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Terrestrial Arthropod Biodiversity Projects
– Building a Factual Foundation

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Abstract

Guidelines for conducting studies of arthropod biodiversity properly are reinforced using results from selected recent studies in Canada. The costs for doing such work are also given explicitly. The necessary components of a biodiversity study, and selected examples, are briefly tabulated for ready reference. Careful advance planning should include explicit scientific objectives and ways to ensure that the work proceeds to completion. Work on more than one taxon is necessary, because neither patterns of species richness nor relevant ecosystem involvements can be extrapolated from one taxon to another. Plans for identification, normally to species, are especially important, requiring specific collaboration with systematists. Protocols for sampling, sorting, specimen preservation and data management should be clearly defined and costed. Curation and retention of specimens and ongoing scientific and other publications are also essential if projects are to have real long-term value. Examples and references illustrate how these components can be developed. Proper support for studies of biodiversity, as opposed to superficial promotion of its importance, therefore requires mechanisms to provide stable long-term funding.

Projets sur la biodiversité des arthropodes terrestres – établissement d'une base de travail

Résumé

Des exemples d'études canadiennes récentes sur la biodiversité des arthropodes viennent valider les directives suggérées précédemment pour ce genre de travail. Les coûts reliés à ce type d'étude sont évalués de façon détaillée. Les composantes essentielles d'une étude de la biodiversité, de même que des exemples choisis, sont présentés ici sous forme de tableaux de référence simples et commodes. Une planification soignée suppose l'identification des objectifs scientifiques précis et des méthodologies qui assureront la bonne marche du projet jusqu'à la fin. L'étude de plusieurs taxons à la fois s'impose, car ni les patterns de la richesse en espèces, ni l'influence des variables écologiques ne peuvent être extrapolés d'un taxon à un autre. L'identification des organismes, normalement jusqu'à l'espèce, est un aspect particulièrement important et requiert le concours de taxonomistes reconnus. Les protocoles d'échantillonnage, de tri, de conservation du matériel et de traitement des données doivent être définis clairement et leurs coûts évalués. La mise en collection des spécimens et la planification des publications scientifiques et autres sont aussi essentielles pour garantir l'intérêt à long terme des projets. Des exemples et des références viennent illustrer comment ces composantes peuvent être agencées. La réalisation d'études de la biodiversité qui soient plus que de simples exercices de relations publiques suppose donc la mise en place de mécanismes propres à assurer un financement continu sur une longue période.

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Introduction

Interest in studying biodiversity, including that of arthropods and other invertebrates, increased following the International Convention on Biodiversity that was signed following the landmark meeting in Rio de Janeiro in 1992. This convention was followed up in Canada (e.g. Canadian Biodiversity Strategy 1995), and as a result increasing numbers of studies on biodiversity began. However, not all of them were based on detailed knowledge about the true, very great, extent of arthropod diversity nor on realistic plans for its assessment. To foster more fruitful approaches, the Biological Survey of Canada produced two briefs offering prescriptions for how to carry out work aimed at assessing and interpreting the composition of the fauna (Marshall et al. 1994; Danks 1996).

The results of recent work in Canada is now becoming available. General information from elsewhere is also accumulating (compare Groombridge 1992; Stork 1994; Stork et al. 1997; New 1998; Redford and Richter 1999; some of the papers on methods cited below). This brief therefore takes stock of the guidelines proposed earlier. Such an examination has proved to reinforce most of the original prescriptions, because we are able to outline the positive rewards of following nearly all of them. Here, we emphasize Canadian work familiar to us, especially work in ancient forests in western Canada, although some of the same points could have been made using other examples.

The examination reinforces earlier contentions that doing things properly pays off, whereas dabbling in biodiversity is a waste of resources. In other words, effective studies to establish a firm factual foundation for understanding biodiversity demand scientific focus and detailed planning for all aspects of the work.

Scope and scale of the work

Because arthropods are so diverse, effective study of their diversity requires a relatively large scope and a relatively long time frame. The main focus here, therefore, is on major projects. However, studies of smaller scope (such as discrete graduate student projects) can make key contributions, especially if they address key themes, questions or taxa within the context of a larger investigation. For example, investigations of biodiversity have been made in relation to forest age for a series of taxa in Newfoundland (Arulnayagam 1995, Puvanendran et al. 1997 for springtails; Dwyer 1995, Dwyer et al. 1997, 1998 for mites; McCarthy

1996 for beetles), and for different forest practices in Alberta (Niemelä et al. 1992, 1993, 1994; Langor et al. 1994; Spence et al. 1996, 1997; see also http://www.biology.ualberta.ca/emend/emend.html) and in British Columbia (Lavallee 1999, Craig 1995, McDowell 1998, Lemieux 1998 for carabid beetles; Brumwell 1996 for spiders). These investigations illustrate the importance of working within a defined conceptual context, which can involve a focus on patterns of diversity (such as species richness) or a focus on processes relevant to ecosystem integrity (such as the effects of disturbance) which function through species and their interactions. Broad assessments of diversity have been initiated in Quebec (Paquin and Coderre 1997a, b), Ontario (e.g. Blades and Marshall 1994), Alberta (e.g. Finnamore 1994; Hammond 1997) and B.C. (e.g. Blades and Meier 1996; other studies cited below). Studies of insects and other groups on the Brooks Peninsula, BC, were carried out in the context of the possible existence of a glacial refugium in the area (Cannings and Cannings 1997). All of these investigations confirm the need to plan for the long term and especially for the inclusion of a wide range of taxonomic expertise.

Information on biodiversity is linked closely to scale. Biological relationships differ at different levels, on a range from microhabitats, sites, landscapes and regions to global patterns. For example, characteristic taxonomic patterns change with latitude (Danks 1981, 1992, 1993). The predominance of particular functional groups or the dominance of particular taxa changes according to the spatial context (cf. Anderson 1997; Niemelä 1997). Therefore, typical studies should be designed to address several different scales, because it is not always clear beforehand at what scale particular processes or patterns operate. Moreover, results for one scale cannot simply be extrapolated to apply at a different scale.

Steps in biodiversity assessment

An adequately planned scientific study of biodiversity requires attention to a large number of steps, from initial objectives and planning to the disposition of specimens and the publication of results (Danks 1996, 1997). These steps, and their potential benefits, are outlined in the first two columns of the Appendix. The final two columns of the Appendix outline selected specific studies that confirm these benefits, with references for the examples. The sections below provide further details and examples of these essential components.

General Planning

The scientific objectives of a biodiversity study should be made clear from the outset, so that work can be targeted at both longer-term and shorter-term results of interest.

Establishing the richness and relative abundance of species in specific habitats makes data available as a *long-term reference* for future use. For example, individuals of the predator guild, composed primarily of arachnid species, are numerically dominant in various sites in the ancient forest canopy. Such numerical dominance (e.g., Voegtlin 1982; Winchester 1997a, 1998; Winchester and Ring 1999) helps to characterize these systems for current and future comparison. The need for detailed work to establish a reliable basis for comparison is confirmed by the fact that the number of species in different sites is similar, but the actual spider communities are dissimilar (e.g. Halaj et al. 1998). For example, only five of the many spider species were shared by all of the three ancient forest sites (Mt. Cain, Carmanah, Rocky Point) studied in this respect in British Columbia (Winchester and Ring 1999).

Specific objectives also are very important for the relevance and continuity of a study. For example, the impact of changes can be assessed by properly designed studies, provided the objectives are considered at the outset. Thus, comparison among forest sites of different ages and histories can provide information to resolve conservation and other issues: ancient forests differ in guild structure and other elements even from relatively old second-growth ones, and apparently certain species persist only in the ancient forests (Battigelli et al. 1994; Arulnayagam 1995; McCarthy 1996; Spence et al. 1996, 1997; Brumwell et al. 1998; Carey 1998; Winchester 1998; Fagan and Winchester 1999). However, the prevalence of species characteristic of older stands varies among taxonomic groups (see below).

A shorter-term objective of particular current interest concerns the impact of introduced species, which can be evaluated using standard protocols. An example is the tracking of bark beetles (Scolytidae) in western forests using specific sampling procedures, long-term monitoring, and an extensive reference collection (L. Humble, pers. comm.)

Work focussed on key groups can provide valuable information about specific habitats after a relatively short period of time. For example, some species characteristic of the canopy of ancient forests are rare and potentially endangered (Campbell and Winchester 1994; Winchester and Ring 1996; Winchester 1997b; Behan-Pelletier and Winchester 1998; Marshall and Winchester 1999; Walter and Behan-Pelletier 1999; Behan-Pelletier 2000; Humble et al. 2000).

Proper general planning also profits from *assembling previous knowledge* and experience. Such aspects are treated by Danks (1996) and Winchester (1999b); see under Sampling methods for more details.

Coupled with these plans in the context of the project objectives, a well constructed *overall plan* is required to define the focus and the availability of resources for the project. A focussed study asks specific questions from a scientific perspective, and so is more valuable than an inventory alone. For example, some species and habitats are especially sensitive to change from human activity. The canopy of ancient forests has “suspended soil” habitats that are easily disrupted (e.g. by timber harvesting) and all but impossible to recreate, because second-growth stands, even those 80-120 years old, do not have well developed suspended soils. Certain species of oribatid mites are characteristic of the suspended soils in these ancient forests (Behan-Pelletier and Winchester 1998; Winchester et al. 1999), and would be especially sensitive to environmental impacts. Other taxa, such as mites of the family Zerconidae, and certain springtails (Fjellberg 1992) also have distinct arboreal components.

A major requirement of the overall plan is collaboration with systematists and ecologists, before the project begins, to help select key taxa, design the sampling, and ensure identifications. The importance of systematics in this context cannot be overemphasized (cf. Danks 1996; Vane-Wright 1996). Also, the *flow of resources must be adequate* to complete the project. Without explicit attention to longer-term resource needs, there will probably be little pay-off from the work in the form of curated specimens, reliable and accessible databases, publications, and conclusions useful to support further action. An analysis of various resource trade-offs of this sort was made for a major project on forest biodiversity monitoring in Alberta (Schneider et al. 1999; Winchester 1999b).

Overall planning also requires *statistical* expertise early in study design, because methods of analysis must be appropriate to test the objectives of the study. Because any particular statistical program or analysis requires that data be entered and stored appropriately, initial datafiles have to be set up properly to favour comparisons. For example, including taxa from all sites and treatments in a single database (so that absence as well as presence is explicit for a given site) allows statistical analysis for differences, and avoids the need to transcribe data from separate "presence only" lists of taxa. Thus most statistical analyses of species richness and abundance require that sites (treatments) form the columns of data and that species (items) form the rows: zeros show absence and numbers of specimens show abundance. Statistical programs normally treat such issues in their documentation (e.g. Systat 1996.)

Detailed Planning

Within the framework of a general plan, important planning decisions have to be made in more detail, especially the level of identifications, the selection of sites, the target taxa, and the duration of the study.

Detailed information of most value for the project normally comes from *identification to species*. In general terms, of course, species names are used to access all biological information (e.g. Danks 1988), so that identification to species allows much wider information to be brought to bear on the results. In particular, attributes that determine the meaning or importance of the results, such as habitat specificity, range, or biological interactions typically are visible only at the species level but not at higher taxonomic levels. For example, many species of arthropods occur only in the high forest canopy, but such arboreal specificity cannot be detected at the family level, as for oribatid mites (Walter and Behan-Pelletier 1999). Differences among spider communities from similar habitats in different geographical regions are visible only from differences in species composition, and not from general measures such as species richness or distinctions at higher taxonomic levels (see above; Winchester and Ring 1999). In this and other contexts, the most striking conclusion about biodiversity studies is that there is very limited resolution without species identifications (Cross and Winchester 2000; Fagan 1999). Of course, such interspecific differences occur on a variety of spatial scales (see above), requiring deliberate decisions about the scales on which sampling will be carried out.

Material is analysed in a sequence, formalized into a series of 7 steps by Winchester (1999b). Each successive step adds complexity (and cost) to the analysis, but at the same time increases sensitivity. The first three steps require arthropod sorting to ordinal or family level, but give only coarse-grained resolution. Subsequent steps require identification to species for the designated target taxa, but provide fine-grained sensitivity to answer biodiversity questions. Useful information about trophic interactions can sometimes be obtained by analysis of guilds at the family level, for example, but typically higher-level sorting is only a staging point in the resolution of pivotal questions using species-level identifications.

An *ideal site* for study would be accessible, discrete, stable, well characterized and representative (Danks et al. 1987; Danks 1996). Such a site makes sampling efficient. Of course, the sites should also be relevant and adequate for assessing the target taxa. In practice the choice of a site will be a trade-off between such things as ready access to a close-by area where a complete sampling program can be carried out relatively cheaply, and a unique, unexplored area of great scientific and conservation value but involving a large cost because of its relative inaccessibility. For example, work in the Carmanah Valley, British Columbia, was led by a high conservation concern for a unique and previously unsampled habitat that includes the world's largest Sitka spruce trees. Therefore, residues (such as the Diptera sorted to family) from multiple samples from this unique site were stored for future benefit (see below).

The *choice of taxa* for the initial work depends on the scientific objectives, but may be modified by the relative ease of trapping or identification. Nevertheless, using feasibility alone to select taxa is not desirable. In several studies carabid beetles have been chosen almost by default because they can be identified relatively easily, and not necessarily for biological clarity in addressing the project objectives.

Because detailed study is costly, many workers have tried to identify "indicators" — characteristic or surrogate species or sets of species — that could serve as a "magic bullet" to describe and evaluate ecological conditions (see McKenzie et al. 1990; McGeoch 1998). Valid indicators would greatly reduce the need to cope with the true diversity. Unfortunately, the criteria used to select indicators are seldom based on objective information. Specific indicator choice generally has not been supported by scientific findings or methodology, although useful procedural steps for justifying the choice are given by McGeoch and Chown (1998) and Dufrêne and Legendre (1997). At present there is little evidence to suggest that any taxon or group of organisms qualifies as a universal biodiversity indicator. This is true from a broad faunal viewpoint, but also for more specific questions. For example, in the study by Neave (1996), species confined to old-growth forests were present, but not in this study among the carabid beetles, the group most often studied in such habitats in Canada and for which old-growth specialists have been claimed elsewhere (e.g. Spence et al. 1996). Results for one taxon do not predict results for another over different spatial scales (e.g. Lawton et al. 1998; Prance 1994; Williams and Gaston 1994; Niemelä 1997). This finding is not surprising, because ecological patterns and processes depend on scale (see above), and different groups differ in local species richness, endemism, habitat association or specificity, vagility and so on (e.g. Prendergast et al. 1993). Some insects are relatively insensitive to environmental factors of potential interest (e.g. Whitford et al. 1999). Faunal composition is dynamic over time (e.g. Ellis et al. 1999). In other words, ecosystems are complex, so that multitaxa approaches (e.g. Hammond 1994) are more realistic.

A second type of short cut in work on biodiversity is the use of summed statistics, often based on supraspecific taxa and usually called biotic indexes. These indexes are supposed to allow simplified comparisons with "normal conditions" or with other sites. They are best developed for "rapid assessment" of aquatic systems (e.g. Washington 1984; Hilsenhoff 1988; Klemm et al. 1990; Rosenberg and Resh 1993; Cao et al. 1996; Pflakin et al. 1989). Some of them merely give numerical scores to specific "indicator" organisms (see above). However, others rely on more or less extensive calculations from the taxonomic composition or abundance at a given place (compare McGurran 1988 for the calculation of various indexes; Colwell 1999b chiefly for estimating species richness). Typically, they confirm obvious differences, but their validity for assessing subtle differences is far from clear. Indeed, different and more useful results are obtained when working at the species level (which takes account of individual species biologies) than by using a particular biotic index. For example, recommendations to prevent the decline of a rare species dependent on a particular foodplant or on a key microhabitat would not emerge from a statistic based on insect community structure.

Given these difficulties, there is no clear consensus as to which groups or species best allow environmental changes to be assessed. Few attempts have been made to contrast attributes that might confer susceptibility or resilience to habitat change. Individual species responses are the key to understanding and measuring these impacts, but species so far examined in biodiversity studies in northern temperate forests might be atypical of the majority of invertebrates because they are taxonomically convenient (e.g., carabid beetles: Huhta 1971; Holliday 1991; Niemelä et al. 1993; Spence and Niemelä 1994; Spence et al. 1997), conspicuous (e.g., butterflies: see Davidar et al. 1994), broadly distributed geographically (see Platnick 1991; Danks 1993, 1994), or have specific habitat requirements (cf. Danks 1979). Moreover, experiments have not always been designed to resolve the effects on local biodiversity of factors such as habitat loss, degree of spatial or temporal isolation, and dispersal capabilities, which influence different taxa to widely different degrees. In other words, ecosystems are heterogeneous (cf. Niemelä 1997), the species richness of different taxa is not well correlated, and limited or arbitrary choices of the study taxa are unwise.

These complexities confirm that it is necessary to sample and assess more than one taxon, and to include the diversity associated with different habitats at different spatial scales. Focussed collecting by collaborating systematists in addition to the standardized trapping is very helpful for such assessments. By the same token, biological features of the taxa should also be considered explicitly in the context of the study. For example, groups characterized by many species with wide distribution and high ecological valency are less likely to point to key microhabitats than are groups with many distinctive stenotypic species.

Finally, because most research on arthropod biodiversity relies on multiple traps, many arthropods will be trapped that do not belong to the initial target taxa. However, these residues are likely to hold the answer to many questions, because we do not necessarily know in advance which group might be suitable to seek the answers, especially because biodiversity concepts, questions and analytical tools evolve over time. Assuring proper curation and availability of the residues therefore is of great future service (see curation below).

The *duration of a study* depends on its objectives. Valuable information, for example about habitat associations, can be gained by short-term inventories, but long-term events cannot be assessed from data for a single season. Even simply assessing the richness of a particular group requires sampling at least throughout the active season. From a practical point of view, whether duration (and sampling methods) are adequate to document richness can be assessed by plotting species accumulation curves: the increase in number of species and its seasonal pattern help to show how likely it is that the samples give a valid estimate of the real diversity (see Coddington et al. 1991; Soberon and Llorente 1993; Colwell and Coddington 1994; Longino 1994; Longino and Colwell 1997; Colwell 1999a).

Sampling and Sorting

Multiple rather than single sampling methods usually are desirable. Using a variety of trapping techniques increases the numbers of species sampled, covers more habitats at a particular study site, and samples a range of species with different vagility. These findings apply to insect orders, and apparently also to families and species (Southwood 1968; Blades and Maier 1996; Winchester and Ring 1996; Winchester 1999b). For example, adding Lindgren traps to pan or pitfall trap sampling increases the number of beetles caught, and catches additional species (L. Humble, pers. comm.).

Making the sampling methods standard is very important to allow meaningful, including statistical, comparisons. For example, standardization allows comparisons of sites, forest ages, and so on (e.g. Spence et al. 1997; Trofymow and Porter 1998). Trapping specifications, including trap type, trap construction and sample design were tested in several large-scale biodiversity studies in Canada and the results (although typically they were not formally published) were used to improve sampling recommendations summarized in Marshall et al. (1994), Winchester and Scudder (1994), Behan-Pelletier et al. (1996), Finnamore et al. (1998) and Winchester (1999b) (see also Paquin and Coderre 1996; for a tropical site see also http://viceroy.ecb.uconn.edu/ALAS/ALAS.html). The progression and development of these standard protocols, and the evolution of the ideas from 1994 until the present day, was expedited through rigorous field work, collaborations among researchers, and the ability to make firm comparisons based on properly curated reference collections and secure permanent sample sites. Aspects of these standards, covered in detail in Winchester (1999b), include the sampling protocols and logistics appropriate for monitoring, detailed costing for time, equipment, processing and storage of data, integration of data, archiving target groups and residues and the infrastructure needed to complete the entire field and laboratory segments of the project, as well as data management considerations.

Because biodiversity sampling of arthropods produces so many specimens, procedures must be as *cost-effective* as possible. Specific analyses of cost are a relatively recent development (Marshall et al. 1994; Scudder 1996; Winchester 1999b; see section on costs below). Cost-effective sampling also comes from fine-tuning procedures for access, sampling and trap placement over time (Winchester, pers. obs.).

The significance of differences to answer ecological questions or test hypotheses can be assessed only with adequate sample design, including *replication* (cf. Krebs 1989, chap. 8). Some ways exist to assess the numbers of replicates needed (see references under Duration of a study, above; Didham et al. 1996). Unfortunately, explicit statistical tests (e.g. ANOVA) are still relatively rare in studies of arthropod biodiversity and the high cost of sampling and sorting misleads many workers into using an inadequate number of replicates.

Sampling must be done carefully. The only way to ensure *quality control* for a large-scale project is to formalize the relevant protocols. For example, the field crew for a pilot project on Alberta forest biodiversity was trained prior to the start of the pilot project in all aspects of the program, according to established procedures for trap installation and other details (D. Farr, pers. comm.; see http://fmf.ab.ca/pro.html).

Sorting is more labour-intensive than sampling: *sufficient time for sorting* must be planned for, as well as its substantial costs (see section on costs below). Note that the efficiency of individual sorters also differs. In all cases, formal protocols for sorting (to avoid cross-contamination of samples, for example), and preservation and curation are needed (see below). Providing continuing positions for trained people, such as parataxonomists and biodiversity technicians, increases the efficiency of sorting and ensures that only as much material as necessary will be prepared further for identification.

Specific procedures for mounting specimens should be obtained from the taxonomists who are collaborating in the project, because each taxon (and even each scientist) has particular requirements. For example, sphaerocerid flies are best prepared by critical-point drying, pompilid wasps require male genitalia to be exposed to aid identification, braconid wasps can be prepared using amyl acetate, and oribatid mites must be correctly mounted on microscope slides to avoid damage and leave key characteristics visible.

Sorting procedures depend especially on the level of sorting, but a hierarchical process is most efficient. For example: 1. Target all Coleoptera from all traps (storing residues properly after Coleoptera have been removed), and enter Coleoptera data into a database; 2. Target specified families from the Coleoptera sets, and store the rest of the Coleoptera as residues; 3. Mount and enumerate all specified families, involving recognition of morphospecies and association with data labels; 4. Proceed to identification by group as required.

It is also essential to develop a system for tracking each specimen and data on its trap, site, date of collection, etc., so that the ecological information associated with each specimen (some of which may be retained by specialists) can be retrieved for the project analysis (see also data management below).

Identification

Identification to species is especially important to interpret results, but requires particular care in planning because there are so many species, many groups are inadequately known, many others are difficult to identify, and taxonomic resources especially specialists are in short supply. For additional discussion, see above under Detailed planning. Collaboration with taxonomists is especially important to ensure that they will be able to budget the necessary time.

Several simple steps facilitate identification. For example, it is necessary to *prepare and ship material* so that it arrives undamaged (e.g. Martin 1977). Hand delivery is often the best choice. Shipment details vary with the type of specimen and the destination, but some organizations have developed formal internal protocols for their own loans or other purposes.

Information provided with specimens can assist identification (and in turn a specialist may then be able to supply useful ancillary information about the taxa). If *mass collections are supplemented* by other material, the task of identification can likewise be made easier. For this purpose, as well as more generally, working with a taxonomist in the field can lead to optimal use and placement of traps and a better understanding of basic biology of the target group, which may help to focus on key hostplants, for example (e.g. Goulet 1996 for sawflies in Strathacona Park, British Columbia).

Such arrangements exemplify *collaborative work*, which has many benefits for both parties. For example, results from broader studies can add to knowledge of species distributions at provincial or national levels, and unique or duplicate specimens can be retained for collections and publications at no cost to the specialist in return for identifications. Published results of such collaborations address ecological and taxonomic themes (including descriptions of new species), for example Fjellberg

(1992), Campbell and Winchester (1994), Lindquist (1995), Behan-Pelletier and Winchester (1998), Winchester et al. (1999), Marshall and Winchester (1999) and Coher (1995, 1999).

It is important to allow *sufficient time for the identifications*. For example, the summary report about invertebrates of the montane forest at Mount Cain, B.C. (Winchester 1999a) contains 4 published or in press papers and an MSc. thesis, reflecting a long-term perspective and the sort of output, validated by peer review, that is desirable (see Results and Completion below). Results from the major study of arthropod biodiversity at Carmanah continue to be published 7 years after the start of the project. Such a pattern will continue as the necessary taxonomic research is completed, confirming the need in any study of arthropod biodiversity for long-term attention to identification.

Results and Completion

Proper payoffs from a study are not possible without explicit attention to how data management, curation and publication will be planned for and completed.

A *data management system* should allow all information to be entered in a standard way from the beginning, so that data do not have to be reformatted or re-entered at a later stage. Specific attention should be given before the project begins to how data will be analyzed statistically (see under General Planning above). Ordinary database or spreadsheet software (e.g. Access, Excel) can be used for databases of smaller scale. Several systems allow much greater sophistication, for example "Biota", which helps to manage specimen-based biodiversity and collections data by providing an easy-to-use graphical interface to a relational database structure (Colwell 1999a). It is important that the taxonomic and geographic information is reliable as well as accessible (Mickevich 1999).

Databases of larger scale require full-time database managers. Extensive use of such data requires cooperative endeavours to develop standard fields (cf. Noonan 1990) and to permit information with different origins to be accessed electronically. Such larger concepts are being addressed by a number of working groups and pilot projects (cf. Umminger and Young 1997; ITIS.ca 1999). Distributed databases coordinated through a central infrastructure show particular promise.

Proper curation (including labelling, storage and access) and retention of voucher specimens is essential for two reasons. First, specific comparisons can be made during the project. Second, later work can be compared or validated effectively. From a general viewpoint, of course, the value of museum collections in these contexts has been stated many times (e.g. Danks 1988, 1991; Wiggins et al. 1991). Such values include the basis for taxonomic work (including type specimens and material for species descriptions) and for ecological work (including association between species and habitats). For specific biodiversity projects, collections often have to be revisited to answer taxonomic or ecological questions and to refine the database, which can only be done if the material is properly organized. A well organized collection saves resources (both for mounting, and the time of specialists), because a large percentage of any trap catch is composed of relatively few species with many individuals, and for many taxa a reference collection allows these species to be identified easily. Such reference uses within the project itself mean that material should be properly preserved and mounted, as indicated above.

Much of the value of typical biodiversity samples of arthropods comes from later use. About 94% of most Malaise-trap catches in ancient forests are Diptera, but no taxonomic experts are currently available for many groups. Therefore, most dipteran groups would not form the initial focus of a project. However, given the ecological importance of the Diptera, there is great value in properly curating these specimens. Material extracted from the Carmanah residues (preserved as explained above under site selection) formed the basis for subsequent studies of mycetophilids, syrphids and sphaerocerids (Coher 1995; Samoszynski 1998; Marshall and Winchester 1999).

Any project that will generate extensive material therefore needs a plan for long-term curation at an institution equipped to do so. For example, collections, especially from some of the projects referred to in this brief, have been consolidated though the participation of the Pacific Forestry Centre in Victoria (Canadian Forest Service), which now acts as a repository for all of the ancient forest arthropods from projects in British Columbia. Conversely, the Royal British Columbia Museum was unable to incorporate these collections.

Proper publication of results is essential to profit from biodiversity studies in the long term, because general patterns are likely to become visible only when a range of sites from different areas and habitats can be compared. On the other hand, typical consultant and other reports that have not been validated through the process of scientific publication are of very limited value. Recent findings, already cited, that are visible from peer-reviewed publications include the facts that ancient forests are source areas of high arthropod diversity; that this diversity applies to several groups; and that certain habitats, and their associated species many of which are undescribed, are found only in ancient forests (and not in second growth areas), including unique microhabitats such as suspended soils. In turn, these findings suggest that retaining diverse habitats is the key to meeting biodiversity commitments.

Such results can also be put to wider use beyond dissemination to scientists. Objective information about the Carmanah Valley was made available to a wide-range of user groups by means such as popular articles and a web site (http://web.uvic.ca/~canopy, which lists other relevant items). Such information for general audiences helped to foster the establishment of Park status for the Carmanah site, for example.

Ongoing publications therefore lead to greater understanding and appreciation of the systems studied. They also tend to lead to growing interest in the sites, as manifested (e.g. for the ancient forest sites emphasized here) by increasing collaboration for work on additional taxonomic groups, increasing interest in the sites and the collections by potential graduate students, national collaborations with interested agencies, and coverage by print and electronic media.

Costs

The costs of proper studies of biodiversity often have been underestimated, because resources have to be made available over the whole period from initial planning to completion and documentation, and because many tasks are very labour-intensive. However, ongoing documentation of costs is very useful for steering long-term projects. A synopsis of realistic costs for various stages of a study are given here.

Costs for sampling and sorting

It is necessary to sample and sort using a reasonable number of replicates, with a few selected techniques, for a diversity of taxa (as discussed above), so that the total cost is significant. Tables 1–3, derived from careful documentation of earlier efforts, shows sample elements of the cost of traps, and typical expenses for sampling and sorting. The tables show that materials and technical assistance for a general survey of terrestrial arthropods with initial sorting to order, and then to family only for the flies, would be expected to cost more than $10,000 per site per season. This cost would comprise $2016 (cost of traps, Table 1) + $1350 (installation and servicing, Table 2) + [$1512 (family sort for Malaise Trap samples, Table 3) x 5 (assuming similar catch and effort for other trap sets)]. It is not realistic to trim the trap and servicing costs ($3366), because they reflect the intensity of effort that is necessary to secure reliable data. The cost of sorting depends partly on the careful selection of taxa *with reference to the study objectives*. Sampling and sorting aquatic insects is also very time-consuming (e.g. Ciborowski 1991), taking at least as long as for the examples given here.

Table 1. Summary of minimum equipment costs ($$ Canadian) for a complete set of traps for a single site (from Winchester 1999b).

	Malaise	Pitfall*	Pan+	Lindgren	Soil/ litter extraction	
Single trap	300	2.50	3	47	82	
No. of traps per site	3	10	10 (12)	12	6	
All traps at site	900	25	30	569	492	
Grand total per site						$2016

*Pitfall traps include cups and covers.
+(12) pans are the pans placed under the Malaise trap.

Table 2. Estimates of minimum costs for installation and servicing of a complete set of arthropod sampling traps for one site, comprising 3 Malaise, 25 Pitfall, 10 Pan, 12 Lindgren, 6 Soil and 3 Litter traps or samples (from Winchester 1999b).

Trap	Time (hours)	Cost ($$ Canadian)
Installation of all traps	12	180
Single servicing of all traps	6	90
Servicing of all traps for the season	(12 visits)	1080
Total seasonal cost (1 site)*		$1350

*Total cost is based on an experienced field crew of 2 people, working for $15 per hour and does not include travel time or benefits.

Table 3. Summary of minimum costs associated with sorting for selected taxa in 30 Malaise trap samples collected from a single study area on Vancouver Island (from Winchester 1999b). Total cost for one site is then calculated from the mean sort time (see table), recommended number of traps per site (3) and recommended number of samples per season (12).

Variable	Mean	Standard deviation	Minimum	Maximum	Range
Ordinal sort – All orders in samples					
No. of Orders	14.9	2.5	8	19	11
No. of individuals	6,482	3,687	1,214	14,088	12,874
Sort time (hours)	9.3	5.9	2.5	26	23.5
Family sort after Order-level sort – 17 Families of the order Diptera					
No. of Families	5	3	1	15	14
No. of individuals	5,342	3,321	852	12,183	11.331
Sort time (hours)	2.8	4.5	0.25	18.5	18.25

Estimated cost for 1 site @ $15 per hour:

	Mean per trap sample	3 traps for the season
Order-level sort (9.3 hours)	$139.50	$5,022
Family-level sort after Order-level sort (2.8 hours)	$42	$1,512

We emphasize in the context of these estimates that for nearly all purposes cheaper short cuts have not been validated. Those tempted to trim costs should note the pitfalls of using short cuts, discussed above under Detailed Planning. Money spent for data that cannot be interpreted is wasted.

Costs for identification

The cost of obtaining independent identifications to species, even if expertise exists and is available for hire (an assumption not often met), varies with the group but normally is very high because in most groups developing the ability to make accurate identifications requires specific long-term experience. For example, expert identification to species is offered by the Entomology Department of the Natural History Museum of London at a cost for each ordinary specimen equivalent to about $150, and even more for difficult specimens or groups (see http://www.nhm.ac.uk/entomology/insident/). On this basis, the identification of a modest range of arthropod material from one site would cost many thousands of dollars. Specific identifications made more cheaply by *generalist* contractors are likely to be unreliable.

Therefore, the direct costs of obtaining independent identifications from qualified systematists normally are avoided by involving systematists closely in the planning, execution and publication of biodiversity studies.

Costs for curation and publication

Adequate follow-up requires curation at least of voucher material, and the publication of results.

The cost of curation has been established for a number of taxa. It is especially high for large vertebrates, but for most arthropods the cost of bringing a specimen into a collection and documenting it ranges from about US $0.25 to $4.00, or $5.00 per lot (West 1988; see also Anderson 1973). The subsequent annual storage and maintenance cost for insect specimens, mainly for housing and adequate environmental control, is much lower if the material is simply stored rather than worked. Nevertheless, acquisition and long-term preservation of a substantial voucher collection costs thousands of dollars (compare Lord et al. 1989b and preview in Lord et al. 1989a; Lord 1991) and two thirds of the operating costs of typical museums are devoted to direct and indirect costs associated with collections (Lord et al. 1989a). However, both the cost of obtaining properly sorted and preserved material and its long-term value for research and reference is many times the cost of curation (cf. Wiggins et al. 1993).

Publication in generally available, peer-reviewed, journals requires significant time and expertise, even if page charges and similar costs can be avoided by the choice of particular journals. Studies of biodiversity conducted by consultants therefore suffer from the great weakness that not only may there be little incentive to publish, but also the cost of employing qualified personnel to prepare appropriate manuscripts (as opposed to much less rigorous reports) is not normally included in the contract price.

Conclusions

This review of some recent results in the light of previous recommendations for biodiversity studies strongly confirms the earlier advice. The necessary procedures can be summarized quite simply – do things properly:

1. Think through the scientific objectives carefully, which will help to define the target taxa and sites.
2. Make sure that full advantage is taken of existing information, specimens and publications.
3. Plan the sample design and select traps and other components after detailed consideration of the project needs.
4. Plan explicitly for expert identification of material, normally including a focus on species rather than higher taxa, and seek early collaboration with systematists.
5. Define the actions to be taken in detail, using clearly defined protocols for sampling, sorting, specimen preservation, and data management.
6. Ensure that resources and plans are in place for the long term, including curation of specimens in a permanent repository, and publication in the scientific literature and elsewhere.

Knowledge of arthropod biodiversity and resources for reference can be built up for wide long-term benefit using this procedure, instead of consuming funds on short-term projects that generate non-standard data of limited detail. In other words (contrary to some hopes or expectations), proper studies of arthropod biodiversity cannot be done over very short time frames. Cheap and limited efforts in isolation will produce worthless results. In particular, it is worth noting that even when the specimens have been collected only a very small percentage of the work has been done. The major data come from sorting and identification, and their major value comes from analysis and dissemination.

Securing funding for biodiversity studies for the long term rather than the short term therefore is the key need, both for overall scientific payoffs and for logistic reasons such as maintaining secure sites, keeping trained field and laboratory crews in place, and allowing appropriate taxonomic expertise to be developed. For many years, lip service has been paid to long-term biodiversity issues, such as environmental sustainability. It now has to be matched by long-term support for research, so that a sound factual foundation can be established from studies of biodiversity that are done properly. Otherwise, the apparent concern with biodiversity exemplified by the International Convention is illusory.

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Appendix

Recommended procedures for biodiversity studies (based on Danks 1996), and examples of the benefits of following them. For further details and examples see text.

Component of study	Benefit of proper procedure	Specific example of benefit	References
Define objectives			
Establish long-term baselines	Comparison with other systems	Identification of spider fauna from ancient forest sites shows the general importance of the predator guild there	Winchester and Ring 1999
	Future use	A reference baseline has been made available for important ancient forest habitats. Also, detailed work has led to tested and effective protocols for study (see below)	Winchester and Ring 1999; Winchester and Fagan 2000
Obtain specific answers, e.g.:			
Impact of change	Experimental design allows valid comparisons	Differences in the fauna associated with forest age were established, including the presence of rare species that persist only in ancient forests.	Spence et al. 1996; Winchester 1998

Component of study	Benefit of proper procedure	Specific example of benefit	References
Uniqueness of habitat	Focus on key groups	Characteristic species of oribatid mites were identified from ancient forests	Behan-Pelletier and Winchester 1998
Existing information			
Gather previous and background knowledge	Unnecessary repetition avoided	Existing information on design, sampling techniques, analysis and costs were used to plan a major monitoring programme efficiently	Winchester 1999b
Overall plan			
Scientific focus for feasibility	Lasting scientific benefit from proper foundation	Detailed information for selected taxa (e.g. oribatid mites) shows the uniqueness and richness of the fauna and hence its importance for conservation	Winchester and Ring 1999
Early collaboration with systematists and ecologists	Material and data collected can be interpreted, not wasted	Collaboration with systematists and collections enhanced identification and preservation of data and specimens	(See Identification and Specimen curation below)
Resources adequate for all phases	Samples exploited efficiently	Appropriate trade-offs were analyzed to help design a major sampling program	Winchester 1999b
	Curated, labelled material set aside for future reference	(see below)	

Component of study	Benefit of proper procedure	Specific example of benefit	References
Statistical design	Handling of data appropriate for objectives	(see text)	
Species level			
Identification to species	Information referenced properly in the biological literature for future use	Species names are the universal biological currency	e.g. Danks 1988
	Detailed information of value for the project	Site specificity of oribatid mites and staphylinid beetles (and hence the importance of sites for various purposes) was shown by species-level but not by genus- or family-level identifications	Behan-Pelletier and Winchester 1998; Winchester 1997b
Site selection			
Accessible, discrete, stable, well characterized and representative; and appropriate for selected taxa	Sampling less costly, sites easily recognized and sampled, protected from damage, background information available and results more widely applicable	Including these criteria improves efficiency, although there may be other trade-offs	(see text)

Component of study	Benefit of proper procedure	Specific example of benefit	References
Taxon selection			
Balance between scientific utility and feasibility	Best compromise between the features of organisms that may address project objectives (such as diversity, habitat specificity, dispersal ability, feeding habits, and others), and the practicalities of sampling, sorting and identification	Many benefits from a proper focus on the objectives coupled with planning from sampling, identification and other standpoints	For sample considerations see Samways 1992, Kremen et al. 1993, Danks 1996, Winchester 1999b
	Select several taxa (not one), and also endeavour to keep residues	Focus is feasible though not too narrow, and additional material is available for future use	(For discussion see text)
Duration			
Long enough to provide information about long-term natural events of interest	Answers address project objectives	"Long-term" studies (long duration mimicked by matched sites of different ages) can show the long-term effects of fire and logging	See http://www.biology.ualberta.ca/emend/

Component of study	Benefit of proper procedure	Specific example of benefit	References
Long enough to compensate for annual and seasonal variations in life cycles and in populations accessible for sampling	Samples accurately represent diversity	Only season-long sampling of staphylinid beetles provided a valid annual data set, because the species collected shifted through the season	Winchester 1997b
Sampling methods			
Multiple methods, and that are appropriate for the taxa selected	Provides proper coverage for the selected taxa	A full range of species is obtained through combined catches from Malaise, flight-intercept and pan traps, and behavioural extractors	Marshall et al. 1994; Blades and Maier 1996
Standardized	Allows comparison with results elsewhere, in same or different project	Direct comparisons of faunas were favoured by identical protocols among different sites by the same as well as different investigators	cf. Winchester 1999b
Cost effective	Labour cost per specimen collected is reduced	Appropriate design of work in the canopy (including the use of passive trapping) led to cost-effective sampling	Winchester, pers. obs.
Replicated	Significance of any differences between sites, treatments, years, etc., can be properly evaluated	Adequate statistics on variance of samples of staphylinid beetles, obtained through multiple trap replicates at each site, allowed real differences between forest habitats to be estimated	Winchester 1997b

Component of study	Benefit of proper procedure	Specific example of benefit	References
Execution of sampling			
Quality control	Variation caused by careless procedures is minimized	Standard written protocols were developed, and training of technical staff carried out, prior to fieldwork, sorting and preservation of arthropods from Alberta forest sites	Alberta Forest Biodiversity project: see http://www.fmf.ab.ca
Sorting and preparation			
Sufficient time for proper sorting	Explicit analysis of time and labour are made, so that short cuts are not required that will compromise the objectives	Analysis ensures that sufficient personnel are available	Winchester 1999b; and see Table 2
Sorted and prepared according to identification requirements	Identification of as many specimens as possible is favoured	Small flies preserved by critical-point drying can be identified much more rapidly	Marshall et al. 1994
Standardized procedures	Ensures that comparison among samples, and with projects elsewhere, are valid, and material can be identified	(see Methods above)	

Component of study	Benefit of proper procedure	Specific example of benefit	References
Specific protocols established early	Cross-contamination and mislabelling of samples avoided, quality of specimens maintained	(see Quality control above, and also see text)	
Identification			
Material prepared and shipped with appropriate care, and adequate data and context provided	Identification is assisted	Proper preparation and shipment and information about host plants assists identification	
Mass collections supplemented with other specimens if possible	Identification assisted	Sampling includes site visits by specialists	(cf. ALAS project: see web citation on p. 12)
Collaborative work	Assistance, reliability and delivery of results enhanced	Allowing retention of specimens of interest by taxonomic specialists and fostering joint subprojects led to relatively rapid analysis and publication on several groups of arthropods from important ancient forest sites	Campbell and Winchester 1993; Coher 1995, 1999; Behan-Pelletier and Winchester 1998; etc.

Component of study	Benefit of proper procedure	Specific example of benefit	References
Sufficient time allowed	Project report as complete as possible	Sampling, analysis and residence at the same institution for 7 years allowed for continuing publications to profit more fully from the original sampling	(As above)
Data management			
Tracking of information	An explicit plan allows all data to be tracked from the beginning of the project	Biota database design has provided a means to assemble and make available a wide range of results	Colwell 1999a
Standardized	Communication and comparison are favoured	(as above)	
Specimen curation			
Vouchers maintained	Reference material allows specific problems to be solved during the project,and also allows findings to be followed up and used more effectively	Faunal differences in ancient forests were verified through material housed at the Pacific Forestry Centre	References cited above; and see text
Publication			
Proper peer review and disemination of results	Information is validated and accessible	Journal papers and chapters in thematic publications have shown key aspects of arthropod diversity and habitat associations	(See text)

Component of study	Benefit of proper procedure	Specific example of benefit	References
	Credible information can be put to wider use	Demonstration and information for the public (popular magazines, general articles, documentaries, talks, web page) has helped to foster wider support for the core research and for the conservation needs based on it	http://web.uvic.ca/~canopy/ , and items listed there
Interim results clearly identified	Data are made available quickly, but results that are not yet definitive are not misapplied, because users are cautioned	Information on sampling effort helps to define futher actions; information on the proportion of undescribed species helps to support further work	(Chiefly documents of limited circulation, but see website cited above)
Ongoing publications as more information and identifications become available	Full value drawn from project, not just initial findings	(see Identification - Sufficient time, above)	