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Why are so many species based on a single specimen?

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Abstract

A considerable number of insect species, including Trichoptera, are described from a single specimen, also known as a 'unique' or a 'singleton'. We ask the question of whether this reflects failure to consider variation and related species, lack of collecting effort, or true rarity. In an attempt to answer this question we examine the available literature and data on the Trichoptera of Tasmania and New Caledonia. We note a low level of taxonomic synonymy among species in these faunas. Moreover, a significant proportion of species from Tasmania that were based originally on singletons have been re-collected subsequently, but this is not true for New Caledonia. The possible significance of these figures is considered following examination of data on diversity and abundance of Hydroptilidae collected by regular, standardised light trapping over almost two years at a northern Australian tropical stream. We conclude that quite a large proportion of the Trichoptera species based on singletons are rare, valid species, but for others the appearance of rarity may be a consequence of inadequate collecting, particular behavioural attributes of the species, including seasonality, and failure to consider fully the structural diversity of related species. Lastly, we discuss briefly the consequences of rarity, apparent or real, on conservation management.

Introduction

Commonly in taxonomic literature, one finds species names established on a single specimen, the holotype, with no further specimens available. This is clearly an unsatisfactory situation, it being impossible to assess intraspecific variation, and our purpose here is to consider how and why it occurs. Most taxonomists have experienced finding a single distinctive specimen amongst the extensive material in front of them. Taxonomic treatment of that specimen will depend on the objectives of the study, whether it is part of a generic revision or a more circumscribed regional study, but also on the experience of the researcher. We searched the available literature on singleton-based species, rates of synonymy and concepts of rarity to try to understand why so many species are based on singletons. We then examine the faunas of two south-western Pacific islands, Tasmania and New Caledonia, to illustrate and investigate the phenomenon of singleton-based species. We follow that up with data from a sampling study of Trichoptera in northern Australian that further illustrate variability in frequency of occurrence of species in field collections.

In recent studies on New Caledonian Hydroptilidae, Wells and Johanson (2012, 2014, 2015) and Wells *et al.* (2013) based 4 out of 34 newly described species (~12%) on single specimens — so-called ‘singletons’. Perusal of Volumes 38–41 of the trichopterists' publication, *Braueria* (years 2011–2014), reveals that in those issues, 45% of newly described species are based on singletons. This high proportion contrasts with the less than 10% singletons in the northern Australian fauna (Table 1), and suggests that many of these names may prove to be synonyms. High levels such as this are not unique to Trichoptera. For example, in an analysis of data on world mantids, Battiston (2015) found that 48% of 2198 species listed by Ehrmann (2002) are "… reported only by the holotype or a single type specimen". And in recent work on Heteroptera (true bugs) Hill (2014, 2015) described 13 new Australian species of Schizopteridae of which eight were based on singletons.

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TABLE 1. Frequency of detections of hydroptilid species in 60 light trap samples from Magela Creek, Northern Territory, taken over almost two years.

Species name	Freq.	% Freq.
Hellyethira ramosa	34	56.7
Orthotrichia tomentosa	31	51.7
Hellyethira veruta	29	48.3
Orthotrichia tyleri	25	41.7
Tricholeiochiton jabirella	24	40.0
Orthotrichia amnica	22	36.7
Hellyethira vernoni	19	31.7
Oxyethira incana	19	31.7
Oxyethira warramunga	18	30.0
Hellyethira cubitans	17	28.3
Hellyethira pulvina	14	23.3
Orthotrichia exigua	13	21.7
Orthotrichia bellicosa	11	18.3
Oxyethira plumosa	11	18.3
Orthotrichia suteri	9	15.0
Tricholeiochiton fidelis	9	15.0
Hydroptila incertula	8	13.3
Orthotrichia turrita	8	13.3
Tricholeiochiton bifurcata	6	10.0
Orthotrichia alata	5	8.3
Orthotrichia eurhinata	5	8.3
Orthotrichia velata	5	8.3
Orthotrichia inornata	1	1.7
Orthotrichia muscari	1	1.7
Orthotrichia paranga	1	1.7

Clearly, Trichoptera workers are not alone in basing new species names on single specimens. The critical question, then, is why is it done? Is it actually a consequence of failure to appreciate variation within and among species, is it inadequate collecting effort and at an incorrect time of year, or simply a consequence of the biology of a species? Both mantids and schizopterids are predators, and usually collected individually, but with modern collecting methods, Trichoptera can be expected to be taken in numbers that reflect their abundances. Thus, if these Trichoptera species really are rare, does this mean that each population is diffuse and involves very few individuals that interact rarely, or are populations strictly localised and thus encountered rarely? We all rely on our colleagues' experience and judgement in deciding species' boundaries — inevitably elements of human variability creep in here.

Nomenclatural validity of singleton-based species

Before querying the quality of the science, we need to address the nomenclature. Nomenclature is guided by the *International Code of Zoological Nomenclature* (ICZN). Under the Code, in fact, there is no impediment to description of new species on the basis of a single specimen, provided other requirements are met (see ICZN 2012, online 2015: Article 73).

Scientific validity of singleton-based species

Most taxonomists are unlikely to select a single specimen from a series and ignore the rest, although this certainly has happened. More commonly an author succumbs to the desire to provide a name for a specimen simply because it occurs in a collection. Moreover, this may be done in no particular context, such as a generic revision, and even without examining type material of similar species. In describing a species, we are erecting a hypothesis. A species definition is a concept and as such is subject to falsification. For the purpose of this study, our thesis is that 'singleton-based species are valid and rare'.

Inevitably, there must be variation among multiple individuals of a species, and the taxonomists' task is to interpret that variation. Describing a species on a single individual fails to allow for this variation. How many species would we make of domestic animals such as cats and dogs on this basis? Similarly, a deformed specimen may be mistakenly described as a new species — Malicky (2014) illustrated a vast number of deformities detected among Trichoptera. Polymorphic forms may be mistaken to be separate species, and males and females have often been described as separate species.

Rates of synonymy give some indication of the validity of species concepts. For some groups of organisms, levels of synonymy are quite considerable. For example, Gaston and Mound (1993) gave a figure of 22% for world Thysanoptera (thrips) and Wortley and Scotland (2004) estimated some 33–88% (mean 66%) for spermatophytes (seed plants). In preparation for the *Atlas of Trichoptera of Southeast Asia*, Malicky identified 176 synonyms among some 2000 valid species (~9%) and also signalled numerous other unresolved taxa (see Malicky 2013). For Australian Trichoptera, the figure for synonymy is very low, at 5% (ABRS July 2015), undoubtedly reflecting the fact that a considerable proportion of the fauna has been described by few workers and only comparatively recently.

If we accept the validity of at least a reasonable proportion of the species described from uniques, how many of these are rare and how many are described from an already existing but neglected pool of specimens that are available in collections? We return to the two examples above — schizopterid bugs and mantids. Significantly, of Hill's (2014, 2015) schizopterids, 10 of the 13 species are known only from the type locality, and from the mantid study, Battiston (2015) deduced that the high level of singleton-based species suggested that most species are probably not common.

But could it be simply that they are under-collected? Indeed, much collecting is spasmodic at best: a collecting expedition may only allow sampling at a site once or twice and often in a single season — climate or funding may impose limitations on access, or sites may have difficult or restricted access. Only a restricted range of collecting methods may be employed, and this results in biased samples.

According to Lim *et al.* (2012), "[r]ecent reviews suggest that in tropical arthropod samples, 30% of all species are represented by only one specimen …, **with additional sampling helping little with eliminating rarity**. Usually, such sampling only converts some of the singleton species to doubletons, with new singleton species being discovered in the process …" [our emphasis].

The concept of rarity

The concept of rarity is examined particularly by community ecologists in attempts to understand the distribution and abundance of species and by conservation managers charged with management of biodiversity. The former recognize patterns in natural assemblages of organisms, finding that distributions of species are highly skewed. Flather and Sieg (2007) concluded that "[i]n virtually all ecological communities around the world, most species are represented by few individuals, and most individuals come from only a few of the most common species". In a particular case, comparing differences in species richness and abundances in a British salt marsh and a fen community, Verberk (2011), found that for both communities most species were represented by few individuals; most individuals were identified as representing just a few species. How to wrestle with problems of real and apparent rarity is a challenge for conservation managers setting criteria for listing threatened and endangered species (see IUCN Standards & Petitions Working Sub Committee 2014). How does a conservation agency deal with a considerable proportion of the fauna under their brief being known from only a single specimen or even just a few? Or from a single locality?

Causes of rarity

Causes of rarity can be of two classes: "*natural* or *intrinsic* causes defined by a species' inherent biological or ecological characteristics; and (2) *anthropogenic* or *extrinsic* causes defined by harmful human activities that have resulted in limited distribution and abundance, independent of their biology" (Flather and Sieg 2007).

Among the first class, a species might occupy a high trophic level, i.e. be a top predator; it may be intolerant of particular conditions; it may occupy an extreme niche; or it may have high habitat selectivity. Rosenweig and Lomolino (1997) invoke the example of copepod species found in the North and South Pacific gyres, species that appear to have persisted in low numbers over geological time (i.e. show temporal persistence), despite a concurrent rapid expansion in abundances of other species, as evidence that rare species have particular attributes. For all groups, this posits a very strong argument for biological studies such as those that uncover curious behaviour, habitats and highly restricted niches. Being predatory would explain the low numbers of the mantids cited in the example above, and similar explanations can surely be given for rarity of some Trichoptera. For example, a microcaddisfly species described by Cairns and Wells (2002) occupies a highly restricted, extreme niche. This species lives among, feeds upon and makes its cases from an aquatic moss growing on a waterfall, and has been found at only one site in far northern Queensland. Although the species is reasonably abundant at the type locality, it has to be classed as rare: it has not been found anywhere else, and the moss is known only from one other site.

Causes of the second class are self-evident — habitat alteration such as pollution and clearing of riparian vegetation, and added to these, possible impacts of climate change.

Singletons and two island faunas

In exploring ideas of 'rarity' in Trichoptera we looked at data on the Trichoptera faunas of two small, proscribed land areas in the Australian Region. These are two islands in the Southwest Pacific for which the Trichoptera fauna are reasonably well collected and studied — New Caledonia, around **1500** km east of the coast of eastern Australia, and Tasmania, less than 200 km south of the south-eastern coast of mainland Australia. Although records are somewhat limited for both, we can also take the next steps of looking at synonymy rates and whether the species based on singletons have been collected subsequent to description.

Concerted efforts to collect Trichoptera were made in New Caledonia over the years 2000 to 2004 by members of the Swedish Museum of Natural History, amassing over 32,000 specimens, and to date, resulting in some 23 taxonomic, phylogenetic and phylogeographic studies. For Tasmania we have the considerable works of Arturs Neboiss, published from 1959–2003 (for full list see Trichoptera Literature Database, Holzenthal *et al.* 2012), augmented by studies by other authors. Based on his extensive collecting over the years 1965 to 1974, Neboiss (1977) published a revision of Tasmanian Trichoptera; his collection was supplemented by 2,000 specimens taken by E.F. Riek of CSIRO, Canberra. Furthermore, Neboiss (2003) updated the Tasmanian list, adding new species and material collected after his review; and several additional species have been added since 2002 by other authors. Records for the major collection of Australian Trichoptera, housed at Museum Victoria, are available from the Online Collections of Australian Museums (OZCAM) through the freely available online Atlas of Living Australia (ALA). Tasmania, with its close proximity to the large land mass of mainland Australia and probably greater or at least longer-term interest in its aquatic fauna than has been the case for New Caledonia, might be expected to have a lower percentage of singletons and a higher percentage of species that have been re-collected.

The described Trichoptera recorded from Tasmania number 194 species, of which 52 or ~27% were described from a single specimen. Since their establishment, however, a number of these have been recorded on mainland Australia and are often found to be abundant there. If we look only at Tasmanian endemics, 46 of these species were described from singletons. Of these, 11 have not been collected since they were described. Overall, in early 2015, some 13% of Tasmanian species are recorded from the type locality only. Five percent of species (10 of the 194) include one or two synonyms.

In the second example, New Caledonia, among the 239 described species recorded, 59 or 23% are based on a single specimen. Of these, 18 species have been collected subsequently, but for seven of these only a small number of specimens have been reported. Forty-one species (~17%) are still recorded only from the holotype. Only three names have been synonymised — a very low number, but significantly, most of the Trichoptera species have been described recently, and frequently also in combination with DNA data for supporting uniqueness of morphospecies.

Hydroptilids of a northern Australian stream

In addition to what we can glean about singletons and putative rarity from the above two island faunas, we examined data from an ecological study on the Magela Creek, in the seasonal tropics of Australia's Northern Territory. From this work, hydroptilid diversity and abundance data are available for the monitoring study based on 60 samples collected over almost two years of regular light-trapping for Trichoptera. The monitoring used a small 6V New Jersey-type light trap (low intensity light, coupled with a fan for suction); details will be reported elsewhere together with hydrological data (Dostine and Wells, unpublished data) but frequency of collection of species and abundance records are considered here.

Over the 22 months of light trapping beside Magela Creek, 10,265 individuals were collected, representing 60 species. Of these, 88.9% of the specimens belong to 25 species of Hydroptilidae. The frequency of detection of these 25 species is shown in Table 1. All but two species were detected in less than 50% of samples. Three species were taken only once, for two of which only one specimen each was recorded, for the third, seven specimens. One of the species, *Orthotrichia muscari* Wells, of which only one specimen was taken, is based on a singleton but has been collected in reasonable numbers at other sites in northern Australia. This species is a parasitoid and thus might be expected to be in low numbers, as it would be dependent on the presence of its hosts. Most of the specimens in the Magela Creek samples represented a single species, *Hellyethira ramosa* Wells, probably a feeder on filamentous green algae. Yet even this often abundant species was trapped in only close to 57% of samples. Although the data reflect the diversity and abundance of hydroptilids at the stream over the collection period, they highlight the chancy nature of spot collections by survey workers and taxonomists, and importance of understanding ecological and microhabitat preferences of the species.

These results from the Northern Territory parallel quite closely the findings of a similar study on Trichoptera of a tropical stream in north-eastern Queensland, Australia, reported by Benson and Pearson (1988). They found fluctuations in abundance of Trichoptera collected by light trapping beside Yuccabine Creek in the Paluma Range. Over the three years of their study they found enormous variability in presence of individual species, even in species that are commonly collected at other times and other sites.

It is, thus, reasonable to conclude that rarity of some species in samples, such as could be reflected in the description of species from unique specimens, results frequently from failure to sample adequately across available habitats and seasonal conditions. Comprehensive faunal surveys require more extensive sampling efforts, but even these may not lead to satisfactory conclusions. In analyses of 42 years' data from a study on Australian desert lizards — for its duration the study a rarity in itself — Pianka (2014), after examining a range of hypotheses concluded that some species of the Australian desert lizards are always rare and that '[n]o general explanation for rarity may exist, but rather each species appears to have its own idiosyncratic reasons for being uncommon'.

Consequences for conservation of species based on single specimens

Rarity is important for conservation managers, but is not the only criterion for inclusion of species on threatened species lists. In Australia, few Trichoptera are included on endangered or threatened species lists. Only in Tasmania and Victoria are any species of Trichoptera listed. In attempting to assess any implications of singleton-based species or 'rarity' for conservation we examine the species that are listed officially for Tasmania.

Currently 16 species are listed on the Tasmanian list of Threatened Species (DPIWE 2005 Tasmania). One of these is categorised as 'extinct', and two as endangered, and the others as threatened on the basis that the '… species are subject to stochastic risk of endangerment because of a naturally small population size and areas of occupancy of less than 2000 km^2'. Four of Tasmania's listed species occur on mainland Australia where they are widespread and often abundant in the east. The others are/or were endemic to Tasmania; for only one of the 16 listed species is the holotype a unique. So there seems not to be any correlation between singleton-based species and conservation status among Tasmanian Trichoptera. The two species listed as 'endangered' were found only at Lake Pedder and have not been collected since flooding by impoundment of the Franklin River. Our study revealed 10 further Tasmanian endemic species that are known only from singletons and have not been reported formally since, but perhaps fall outside the criteria for listing.

Conclusions

Trichoptera workers are not alone in describing species on the basis of single specimens. Rarity of some species in samples, which would naturally be reflected in description of species on the basis of unique specimens, results frequently from under-collecting. Furthermore, it appears that on the basis of available data and taking the concept of rarity as low abundance of a species within a delimited area, many Trichoptera species are 'rare'. However, a critical item that is lacking is good data on variation within Trichoptera species and a far better understanding of the biology of individual species. This may well be a factor in apparent low abundances. Frequently Trichoptera are collected by light trapping, however some species appear only rarely to come to lights, for example species of the Australian endemic genus, *Orphninotrichia*, which are usually active only at daytime. When one is aware of the often-restricted niches occupied by species, collecting methods can be adjusted accordingly.

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