonomy

When a sufficient number of specimens of the target group has been accumulated, that is, when representatives of several apparently distinct forms with consistently differing morphological features have been amassed, the taxonomic investigation can begin. It is useful, initially, to adopt a null hypothesis.

Assume that all previous work has no value, and that determination labels on all specimens (except genuine type-material that happens to be at hand) are incorrect or are misidentifications.

This will certainly be untrue for a proportion of the already-named specimens, but is a good way to begin as it puts every specimen on the same philosophical level.

Get to know the group intimately; take time over it. Examine closely all the material that is available and compare and contrast individuals and groups of individuals. When a good overall knowledge of the group's morphology and variation has been acquired, and when the researcher is conversant with any specialized morphological terminology that the group may require, search for the following:

i unique characters that discriminate individual species,
ii characters that unite pairs or groups of species,
iii universal characters that encompass all species.

Polarity of these characters, that is whether they are plesiomorphic (ancestral) or apomorphic (derived) characters, is not important at this stage; what the characters are, and their presence or absence through the various species of the group, is the important feature as the aim is to establish unique identity, not phylogeny. If, later in the investigation, a phylogeny is to be constructed, the characters can quickly be reassessed for phylogenetic utility and fed into an appropriate data matrix.

As characters in groups i - ii are detected, arrange the specimens in collection drawers or good quality specimen boxes, so that individuals considered to belong to a single species are grouped together, and species that appear to be closely related because of shared characters are in proximity. Separate these from species or groups of species with different shared characters.

During this process, or when all the species are considered to be adequately segregated, give each a numerical or alphabetical recognition code; something simple like "species A", or "species 1". Do not worry about names at this stage, that will come later.

Also during this initial sorting of material take preliminary notes of the main characters of each taxon. Make a separate heading for each of the taxa, using the code-number or code-letter heading of each, and under it write down the critical characters so far discovered and which characters are also shared with other taxa. Add observations on variation, if any, and list the locality data of the material examined. For example:

Species A
Characters:
i) Antenna with 11 segments.
ii) Apical antennal segment with scale-like sensory hairs.
iii) Mandible with 5 teeth; third tooth from apex the longest.
iv) Second abdominal tergite smooth and shining everywhere.
v) Hind femur with spines present on dorsal surface.

Character comparisons:
i) also in sp. C and sp. E.
ii) and iii) also in sp. B.
iv) also in sp. C.
v) not in any other species.

Material examined
ENGLAND: Surrey, Kew Green, 12.x.1975, on oak tree trunk (*collector's name*); BELGIUM: 5 km east of Ronse, 23.v.1906, on soil at base of oak tree (*collector's name*); HOLLAND: Bunnk, near Utrecht, no further data.

Using those characters that have been found to unite some species and separate them from others, and those characters that are uniquely applicable to single species, and using the species codes as end-points, the first draft of an identification key can be constructed.

First draft key

The key is the most important part of the study. *It should be built up, developed and continually revised and updated as the study progresses, so that it acts as a continuing bench-mark for the progress of the work, and allows you and others to test the reproducibility of the results.*

At risk of boring because of repetition, I stress: key construction and modification should be a continuous process through the course of the study. The key should be modified and expanded as the work progresses and as more taxa and their characters are discovered or differentiated and added in. It is the most important part of the study, the part that reflects your hypotheses of what constitute species in the group. It is also the part of the work that allows your conclusions to be tested by others. Without an accurate key there is no easy way for any other worker to gain access to your species concepts. It should not be the last task undertaken. In some taxonomic works it is obvious that construction of the identification key has been the last act of the study. In other words, after the researcher has examined the material, made decisions about species differentiation and written all the descriptions, only then has the key been constructed, but from the descriptions and not from the actual specimens. The key is thus being treated as a mere adjunct of the descriptions, built with characters abstracted from the descriptive work and implying that the descriptions provide more information than the specimens from which they were derived.

There are many ways of constructing keys for identification purposes but the simplest to understand, and usually the most universally functional, is the dichotomous key. In this system the reader is presented with a series of pairs of alternatives, each of which leads either to a second pair of alternatives or an identification. Each pair of alternatives is called a couplet, and each half-couplet a lug. The specimen to be identified is compared with the character(s) listed in each lug of the first couplet, and the one which corresponds is followed through the remainder of the key.

Imagine that the "species A" mentioned above belongs in genus *Xus*, and let us say that after the preliminary work described above five species have been differentiated and are represented by the recognition codes "species A, B, C, D and E" respectively. Let us also say that these five can apparently be grouped and segregated by different expressions and combinations of the following characters: number of antennal segments, form of sensory hairs on the apical antennal segment, number of teeth on the mandible and their relative lengths, form of sculpture on the second abdominal tergite, and presence or absence of spines on the hind femur. A dichotomous key such as the following could be drawn up.

1 Antenna with 11 segments 2
- Antenna with 12 segments 4

2 Mandible with 5 teeth. Hind femur with spines present on dorsal surface ..... species A
- Mandible with 8 teeth. Hind femur without spines on dorsal surface 3

3 Second abdominal tergite smooth and shining. Counting from apex of mandible tooth 3 is longer than teeth 4 and 5 ..... species C
- Second abdominal tergite densely reticulate-punctate. Counting from apex of mandible tooth 4 is longer than teeth 3 and 5 ..... species E

4 Principal sensory hairs on apical antennal segment scale-like. Mandible with 5 teeth. Second abdominal tergite finely and densely longitudinally rugose ..... species B

Principal sensory hairs on apical antennal segment filiform. Mandible with 7 teeth. Second abdominal tergite transversely striate on basal half, smooth apically .....species D

Thus a specimen of *Xus* species E would track through the first lug of couplet 1 (which leads the reader to couplet 2), the second lug of couplet 2 (which leads to couplet 3), and the second lug of couplet 3, which gives the identity.

The sole function of a key is to allow taxa to be identified. It is concerned only with the establishment of identity and to allow the recognition of taxa based on an ordering of characters. It does not need to reflect classification or phylogeny, nor should it be a vehicle for reflecting the ability of the author to impress the reader.

A few guidelines for key construction:

i Chose obvious and clear-cut characters, especially for main couplets that segregate groups of species. Describe them accurately (illustrate if necessary). If any special condition, or a particular orientation or viewing angle, is necessary then note it in the couplet; do not leave the reader to guess.

ii Avoid hanging comparatives that are incomprehensible to a reader (*e.g.*, legs longer *versus* legs shorter; which begs the question "than what?"). Always give some indication of what the comparison means. For example by direct comparison with some other aspect of the same specimen (legs longer than head width *versus* legs shorter than head width), or use comparative measurements (legs > 1.5 times head width *versus* legs < 1.5 times head width), or use absolute measurements (legs 3.0 mm or more *versus* legs 2.0 mm or less).

iii Avoid purely subjective nonsense such as, " head more reddish *versus* head not so reddish"; "known from queens and workers *versus* known from workers alone". A reader cannot possibly interpret such statements unless all the author's original specimens are to hand, which is extremely unlikely. Experience teaches that even on the rare occasion when the specimens are all available the task frequently remains impossible.

iv Ensure that lugs of couplets contrast directly. A couplet such as "legs red *versus* thorax black", is an absurdity as the two lugs are not directly comparable.

v Avoid the "not as above" lug. This involves a couplet that gives many characters, or even a short description, in the first lug but merely says in the second lug "not as above", or "characters otherwise", or words to that effect. Such couplets are incredibly frustrating as the second lug is not transmitting any useful information. It leaves the reader in limbo, with no direct alternatives between the two lugs to which the specimen under examination can be compared.

Culmination of initial phase

By this stage the following results have been achieved:

i all the available material has undergone a careful sorting to species and the species have been allocated recognition codes,

ii characters diagnostic of the species have been noted under corresponding coded headings,

iii characters that unite groups of species, or that isolate groups of species, have been noted,

iv a first-draft key, using the species-codes as end-points and the characters detected, has been constructed.

INTERMEDIATE PHASE OF THE PROJECT

Consultation of literature

It now becomes necessary to search out and consult earlier literature on the group. The function of the literature search at this stage is:

i to build up a complete list of previously established names,
ii to obtain the references that give the original descriptions of the names,
iii to establish what the type-material consists of and where it is deposited,
iv to discover the type-locality of each nominal taxon,
v to establish the current status of the name by reference to usage in the literature, between its original description and the present.

All these data will be used later in the construction of the taxonomic synopsis of each species, discussed below. Sometimes there is a recent check-list available for the group in question, or even a full catalogue, which is better as it usually provides much more information than a check-list. Either of these will provide a compendium of the required names and the latter will also give the essential references in full. Sometimes however it is necessary to consult abstracting journals such as *Zoological Record* or on-line compendia and go through them searching for appropriate entries of original descriptions or later references involving names in the group. If a check-list or catalogue is available ensure that the abstracting journals are checked from the catalogue's date of publication to the present, to catch any contributions published after the appearance of the catalogue. As references are found, look them up in the library or reprint collection, or search for them on-line; photocopy them if necessary. Be aware of the Inter-Library loan system, which can be extremely valuable in obtaining copies of more obscure publications. If the authors of any previous contributions are still alive, write and ask if a reprint or photocopy of the publication is still available. Most authors are happy to distribute free copies of their papers to enthusiastic researchers.

The species in these publications will of course bear names, and these names will not correspond to your species-codes at this time, nor do they need to. Open a separate entry or file for each published name, regardless of its current status or rank. Under each name, as it is tracked down, note the taxonomic name, author and bibliographical reference, what the type-material is and how much there is of it, the type-locality and any other relevant data that are given, the name of the collector and the institute in which the type-material is deposited. Also note any data concerning material examined but excluded from the type-series and other comments (if any). Build up the data thus obtained into a taxon file and a references file.

The relevant data for some species of our imaginary genus *Xus (Xus aus, Xus bus, Xus cus* and *Xus dus)*, together with their equally imaginary authors and other information, would appear as follows.

TAXON FILE

Xus aus Green
Xus aus Green, 1883: 207, fig. 1. Holotype queen, FRANCE: near Paris, 15.vi.1880, under stone (*M. Brun*) (Paris Museum).

Xus bus Green
Xus bus Green, 1885: 12. Syntype workers, BELGIUM: near French border, ix.1884, on tree trunk (*U. Blanc*) (Paris Museum). [Junior synonym of *aus*: Blanc, 1890: 31 (Blanc maintains that queen *aus* and worker *bus* belong to same species).]

Xus cus (Schwarz)

Gus cus Schwarz, 1888: 89. Syntype workers, GERMANY: no accurate locality given, 1886, swept from plants (*H. Grün*) (Berlin Museum).
Xus cus (Schwarz); Blanc, 1890: 35 [combination in genus *Xus*].

Xus dus Blanc
Xus dus Blanc, 1890: 33, figs 1 - 4. Syntype workers, queens and males, FRANCE: near Belgian border, 21.ix.1885 (*U. Blanc*) (Paris Museum and Brussels Museum).

Note that proper names of species are always written in *italics*, and that the initial letter of the genus-rank name only is a CAPITAL. Note also the brackets (parentheses) round the author's name in the case of *Xus cus* (Schwarz). These indicate that the species name has been transferred away from the genus name with which it was originally combined (*Gus*) because a later author, in this case Blanc, has judged that the name *cus* is properly ascribed to genus *Xus*, not genus *Gus*. Thus in the original combination *Gus cus* Schwarz, the author's name is not in brackets; in the changed combination *Xus cus* (Schwarz) it is. This is the only circumstance in which brackets are placed around the name of an author. Should the name *cus* revert to genus *Gus* at a later date (*i.e.* Blanc got it wrong) then the brackets will again disappear. Note also that species described from series of specimens at these relatively early dates usually leave them as a syntypic series, without nomination of a holotype. During revision of such series it may be necessary to nominate one specimen as a lectotype: see the appropriate sections of the *International Code of Zoological Nomenclature* (Fourth Edition, 1999) for the correct procedure.

It is preferable to include the complete data of the type-material for each taxon in these synopses; see the discussion of taxonomic synopses, below. Some authors include only the name and bibliographical reference here (for instance *Gus cus* Schwarz, 1888: 89), and relegate all the other information to other places in the text. I consider it important for any reader to have the full data that applies to the type-material immediately visible, not to have to go searching for it in several different places in the text or to have it mixed in with the list of other material that has been examined. This is especially important in species with extensive synonymies as it allows the reader access to all the relevant data pertaining to types and taxonomic history merely by running an eye down the list of entries.

At the same time that the above data are being amassed, open a references file (bibliography) and list all references found from which data have been abstracted. List them in alphabetical order by author and in publication date order for each author who has provided more than one contribution to the group. It is best practice to write out the name of the periodical, journal or book in full. In the past it was common for authors to present the names of periodicals in abbreviated form, but these days there are so many journals with very similar titles that full writing of their names is necessary to avoid confusion. As with our imaginary taxa, so the authors, dates, titles and journals mentioned here are also imaginary.

REFERENCES FILE

Blanc, U. 1890. *Xus bus* est un synonyme de *Xus aus*, et autres choses nouveaux. *Journal d'Entomologie Incroyable* **12**: 30-35.

Green, A. 1883. The genus *Xus* described for science. *Bulletin of Imaginary Taxonomy* **3**: 200-250.

Green, A. 1885. Yet another species of the genus *Xus* in the West Palaearctic region. *Bulletin of Imaginary Taxonomy* **5**: 1-18.

Schwarz, E. 1888. *Beschreibungen nicht-existierender Insekten Deutschlands*: 1000 pp. Berlin.

Examination of types

At this stage it is possible to begin replacing the species-codes in the key and the taxon file with genuine names. By reference to the data compiled in the taxon file, the various museums and other institutions where type-material is deposited can be contacted and loans of the appropriate specimens arranged. Or, if funds are available, the institution can be visited, which is usually pleasant and may even broaden the mind. When borrowing specimens always ensure that the loan conditions stated by the lending institution are complied with. Any specimen has considerable scientific value, as well as historical value, but in the case of type-material this is particularly true because:

It is the type-material that establishes and carries the name of the species; not its original description, not any later interpretation of the species, not any later opinion, not any later mention in the literature.

Treat materials borrowed from other institutions with great care because any specimen entrusted to you for study remains the property of its home institution and it must be retained in good condition for future researchers.

On receipt of a purported type-specimen it should immediately be checked against the taxon file and the original description, to ensure that it is genuine. This is important as sometimes material becomes mislabelled at some point in its history, or labels may have been inadvertently switched at some time in the past, or the original labels may have been misunderstood by a later curator so that the specimen has acquired a spurious type-status when it is not actually part of the original type-material. Its data label(s) should match the data noted for the specimen in the original description, and the specimen itself should fit the description. On occasion, and especially with older material, the data label(s) on the specimen may have information additional to that given in the original description. Additional data from the label should be added to the taxon file, but only provided the identity of the specimen is assured.

When a type-specimen has been confirmed as valid it should then be run through the already-prepared draft identification key. There are four possible results.

i The type-specimen runs directly to one of the species-codes in the draft key.

It can then be compared directly to specimens bearing that code in the study collection. If the type-specimen and coded collection material are judged identical and conspecific within the known limits of variation of the species then the code reference can be abandoned **throughout the manuscript** and replaced by the name.

For example, the type-material of *Xus cus* is found to run to species A of the draft key. The key end-point (at first lug of couplet 2) is changed to reflect this.

1 Antenna with 11 segments 2
- Antenna with 12 segments 4

2 Mandible with 5 teeth. Hind femur with spines present on dorsal surface ..... ***cus***
- Mandible with 8 teeth. Hind femur without spines on dorsal surface 3

3 Second abdominal tergite smooth and shining. Counting from apex of mandible tooth 3 is longer than teeth 4 and 5 ..... species C
- Second abdominal tergite densely reticulate ..... *etc*.

Also the file covering the taxon is changed from

Species A
Characters:
i) Antenna with 11 segments.
ii) Apical antennal segment with scale-like sensory hairs.
iii) Mandible with 5 teeth; third tooth from apex the longest....*etc*.

to

Xus cus (Schwarz)
Gus cus Schwarz, 1888: 89. Syntype workers, GERMANY: no accurate locality given, 1886, swept from plants (*H. Grün*) (Berlin Museum).
Xus cus (Schwarz); Blanc, 1890: 35 [combination in genus *Xus*].

Characters:
i) Antenna with 11 segments.
ii) Apical antennal segment with scale-like sensory hairs.
iii) Mandible with 5 teeth; third tooth from apex the longest....*etc*.
iv) The type-specimen fails to run to any keyed species code.

The key must therefore be modified to accommodate this extra taxon *and also a new taxon file must be created*. Write a new couplet and insert it at the appropriate place. Remember to adjust couplet numbers, and lead-on numbers at the ends of lugs, where necessary throughout the remainder of the key.

For example, the holotype of *Xus fus* has been obtained and fails to run to any terminal lug in the key because its diagnostic characters exclude it from all previously incorporated taxa. Let us say that *Xus fus* has 11 antennal segments and 8 teeth, which would bring it out in couplet 3 of the original key, but that its head is longer than broad and its second abdominal tergite is densely rugose, whereas the previous occupants of couplet 3 (species C and E) have heads that are broader than long and different abdominal sculpture. The key can be modified to accommodate the extra species by writing a new couplet 3 and making the original couplet 3 become couplet 4; but note how this affects couplet numbers throughout.

1 Antenna with 11 segments 2
- Antenna with 12 segments 5

2 Mandible with 5 teeth. Hind femur with spines present on dorsal surface ..... cus
- Mandible with 8 teeth. Hind femur without spines on dorsal surface 3

3 Head longer than broad. Second abdominal tergite densely rugose ..... fus
– Head broader than long. Second abdominal tergite smooth or reticulate-punctate, but not densely rugose 4

4 Second abdominal tergite smooth and shining. Counting from apex of mandible tooth 3 is longer than teeth 4 and 5 ..... species C
- Second abdominal tergite densely reticulate-punctate. Counting from apex of mandible tooth 4 is longer than teeth 3 and 5 ..... species E

5 Principal sensory hairs on apical antennal segment scale-like. Mandible with 5 teeth. Second abdominal tergite finely and densely longitudinally rugose ..... species B
- Principal sensory hairs on apical antennal segment filiform. Mandible with 7 teeth. Second abdominal tergite transversely striate on basal half, smooth apically ..... species D

It is not compulsory to add the new couplet where it is placed in the above example, although in this case it is reasonable because other characters of *Xus fus* seem to imply that it is closely related to species C and E (same antennal segment count, same teeth). But suppose that *fus* is the only species in the entire group which has the head longer than broad and that this feature is very obvious and unmistakable. It could therefore be justified to make *fus* run out first, as the subject of a new couplet 1.

1 Head four times longer than broad..... ***fus***
- Head two times broader than long 2

2 Antenna with 11 segments 3
- Antenna with 12 segments 5

Similarly, because it shares the same number of antennal segments with *Xus cus*, species C and species E, it could be inserted as a new couplet 2.

1 Antenna with 11 segments 2
- Antenna with 12 segments 5

2 Head four times longer than broad..... ***fus***
- Head two times broader than long 3

3 Mandible with 5 teeth. Hind femur with with spines present on dorsal surface ..... ***cus***
- Mandible with 8 teeth. Hind femur without spines on dorsal surface 4

4 Second abdominal tergite smooth and shining. Counting from apex of mandible tooth 3 is longer than teeth 4 and 5..... species C
- Second abdominal tergite densely reticulate-punctate. Counting from apex of mandible tooth 4 is longer than teeth 3 and 5 ..... species E

For best results always organize a key so that the characters used, and the order in which they are used, impart maximum clarity to the key and maximize the chance of a reader obtaining a correct identification.

iii The type-specimen terminates at a lug already occupied by a name, that name being in place as the result of keying in a previous type-specimen of a differently named taxon.

This event usually implies that synonymy, a situation in which a single taxon has been described more than once, and has therefore been invested with more than one name, may be present. However, it sometimes implies that further analysis may be required because two species really are present but they are distinguished by characters that have not previously been included in the analysis, so both of them will therefore run to the same end-point in the key.

Compare the type-specimens of the two nominal species directly and with any other material standing under the original name in the collection. Review all previously used characters and their variation (if any) and analyze for other discriminating characters, to ascertain if both type-specimens represent one species or if two species are really present. If, after this re-analysis, all the material is

judged to represent one species, then there is synonymy and the appropriate rules come into force because no single species is allowed to bear two different proper names. If two species can be discriminated after the re-analysis, insert a new couplet in the key (as in **ii**., above) that accommodates the new findings.

In the case of a confirmed synonymy combine the taxon files of both names under the senior name (the older, first-described name is senior except when it is a junior homonym in need of replacement). Replace the junior synonym (the younger, second-described name) with the senior synonym if the junior happens to appear anywhere in the text, except where it appears in the taxon file of the senior name, of course (see taxonomic synopses, below); and ensure that the correct name occupies the end-point of the appropriate lug in the key.

iv The result of running the type-specimen through the key is ambivalent.

Re-examine all taxa that are grouped around the point where the type-specimen fails in the key. Compare the type-specimen with all apparently related species and re-assess the validity of the species themselves. It may be necessary to re-analyze and re-order a group of species and find alternative characters, or it may be that the ambivalence is the result of previously unsuspected variation. After re-examination has been concluded re-run the results through the revised key and proceed through the above sections i, ii or iii again, if necessary.

When the study has reached this stage, or when convenient prior to this stage, enquiries should be made to institutions and other entomologists that have not previously been approached, to ascertain if any more material of the group under study is available. If the response is positive then ask to examine it, by loan or visit. This will ensure that the study will have the maximum representation of species and reasonable numbers of specimens of each species, and will furnish extra information on variation and distribution. Any extra material acquired should be sorted and run through the key. If previously unseen species are represented then new taxon files can be created and new couplets inserted in the key. It is very useful to obtain some previously unseen material at this time and feed it into the revision as it provides a test of the efficiency of the key and gives valuable information about the validity of the characters used and the stability of the taxonomic conclusions that have been postulated.

Finalizing the key

When the type-material of all previously described taxa has been keyed successfully then those lugs that still terminate in a species-code number or code letter automatically represent undescribed taxa (new species). Names must be selected for these and formal descriptions of them will need to be made. It is worth bearing in mind that *in the key the sum of all lugs leading to an identity constitutes a definition of that species.*

Additions to the key can also be made at this stage to include the known distributions of the taxa and the figure numbers that illustrate the characters mentioned. Distributions need only be generalized (countries or states/counties within larger countries), to give the reader an indication of the range of the taxon, because more detailed geographical information will be available under the heading of "Material examined" for each taxon.

1 Antenna with 11 segments 2
- Antenna with 12 segments 5

2 Head four times longer than broad (Fig. 1). (Britain, Germany, Poland, Denmark, Norway, Sweden) …… ..... ***fus***
- Head two times broader than long (Fig. 2) 3

3 Mandible with 5 teeth. Hind femur with spines present on dorsal surface (Fig. 3). (Germany, Austria, Belgium, France, Spain).....***cus***
- Mandible with 8 teeth. Hind femur without spines on dorsal surface (Fig. 4)..... 4

CONCLUDING PHASE OF THE PROJECT

Taxonomic synopses

i Taxonomic synopses of previously described taxa

At completion of the study each previously established name should be subtended by a formally laid out taxonomic synopsis that enables a reader to see at a glance the current status of the name and a history of its use and how it was interpreted. The synopsis should show an initial entry giving the reference of the original description, type-data, type-locality, type-depository, and an indication of whether type-material has been examined during the course of the study. Subsequent entries should indicate any synonymy or homonymy in which the name has been involved, any changes of status or combination that the name may have been subjected to, and any other references that are felt to be critical, such as those describing castes or sexes different to that of the original description.

What need not be included here is a compendium of papers that mention the name in a context that is not critical to understanding its taxonomic history. References to ecology, ethology, zoogeography and so on, can usually be relegated to the general discussion of the species following its formal diagnosis or description. However, if such references are deemed necessary for any reason, then they should be incorporated in the taxonomic synopsis in a way that makes it clear they are not an essential part of the taxonomic history. For instance, they can be enclosed in square brackets, or indented from the main text, or both. They should not interfere with the understanding of the taxonomic synopsis, which should be clear and concise.

For example, imagine that all the presumed species listed in the initial taxon file above (*Xus aus, bus, cus, dus*) had been examined, all their type-material and much other material had been analyzed and compared, and the conclusion reached that only a single real species was represented. That is to say, all the apparent differences invoked by the original describers of the names were merely the result of normal variation within a single species. The taxonomic synopsis covering all these events would appear something like this:

Xus aus Green

Xus aus Green, 1883: 207, fig. 1. Holotype queen, FRANCE: near Paris, 15.vi.1880, under stone (*M. Brun*) (Paris Museum) [examined].

Xus bus Green, 1885: 12. Syntype workers, BELGIUM: near French border, ix.1884, on tree trunk (*U. Blanc*) (Paris Museum) [examined]. [Junior synonym of *aus*: Blanc, 1890: 31 (*aus* and *bus* are queen and worker of a single species); synonymy confirmed.]

Gus cus Schwarz, 1888: 89. Syntype workers, GERMANY: no accurate locality given, 1886, swept from plants (*H. Grün*) (Berlin Museum) [examined]. **Syn. n**.
[*Xus cus* (Schwarz); Blanc, 1890: 35 (combination in genus *Xus*).]

Xus dus Blanc, 1890: 33, figs 1 - 4. Syntype workers, queens and males, FRANCE: near Belgian border, 21.ix.1885 (*U. Blanc*) (Paris Museum and Brussels Museum) [examined]. **Syn. n**.

All the data necessary to understand the history and current status of this species, and the specimens that were involved, are immediately obvious. They are presented in temporal order,

earliest event first, as far as is possible. In this example the only reference that is not in date order is that indicating the synonymy of *aus* and *bus*, which immediately follows the entry for *bus*.

Note that in the case of *cus* the indication of synonymy follows the entry for the original description, not the later entry indicating its change of generic combination. This is because the original reference contains the type-data and it is the type-material that carries the name. Note also that there are no punctuation marks allowed between the name of a taxon and the name of its original author.

ii Taxonomic synopses of new taxa

New species do not have a formal synopsis such as that given above, for the simple reason that they have no former history. It is, however, necessary to give each new species a name, and that name must be different from any other formerly used in the genus. This applies to names that are currently in synonymy as well as those still considered as valid species. The reason for this is that names in synonymy are still taxonomically available because a later researcher may produce evidence that a previous synonymy was incorrect. When this occurs the later researcher is at liberty to resurrect the name from synonymy. The name of a new species must also be different from any name that was originally proposed in the genus but which has since been transferred to a different genus. When a name is proposed for the first time it must be followed by an indication that it is new. The term "new species" may be written immediately after the name, or a contraction of the Latinized version of this (*species novus*) may be used: **sp. n.**

Data explaining the type-specimens and provenance of new species must be included at some point following the introduction of the new species. There is no fixed place to do this but it is usually accomplished directly after the title of the species or immediately following the description. Suppose that a new species was detected in our imaginary genus *Xus*, which was described and published by Dr Black in 1952, who nominated the species as *Xus nus*. Black decided to propose the name, then give the description, and then the type-data, thus:

***Xus nus* sp. n.**

Holotype worker: definition (see diagnoses and descriptions, below).

Paratype workers, queens and males: further definition if necessary and notes on variation if any.

Holotype worker, GERMANY: 2 km. NW of Riesa, on bank of Riv. Elbe, 21.x.1950, on trunk of alder tree, no. 602 (*H. Brun*) (Humboldt University Museum).

Paratypes. 10 workers, 2 queens and 4 males with the same data; 5 workers and 1 queen with same data but 1 km. NW Riesa, 22.x.1950, no. 605, under stone (*H.Brun*) (Humboldt University Museum, BMNH, MNHN).

The type-data indicate what the type-material is, how much of it there is, where and when it was collected, other data referring to the specimens (on alder tree and collection number), the name of the collector (in italics in parentheses), and the institutions in which the type-material is deposited, either by name or by abbreviation, also in parentheses.

At a later date, if this species is referred to again in a revision or other formal taxonomic publication, the above data will form the information of the taxonomic synopsis and will appear like this:

Xus nus Black

Xus nus Black, 1952: 64. Holotype worker, GERMANY: 2 km. NW of Riesa, on bank of Riv. Elbe, 21.x.1950, on trunk of alder tree, no. 602 (*H. Brun*); paratype workers, queens and males with same data and paratype workers and queen, 1 km. NW Riesa, 22.x.1950, no. 605, under stone (*H.Brun*) (Humboldt University Museum, BMNH, MNHN) [examined].

Diagnoses and descriptions

The definition of a species may consist of a diagnosis, a description, or both. Some authors present diagnosis and description as separate entities but often the former is included within the latter.

In a formal sense a diagnosis is a short statement that absolutely isolates a species (or a taxon of any rank). It consists usually of the autapomorphy or autapomorphies that are unique properties of the taxon and of none other in the group under investigation.

A description is more general and attempts to give an outline of the salient features of the species, to give the reader an overview of its characterisation, regardless of whether the individual characters are apomorphic or plesiomorphic. Having said that, a description within a large taxonomic study should be concise and accurate. There is no need to repeat characters of significance at genus rank as these are common to all species in the genus. Those characters that diagnose the genus are usually presented before the part of the work that deals with the species, so that the reader can quickly see what characters the researcher considers common to all the species in the study. Similarly, if the various species can be arranged into groups which share one or a number of critical characters (species groups), then those characters can be abstracted and listed separately as common to the whole group and need not be repeated in each species description. As well as being informative of how species fall into groups this is also a useful space saving device.

For instance, in our imaginary genus *Xus* only two species have 12-segmented antennae, all the rest have 11. There happen to be other consistent characters in our genus, associated with antennal segment count, that can be used to split the genus into two distinct groups.

Xus aus group
Antenna with 11 segments.
Maxillary palp with 6 segments.
Mandibles unsculptured.
Setae on vertex of head simple.
Included species: *aus, cus, dus, fus*.

Xus bus group
Antenna with 12 segments.
Maxillary palp with 4 segments.
Mandibles sculptured.
Setae on vertex of head plumose.
Included species: *bus, eus*.

The groups as stated convey only taxonomic information relating to identity; they do not give any data with direct phylogenetic value. However, if the polarity of some or all of these characters can be ascertained, then monophyly of the groups can be established and the apomorphies incorporated into any phylogenetic analysis deemed necessary.

After characters common to the genus, and those common to various species groups have been abstracted, what remains in each taxon file constitutes the basic skeleton of the species description. This information is often sufficient by itself, but if not the author should be prepared to add whatever features and comments are deemed necessary to give a good representation of the species.

When the formal description of a species has been completed it is always useful to add a few lines or a short paragraph in which the species is compared to and contrasted with its closest relatives. The reader can use this as a quick reference to what the author considers to be the most important points for differentiation of the species.

Discussions

Beyond the description it is up to the author to decide what other information should be included, but any doubts that remain about the sole identity of any species should be expressed. For instance, it may sometimes be suspected that a taxon consists of two sibling species that cannot be differentiated absolutely in the current treatment. Suspicions of this sort usually arise when there is greater than normal variation in one or more characters but where insufficient material is available to decide the significance of the variation. Note when this happens and discuss the reasons so that the potential pair can be investigated later by molecular or other techniques, if necessary. Also, it may be deemed necessary to discuss any new synonymy that has occurred, there may be publications dealing with aspects of behaviour, ecology, etc., that the author judges necessary for discussion, or there may be reasons to debate aspects of the species as it was treated by previous authors.

Material examined

At the conclusion of the description and discussion of each species a list of all the material seen during the course of the study should be appended. The amount of information and degree of accuracy of geography depends upon how important the author considers this aspect to be. At the very least it should give a fair indication of the known range of the species, but geographical overkill is not recommended. It is not necessary to list all the localities of the specimens as well as recording their latitudes and longitudes and also drawing up a detailed distribution map as well. This is too much information; or rather, it is repeating the same information too often.

Illustrations

The illustrations prepared, whether drawings, light photographs, or electron microscope pictures, should be sufficient to encompass all the important aspects of the group in question. They may be produced gradually during the course of the study or done as a single exercise when the text is more or less complete, or by a combination of both. A gradual accretion of illustrations as the study progresses allows the selection of the most essential and best illustrations at the end of the survey. On the other hand doing all the illustrations after the text is complete allows for more accurate selection of what is essential, but depends upon the necessary specimens still being to hand.

There is usually no need to illustrate every character or every taxon, though sometimes some species will require more illustration than others. The number of illustrations needed per species or per group depends roughly upon the difficulty of describing the characters of the group and the degree to which characters are shared among the various species. In species where variation in shape of body parts is critical to recognition it will obviously be more valuable to include illustrations of the different shapes rather than to attempt their descriptions in words. On the other hand in taxa where there are very conspicuous differentiating characters that can easily be described in a few words, large numbers of illustrations are unnecessary.

Illustrations should be grouped to provide best access for a reader. Sometimes it is best to group all illustrations in a single place (at the end of the key, at the end of the text, *etc*.) but other times it may be deemed best to space them out (at the end of each species group, at the end of the fauna of a single zoogeographical region, *etc*.). In some instances they may be included in the key as marginal illustrations, but they should never interrupt key couplets or the flow of the text. Illustrations in the

margins of keys may be useful but they have the disadvantage of considerably narrowing the page and thus reducing the width available for the key couplets.

Final points

When everything has been completed, review the manuscript for content, layout and spelling, then apply these questions:

1 Is the revision an advance over any previous system?
2 Can the new system be followed and understood by other taxonomists?
3 Are the taxa adequately defined and differentiated so that their identities can be discerned by others, who may not necessarily be taxonomists?
4 Is the system adequately presented, so that its findings can be duplicated, expanded or altered by later taxonomists?
5 Does it satisfy normal taxonomic and nomenclatural procedure?

If the answer to all these questions is in the affirmative then the final step is publication of the results.

APPENDIX: TAXONOMIC AND SCIENTIFIC COMMON SENSE

Taxon inflation

Taxon inflation is a possible pitfall in all taxonomic studies but is particularly one that afflicts the inexperienced, or those working on higher taxa for the first time. It occurs when the student spends all available time intensively studying a single group so that its characters, particularly its differentiating characters, assume an importance that is out of proportion to those of the remainder of its group (tribe, subfamily, family, *etc*.). The result is usually that the student promotes all his or her taxa by one or more ranks. Thus subgenera become genera, genera become tribes, subfamilies become families, and so on. The cause of this is generally lack of broader knowledge and experience of groups that are closely related to that being studied. The result of it is that all taxa within the inflated group end up out of proportion with their relatives in equivalent taxa.

To illustrate this, imagine that the ant fauna is being studied in a very small area, for example the garden of an ordinary house. Two species are found in the soil, one of which is yellow and has small eyes, the other of which is black and has large eyes. In the context of the garden alone these two taxa can be assigned to any rank as they are being compared only to each other, not to the fauna of the rest of the world. When viewed with a whole world perspective the characters that seemed so important in the restricted area are discovered to be of little relevance whilst other characters, apparently inconsequential in the small area, are constant and universal through all the species of all the world: the two apparently so different taxa turn out to be two species that belong in the same genus.

"Common names"

Back before 1758 Linnaeus had a remarkable insight, a flash of genius. He realized that any living thing could be named accurately by the use of just two words. The two words, the first representing a genus and the second a species, represent the unique proper name of a species that is universally recognizable. And as they are pitched in a language that is extinct, no living language is given priority over any other. It is a marvelous thing to contemplate: the name of any insect species in the whole world, and there are now about a million of them, can be recognized by anyone. A

native English speaker can say the name of a species to a native speaker of Japanese and both immediately understand what the species is. Set against this incredible achievement and its universal application is the misplaced effort of formulating "common" names for species that do not need them and are often anything but common. These "common" names are often formulated by a single individual and are only understood in one language, and sometimes only in part of the range of one language. Obviously, this condemnation does not apply to names that have evolved naturally for large species in any language because such species feature in the lives of the whole population, for instance oak, cow, dog in English. But deliberately to sit down and make up "common" names for ant species is an exercise in pointlessness and futility.

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