Arthropod Morphospecies versus Taxonomic Species: a Case Study with Araneae, Coleoptera, and Lepidoptera

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Abstract: *In times of biodiversity crisis there is an increasing need for faster and cheaper methods by which to achieve conservation goals. This situation is especially troublesome for invertebrates, and the use of morphospecies instead of taxonomic species has been proposed as a way around the taxonomic constraints in particular situations. We conducted a study in a modified native shrubland on New Zealand's South Island in which we sampled Lepidoptera, Coleoptera, and Araneae in autumn by beating and pitfall traps. All specimens were separated into morphospecies by a nonspecialist and identified by specialized taxonomists, and the results were compared. Results were analyzed with respect to correct separations (one taxonomic species to one morphospecies), lumping (more than one species classified as a single morphospecies), and splitting (one species separated into more than one morphospecies). Among the individual orders, Lepidoptera yielded the most accurate results (91% correct separation), whereas Coleoptera and Araneae yielded poor results (63% and 50%, respectively). The overall difference between the morphospecies and taxonomic species estimates for the site was only 3.3%, but this was an artifact caused by the splitting and lumping results balancing each other out. The accuracy of morphospecies separation varies greatly among different invertebrate groups, so the relationship between morphospecies and taxonomic species for a particular target group must be established beforehand. We recommend that some prior orientation should be given by expert taxonomists. When adopted with care, morphospecies present a useful tool for conservation, particularly for environmental impact assessment and when inventorying diversity does not require information on particular species.*

Morfoespecies de Artrópodos versus Especies Taxonómicas: Un Estudio de Caso con Aranae, Coleóptera y Lepidóptera

Resumen: *En tiempos de crisis de biodiversidad hay una creciente necesidad de métodos más rápidos y baratos para alcanzar las metas de conservación. Esta situación es especialmente problemática para invertebrados, y se ha propuesto el uso de morfoespecies en lugar de especies taxonómicas como alternativa a las constricciones taxonómicas en situaciones particulares. Condujimos un estudio en un matorral nativo modificado en la Isla South en Nueva Zelanda en el que tomamos muestras de Lepidóptera, Coleóptera y Aranae en verano con trampas de golpe y de canasta. Todos los especímenes fueron separados en morfoespecies por un no-especialista y luego identificados por taxónomos especializados, y se compararon los resultados. Los resultados se analizaron con respecto a las separaciones correctas (una especie taxonómica a una morfoespecie), a las agrupaciones (más de una especie clasificada como una sola morfoespecie) y a las separa-*

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ciones (una especie separada en más de una morfoespecie). Entre las órdenes individuales, Lepidóptera produjo los resultados más precisos (91% de separación correcta) seguida por resultados pobres en Coleóptera (63%) y Aranae (50%). La diferencia general entre las estimaciones de morfoespecies y especies taxonómicas del sitio fue de sólo 3.3%, pero esto fue un artificio causado por el balance mutuo de los resultados de separación y agrupamiento. La precisión de la separación de morfoespecies es muy variable entre diferentes grupos de invertebrados; por lo tanto, se debe establecer de antemano la relación morfoespecie-especie taxonómica para un grupo en particular. Las morfoespecies son una herramienta útil para la conservación, particularmente para la evaluación de impacto ambiental y cuando el inventario de biodiversidad no requiere de información de una especie en particular.

Introduction

Human activities are causing a major decline in biodiversity, especially through habitat destruction (World Conservation Union 1987; Lovejoy 1997; Pimm & Raven 2000). The problem is so serious that combined human impacts have accelerated extinction rates to 1000–10,000 times the natural rate (Lovejoy 1997). Briggs (1994) predicts that at the current rate of extinction more than 75% of all terrestrial species will be lost within 200 years.

There is limited knowledge about what is happening to invertebrate communities worldwide as a result of anthropogenic disturbances. A major constraint on understanding invertebrate communities is a lack of experts to work at biodiversity hotspots around the globe. Golley (1984) estimates that only 4% of practicing ecologists are based in Latin America and sub-Saharan Africa, whereas Gaston and May (1992) roughly estimated that only 7% of insect taxonomists are based in Neotropical and Ethiopian realms. As a result, although there is a daunting number of invertebrate species undiscovered in the tropics, the unbalanced distribution and declining number of taxonomists worldwide lead us to conclude that most of the unknown invertebrate species will remain unknown, and many are likely to disappear before they are ever recorded. Furthermore, the number of alpha taxonomists is not only declining (Wilson 1985), but those that remain are receiving reduced support (J. R. Oliver 1988; Cranston 1990; Disney 1998; Jaspars 1998).

To allow certain conservation efforts to go ahead in the face of accelerating land modification, reliable alternatives are urgently required, especially when lack of time and/or funding cause invertebrate inventories to be excluded from most conservation projects (Kim 1993). One such option is the use of the so-called "parataxonomists" (Gamez 1991) or "biodiversity technicians" (Cranston & Hillman 1992). The parataxonomists trained by taxonomists to work on the inventory of Costa Rica's biodiversity, for instance, were local people who had no previous biological training and were taught to collect, prepare, and sort specimens (Gamez 1991). The importance of parataxonomists has been recognized by a program of the International Union of Biological Sciences (IUBS), the Scientific Committee on Problems of the Environment (SCOPE), and the United Nations Educational, Scientific and Cultural Organization (UNESCO) as the people responsible for most of the implementation of protocols in their proposal for an international network for inventorying and monitoring biodiversity (Di Castri et al. 1992).

In a time of biodiversity crisis (Wilson 1985; Stork 1994), when in most of the world neither resources nor time for detailed taxa inventories are available (Raven & Wilson 1992; Prendergast et al. 1993), parataxonomists could have an important role in the implementation of rapid biodiversity assessments (RBAs). Such assessments have different meanings and approaches (Trueman & Cranston 1997), and they have been increasingly linked to the use of recognizable taxonomic units (Cranston 1990; Trueman & Cranston 1997) or morphospecies (Oliver & Beattie 1996*a*). Morphospecies, as we refer to them here, do not involve the identification of species per se, but rather the separation of taxa based on morphological characters that are easily observable. The assumption underpinning such an approach is that the use of morphological characters allows distinction of taxa to some degree.

Kremen et al. (1993) and especially Oliver and Beattie (1996*a*) propose that morphospecies be used as surrogates for taxonomic species in environmental monitoring and conservation. It has been suggested that nonspecialists may be used to classify invertebrates to morphospecies without compromising scientific accuracy (Oliver & Beattie 1993, 1996*a*, 1996*b*; Beattie & Oliver 1994; Pik et al. 1999). Because of the huge diversity of invertebrates and our often poor taxonomic knowledge of so many of them (Cranston & Trueman 1997), the morphospecies approach can greatly enhance the practicability and viability of environmental and conservation surveys by reducing the time required for the taxonomic identification of specimens.

Morphospecies are therefore particularly useful for tackling environmental impact assessment and monitoring. Even entomologists are adopting the morphospecies approach when applying their work to conservation and land-management issues (Klein 1989; Andersen 1991;

Kremen 1992; McIver et al. 1992; Kremen et al. 1993), and some believe that for assessment of aquatic ecosystems, for instance, the use of morphospecies may be the only feasible solution (Cranston 1990). Furthermore, knowledge of many invertebrate taxa may actually be absent. Oliver and Beattie (1993) cite the collection of 900 species of soil and litter arthropods in an Australian eucalyptus forest, 80% of which could not be named.

Morphospecies are useful in species inventories because parataxonomists can potentially provide most of the labor. Taxonomists can provide initial baseline comparison between morphospecies and a particular target group, training of biodiversity technicians, and regular quality control to ensure that morphospecies are accurately separated (Kremen et al. 1993; Oliver & Beattie 1993; Beattie & Oliver 1994). Taxonomists could then concentrate on detailed identification of voucher specimens of individual morphospecies. This method provides a real advantage for inventories of tropical forests (Kremen et al. 1993), especially in the developing world.

There has been vigorous debate over the possible applications and usefulness of morphospecies (Beattie & Oliver 1995, 1999; Brower 1995; Goldstein 1997, 1999*a*, 1999*b*; Oliver & Beattie 1997). There is general agreement, however, that morphospecies can be useful in the initial sorting stage, before specimens are passed on to trained taxonomists. Goldstein (1997) criticized the use of morphospecies in conservation decision-making, questioning the use of selected invertebrate groups for habitat selection because they may not reflect the richness of unrelated groups. We believe, nevertheless, that if resources are limited, it may be worth condoning the use of morphospecies of selected groups from which voucher specimens can then be later assessed by taxonomists if necessary. Dickinson et al. (1998) conducted one of the most thorough ecological surveys done so far in New Zealand in which they identified many species of Lepidoptera and Coleoptera. However, they cited no dipterans for instance, because of lack of time, funding, and—for some groups—expertise.

Morphospecies inventories have attracted some criticism because they are linked to the use of species counts for conservation decision-making. Goldstein (1997) criticized the use of species richness as a primary criterion for the selection of natural areas, as did Trueman and Cranston (1997). The latter believe, though, that species richness is the one aspect of biodiversity that can be reliably surveyed, because genetic and ecosystem diversity are not measurable for most invertebrate taxa due to poor knowledge; they point out that "differences in site species richness clearly are relevant in comparative studies in ecology and evolution." Goldstein (1997) also added that too often species-rich sites might not actually be of conservation concern because rare and endemic taxa may well lie within species-poor areas. Trueman and Cranston (1997) stressed that "RTUs–based methods cannot discriminate between common and rare taxa, or between those taxa which are threatened and those which are not."

Although we agree with these views, to perform thorough taxonomic inventories in every case requiring conservation decisions is not possible at the scale demanded by the present rate of biodiversity loss. We maintain, therefore, that although not perfect, the morphospecies approach applied in a scientifically robust manner could contribute to significant advances in insect conservation.

The morphospecies approach can be complicated, however, by varying degrees of interspecific and intraspecific variations within particular taxa. Small interspecific variation means that proper species separation is often possible only with a detailed study that may include dissection of genitalia. In these cases, use of morphospecies can result in underestimation of species richness due to lumping. Nonspecialists are likely to assume in such situations that the small variation relates to the same species. Another problem comes from overestimation of species by splitting when there is much intraspecific variation, such as sexual dimorphism or large morphological differences between adult and juvenile instars.

New Zealand as a Case Study

New Zealand has been listed as one of the world's 25 biodiversity hotspots (Myers et al. 2000) because its fauna and flora are not only highly endemic but also highly threatened. In New Zealand's Protected Natural Areas (PNA) program, however, the selection of natural areas for conservation is based mostly on the least modified vegetation and flora, and the extent to which these (or vertebrate taxa) reflect invertebrate diversity is poorly defined (Disney 1985; Yen 1987; Prendergast et al. 1993; Cranston & Trueman 1997; Crisp et al. 1998).

As is the case elsewhere, the invertebrate fauna is poorly known taxonomically and the number of trained taxonomists is low. Meanwhile, land modification and biodiversity loss continue, leading the recently released New Zealand Biodiversity Strategy (Department of Conservation & Ministry for the Environment 2000) to focus on "halting the decline" within a 20-year time frame. In the face of this declining biodiversity, the expertise needed to inventory the invertebrate fauna in the time required is not available. Consequently, more efficient techniques are urgently needed. However, the use of invertebrate morphospecies and parataxonomists has not been tested rigorously in this country.

We sought to test the accuracy of invertebrate morphospecies as surrogates for taxonomic species for three Arthropod orders—Araneae, Coleoptera, and Lepidoptera—in a New Zealand shrubland. These three groups are not only widespread, abundant, and dominant, but are easily sampled in grassland-shrubland systems. They are potentially useful for rapid biodiversity assessments in New Zealand because there is also good taxonomic information allowing accurate identification of taxonomic species by trained taxonomists. Moreover, these groups pose different levels of difficulty for proper identification of species, which is likely to affect the accuracy of morphospecies separation.

Study Site

We conducted invertebrate sampling in a modified native shrubland at 450 m elevation (lat 45°30′S, long 170°03′E) in the Brookdale Conservation Covenant (private land protected under the Reserves Act 1977) on the lower eastern slopes of the Rock and Pillar Range, South Island, New Zealand. The covenant is protected in perpetuity in the land title, and, although limited grazing is allowed, the use of fire as a management tool is not (Reserves Act 1977–s.77). Located 50 km inland, the range rises gently to an elevation of 1450 m (Talbot et al. 1992). These mountains are one of the several rolling block-faulted schist ranges running northeast to southwest, inland from coastal Otago, that form the distinctive and characteristic Central Otago tor landscape (McCraw 1965). It is a region of extensive modified tussock grasslands, shrublands, and alpine vegetation.

The native vegetation has been dramatically altered since human occupation of the South Island approximately 800 years ago (McGlone & Wilmshurst 1999). In the region of the Rock and Pillar Range, this continuous process of human disturbance resulted in the restriction of lower-elevation shrublands to gullies, which have been protected from fire (and also often from heavy grazing) by the topography. These shrublands probably do not represent the original prehuman vegetation (McGlone 2001), but are still dominated by native woody species that survived the disturbance processes.

Such areas of lowland to montane tussock-grasslands and shrubland are poorly represented in New Zealand's protected natural areas systems (Crisp et al. 1998). These areas are generally modified to some degree but may still harbor significant indigenous invertebrate biodiversity, even though botanically there may be a prominent exotic species component. As is the case elsewhere, little is known of the faunal diversity and urgent assessment is required.

Methods

For the collection of invertebrate specimens, we focused on the two most important native shrub species in the shrubland community: *Olearia bullata* H.D. Wilson & Garnock-Jones (Asteraceae) and *Coprosma propinqua* A. Cunn. (Rubiaceae), both divaricating species (McQueen 2000). Moreover, these two genera harbor a rich invertebrate fauna (Dugdale 1975; Patrick 2001). Thirty *O. bullata* and 30 *C. propinqua* shrubs were selected through random numbers and coordinates. They were sampled for invertebrates in late summer and early autumn (March and April 1999, respectively) with the beating method (Southwood 1978; Davies & Stork 1996; New 1998). Each plant received 10 downward strokes with a 1.5-m-long metal rod, and the material that fell was collected on a polythene sheet, 1.0 × 1.3 m, that had been placed under the shrub. The material was sealed in a plastic bag, labeled, and frozen. Of the 30 *C. propinqua* sampled, only 14 were examined and used in the analyses because the remaining samples were heavily fruited, and the resulting stickiness impaired the separation of invertebrates.

During the same period, 50 pitfall traps (Davies & Stork 1996; New 1998) were also set under 20 *Olearia* and 20 *Coprosma* plants. Ten other traps were scattered on nearby open patches of grassland dominated by the exotic *Agrostis capillaris* L. (browntop) and *Anthoxanthum odoratum* L. (sweet vernal). Each pitfall trap consisted of a PVC pipe 80 mm in diameter and 100 mm long containing a plastic cup (opening 75 mm in diameter). Each cup was two-thirds filled with antifreeze (ethylene glycol), and a plastic lid supported 10–20 mm off the ground by bent wire covered the trap. The traps were emptied after 2 weeks.

J.G.B.D., an ecologist with no invertebrate taxonomic training, used a low-power binocular microscope to conduct the initial sorting of invertebrates into morphospecies. No keys and only obvious external morphological features such as body shape and color patterns were used. No genitalia or other inconspicuous features were examined. The vials containing the numbered morphospecies were then sent to taxonomic experts to be identified as close to species level as possible. Immature forms were considered in the analyses whenever the taxonomists were able to safely distinguish them from other species.

Analyses of the results were based on the methods used by Oliver and Beattie (1996*a*). When we compared the morphospecies and taxonomic species data, we recorded the ratios of correct 1:1 separation (one taxonomic species to one morphospecies), of lumping (more than one species classified as a single morphospecies), and of splitting (separating the same species into more than one morphospecies). When we noted the number of occurrences of splitting and lumping in a particular order or family, we counted the overlapping results independently. For instance, say the nonspecialist made the following separation: (1) some specimens from species A were classified as morphospecies 1, whereas others were classified as morphospecies 2; (2) all specimens from species B and species C were classified as morphospecies 2; and (3) only specimens from species

Table 1. Estimated richness of selected Arthropod orders from two sampling methods based on morphospecies and taxonomic species inventories.

Inventory	*Lepidoptera*	*Coleoptera*	*Araneae*	*Overall*
Morphospecies	37	54	36	127
Taxonomic species	33	58	32	123
Error (%)*	12.1	6.9	12.5	3.3

**Error = (no. of taxonomic species − no. of morphospecies)/(no. of taxonomic species) × 100.*

D were classified as morphospecies 3. These results would have been summarized as one case of correct 1:1 separation (species D:morphospecies 3), one case of lumping 3:1 (species A, B, C : morphospecies 2), and one case of splitting 1:2 (species A : morphospecies 1, 2).

Results and Discussion

Morphospecies and Their Accuracy

The number of individuals collected was 1915 spiders, 455 beetles, and 90 moths. Of these, 273 spiders and 25 beetles were discarded because they could not be identified to a taxonomic level that allowed distinction from other species. Most of those discarded specimens were juveniles, and others were too damaged to identify.

The outcome of the morphospecies separation varied among the different arthropod orders. The numbers of taxonomic species and morphospecies identified were similar for the three groups (Table 1). The use of morphospecies led to a slight underestimation of the true Coleoptera species richness for the site (Table 1), with a ratio of taxonomic species to morphospecies of 58:54. The opposite occurred for Araneae and Lepidoptera, with the number of taxonomic species being overestimated for both orders (32:36 and 33:37, respectively).

Overall, the assignment of 123 species to 127 morphospecies represented a species overestimation of 3.3% (Table 1), suggesting that morphospecies were perhaps reasonable surrogates for taxonomic species. This result is misleading, because overall both splitting and lumping balanced each other out. Species overestimation for Araneae and Lepidoptera was compensated for by the underestimation for Coleoptera. This balancing effect also occurred to some degree within all three orders (Table 2).

Araneae

The frequency of correct separation of Araneae taxonomic species into morphospecies species (1:1) was only 50% (Table 2). The greatest error came from splitting, which accounted for over 32% of the overall separation frequency, indicating widespread intraspecific variation. Splitting occurred in 7 out of the 15 families. The family Theridiidae was the most problematic, with four cases of splitting (indicating considerable intraspecific variation) and two cases of 3:1 lumping (some low interspecific variation).

The identification of spider species is not usually an easy task, because species identity can usually be established only by the examination of genitalia that appear only in the final (adult) instar. Even though it is the most reliable method for differentiating species, the use of such characters is not necessarily straightforward. For instance, most adult female spiders possess a sclerotised structure on the ventral side of the abdomen (epigynum). This structure contains one or two openings to the internal genitalia and is often used as a diagnostic character by spider taxonomists. Some families (e.g., Orsolobidae) lack this feature, however, and in such cases, short of dissecting the spider, it can be difficult to determine whether a specimen is an adult identifiable to species on the basis of its internal genitalia or a juvenile.

For the lay person, separation of spiders may seem a relatively easy task because of their distinct body color patterns, but these more obvious traits are not always reliable. For instance, many New Zealand members of the family Araneidae exhibit a great variety of color patterns within a species, which can lead to overestimation of species because different color morphs may be interpreted as belonging to different species. In other spider

Table 2. Summary of morphospecies (morph) separation for Araneae, Coleoptera, and Lepidoptera showing ratios of taxonomic species to morphospecies and the respective frequencies and percentages out of the total.

		Araneae		*Coleoptera*		*Lepidoptera*	
Separation type	*Spp:morph ratio*	*frequency*	*% of total*	*frequency*	*% of total*	*frequency*	*% of total*
Lumping	4:1	0	0.0	0	0.0	0	0.0
Lumping	3:1	3	8.8	5	9.8	0	0.0
Lumping	2:1	3	8.8	5	9.8	0	0.0
Correct	1:1	17	50.0	32	62.8	30	91.0
Splitting	1:2	11	32.4	7	13.7	2	6.0
Splitting	1:3	0	0.0	2	3.9	1	3.0
Splitting	1:4	0	0.0	0	0.0	0	0.0

groups such as Lycosidae, similarity of color between some species may be a problem and can result in species being lumped.

Sexual dimorphism can also lead to overestimation of species numbers in a morphospecies-based approach. For example, many male Linyphiidae, such as *Diplocephalus cristatus*, have eyes on raised areas of the carapace, whereas females lack these raised areas. An inexperienced worker has little reason to suspect that what they have interpreted as two species may in fact be only one, as happened in this study. Size and color may also differ between sexes, with similar consequences for estimation of species numbers.

Besides problems arising from sexual dimorphism, immature forms can lead to confusion, and the accurate separation of juveniles into species is often impossible. However, the difference in size between juvenile and adult instars is not likely to give rise to errors, because most researchers would assume that two apparently identical spiders of different size are likely to belong to the same species. More problematic is that the coloration of juvenile spiders may differ markedly from that of adults, resulting in an overestimation of species should juveniles be counted as morphospecies. This problem was encountered in our study when numerous juveniles were found, most likely due to the time of sampling (late summer and early autumn). Of the 47 Araneae morphospecies identified, 12 were found by the taxonomist to be unidentifiable juveniles and were consequently excluded. It is therefore possible that the use of morphospecies could lead to a major overestimation of the Araneae species richness within a site. It is also possible, however, that juvenile specimens may represent taxa that are not otherwise represented by adults.

The large number of spiders collected made some subsampling necessary. For instance, the Araneae morphospecies 3 (*Dolomedes* sp.) appeared in the hundreds, so only a dozen or so were kept. However, all the specimens should have been kept and later subsampled in a standardized manner, such as keeping a certain number of specimens for each morphospecies. Keeping few of some morphospecies and many of others could be misleading because it may affect the outcome of the actual ratio of species to morphospecies.

Coleoptera

With the Coleoptera the untrained worker was able to assign specimens to species correctly in almost 63% of the cases (Table 2), with the degree of lumping and splitting being approximately equal. This balancing-out effect, as in the case of spiders, led to the close overall ratio of 54 morphospecies to 58 actual species. As would be expected, errors were made most commonly when several similar species in the same family were present (e.g., small Coccinellidae species and Staphylinidae). The Staphylinidae species were correctly assigned only half of the time, with two cases of 3:1 lumping and one case of 1:2 splitting. Oliver and Beattie (1996*a*) found that in morphospecies assignment of Staphylinidae was most prone to errors.

The Curculionidae presented some problems in morphospecies assignment, with mistakes being made in lumping rather than splitting species. This is understandable because the species involved were mainly broad-nosed weevils (Brachycerinae; Entimini), for which dissection of genitalia is required even by trained taxonomists. As with the Araneae, sexual dimorphism can also be a problem. In the Coleoptera, differences in body size (females typically larger than males) can lead to incorrect splitting of species, although no obvious instances of this occurred here. For families with a distinctive morphology and for which only a single species was present, morphospecies corresponded with actual species quite closely (e.g., in the families Byrrhidae, Tenebrionidae, Ptilidae).

Lepidoptera

Separation of Lepidoptera into morphospecies yielded the best results (91% correct) (Table 2), with a slight overestimation of taxonomic species (33:37) occurring. Such accuracy can be attributed to the generally gross differences in both larvae and adults between various families and many species of Lepidoptera. This allowed accurate assignment (by J.G.B.D.) of specimens to morphospecies based on external morphological characters alone. Despite the fact that Lepidoptera taxonomy is based on adults, the taxonomist (B.H.P.) was able to accurately separate the larvae into different species, even though it was not possible to taxonomically identify them beyond family level in most cases.

Sexual dimorphism of adult moths may have a bearing on accurate separation of morphospecies into actual species, but it was not a problem here. Separation errors can also occur in the families in which individuals are relatively small, such as Nepticulidae and Tortricidae. One case of 1:2 splitting occurred in the Nepticulidae. Some species in the families Geometridae and Tortricidae can be intraspecifically variable, explaining the 3:1 lumping for *Declana junctilinea.*

Conclusions

Probably the greatest constraint on morphospecies inventories is that they work well for some taxa but are not accurate enough for other groups, as shown in our study. Oliver and Beattie (1993) obtained a correct 1:1

separation of 88% for ants, but the ratio for polychaetes was only 43%. Our study indicates that morphospecies separation is not accurate for groups in which species identification is problematic even for experienced taxonomists. Such was the case for species in Araneae and to a varying degree Coleoptera.

To overcome identification errors due to the presence of immature forms, Oliver and Beattie (1993) suggest that including all life stages or sexes may lead to large errors. For some groups such as Coleoptera and Lepidoptera, larval stages are distinct and can be assigned correctly. For other groups such as Araneae, however, we question whether it would be feasible for an untrained worker to reliably discriminate immature forms in practice. Our results therefore suggest that morphospecies are not good surrogates for Araneae species richness. Furthermore, families of Araneae are not always readily distinguishable to the untrained eye.

For the Coleoptera, however, some families are fairly distinct. One promising case is the Curculionidae, the largest family in the animal kingdom (Grant 1999). Weevils are easily distinguished from members of other families. In our study, this family yielded the best results of matching morphospecies to taxonomic species for Coleoptera, with a correct separation frequency of 77.8%. Even this level of accuracy was not considered acceptable, however, and some previous taxonomic training is obviously advisable.

The greatest matching accuracy was achieved for Lepidoptera, with a correct frequency of 91%, and morphospecies appear to provide a relatively reliable alternative to taxonomic species in this family. Prior training would likely improve accuracy still more.

Another problem with the use of morphospecies may arise from the different levels of separation accuracy obtained by different parataxonomists. No studies have looked at this aspect in detail. Oliver and Beattie (1993) used 13 students with no previous taxonomic training to do some morphospecies separation, but they did not discuss in detail the differences in their results, apart from pointing out that the standard deviation from the students was high (mean = 14.4%, SD = 12.1%). Although the level of variation among them is of concern, none of the students had any previous taxonomic training, so it is possible that some prior training of the group would have reduced the problem.

In Oliver and Beattie (1993), the nonspecialist received 3 hours of basic taxonomic training for each group analyzed on the most important and easily identified taxonomic characters and on the possible problems that we discussed above. Although the effect of that level of training on their results cannot be judged, we believe that morphospecies matching accuracy would improve if parataxonomists were to receive one day of taxonomic training from a recognized expert. We have anecdotal evidence from students working with Coleoptera, that even a couple of hours of training can greatly increase accuracy.

An important aspect of morphospecies studies, which must be factored into any studies using this approach, is that morphospecies–taxonomic species relationships potentially vary across invertebrate groups, so it is important to assess the relationship for a particular invertebrate group before proceeding. The assessment has to be based on the frequency of accurate separations and not on the overall difference between the taxonomic species and morphospecies estimates. The latter can be misleading. In our study, for example, there was an overall overestimation of four species for both Lepidoptera and Araneae, whereas the frequency of correct 1:1 separation was 91% for moths and only 50% for spiders.

The availability of published keys may also influence the standard achieved by biodiversity technicians (Cranston & Hillman 1992). Most keys require good biological knowledge, however, especially regarding the morphology and anatomy of invertebrates, largely limiting the range of people that could be employed as parataxonomists. The development of tools to assist parataxonomists is highly desirable, and the biggest improvement for the accuracy of morphospecies matching may be through information technology (Oliver 1999). The use of virtual biodiversity assessment systems (Oliver et al. 2000) is promising. They allow the storage of large quantities of textual and photographic data on invertebrate species and quick access to large databases through the Internet. Such tools will make identification of specimens much easier, quicker, and more accurate (Oliver & Beattie 1997; Beattie & Oliver 1999; Oliver et al. 2000).

Morphospecies have potential use in conservation, mainly for environmental impact assessments and for inventorying and comparing species richness between similar sites at a local or regional level, but their accuracy must be tested for particular invertebrate groups. Furthermore, caution should be exercised in extrapolating the morphospecies–taxonomic species relationship from one habitat to another. We cannot overemphasize the importance of invertebrate taxonomists. They are relatively few in number, however, and the morphospecies approach provides a mechanism for the efficient use of their expertise in an era of accelerating biodiversity loss.

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