ISBN-0-9692727-6-6

How to assess insect biodiversity without wasting your time

Biological Survey of Canada (Terrestrial Arthropods)
Document Series No. 5 (1996)

Biological Survey of Canada
Commission biologique du Canada

Published by the
Biological Survey of Canada (Terrestrial Arthropods)
Ottawa
1996
[Reprint edition 2006]

Written by H.V. Danks
Biological Survey of Canada (Terrestrial Arthropods)
Canadian Museum of Nature

The Biological Survey of Canada (Terrestrial Arthropods) develops and coordinates national initiatives in systematic and faunistic entomology on behalf of the Canadian Museum of Nature and the Entomological Society of Canada.

The document series of the Biological Survey of Canada comprises invited bibliographies and other miscellaneous publications that are especially relevant to the fauna of Canada.

Additional copies of this document are available in limited numbers from the Biological Survey of Canada (Terrestrial Arthropods), Canadian Museum of Nature, P.O. Box 3443, Station "D", Ottawa, Ontario, Canada K1P 6P4 or on the web at: http://www.biology.ualberta.ca/bsc/briefs/brassess.htm

How to assess insect biodiversity without wasting your time

Abstract

The diversity and ecological importance of insects makes them very valuable for studies of biodiversity. However, the same overwhelming diversity means that valid and useful results will only be obtained if studies are properly planned.

This synopsis outlines the steps required for appropriate biodiversity assessments. Steps that have to be planned from the outset are: definition of objectives, gathering of existing and background information, development of a plan for the project as a whole, definition of level of detail, site selection, selection of taxa, duration of study, selection of sampling methods, quality control of actual sampling, sorting and preparation of samples, identification of material, data management, curation and disposition of specimens, and publication and dissemination of information.

The initial definition of objectives is especially important so that studies will answer specific questions, not just generate isolated sets of general information. Planning in advance for identification to species is essential, because using the results requires specific identifications, yet expertise for proper identification is limited. Indeed, project resources may well have to be explicitly devoted to the development of expertise for identification. Finally, it is very important that results are available in the published scientific literature, and not just in unpublished reports, and that voucher specimens remain available, both to validate progress toward the project objectives, and to add to the fund of knowledge that is required to make real advances in understanding biodiversity.

Comment évaluer la biodiversité des insectes sans perdre de temps

Résumé

À cause de leur diversité et de leur importance écologique, il est très utile d'étudier les insectes lors d'une étude de la biodiversité. Toutefois, l'importance même de cette diversité nous oblige à planifier soigneusement nos études si nous voulons obtenir des résultats utiles.

Le présent sommaire résume les étapes d'une étude adéquate de la biodiversité. Les étapes devant être planifiées d'entrée de jeu sont les suivantes: la définition des objectifs, la cueillette de renseignements existants et contextuels, l'élaboration d'un plan global du projet, la définition du degré de détail souhaité, le choix du site, le choix des espèces, la durée de l'étude, le choix des méthodes d'échantillonnage, le contrôle de la qualité de l'échantillon, le tri et la préparation des échantillons, l'identification, la gestion des données, la préservation et la disposition des spécimens et la publication de l'information ainsi que sa diffusion.

La définition initiale des objectifs est particulièrement importante car elle permet à l'étude de répondre à des questions précises plutôt que de produire de l'information générale d'une façon isolée. La planification de l'identification des espèces est indispensable, car le nombre d'experts disponibles pour effectuer des identifications précises reste limité. En fait, il faudra peut-être même consacrer une partie des ressources du projet pour acquérir des compétences en identification. Enfin, il est très important que les résultats soient publiés dans des revues savantes, et non seulement sous forme de rapports à circulation limitée. Les spécimens témoins doivent rester disponibles, tant pour démontrer la validité des progrès vers les objectifs que pour accroître le fonds de connaissances nécessaires pour faire avancer réellement l'étude de la biodiversité.

Introduction

The attention being paid to the study of biodiversity has led to increasing interest in assessing the diversity of insects and their relatives, because these groups dominate terrestrial and freshwater ecosystems and are valuable indicators of their health. Recent legislation in British Columbia even requires that studies of invertebrates be included in any assessment of forest biodiversity. Because there are so many insects, however, it is difficult to obtain a balanced picture of what is required for such assessments, given finite resources. This synopsis attempts to provide a primer for individuals (with or without a specific background in entomology) who have been called upon to lead or organize studies of insect biodiversity.

Insects are extremely diverse and important to ecosystems (e.g. Wiggins 1983; Finnamore 1996a). They have permeated the diverse and essential natural processes that sustain biological systems, making up over 75% of known species of animals. Indeed, our present ecosystems would not function without insects and arachnids (Wiggins et al. 1991). However, so many species exist that most groups are very inadequately known. For example, only about 34,000 of the 67,000 species of insects and their relatives in Canada have even been described (Danks 1988b), and only some 100,000 of 181,000 in North America as a whole (Kosztarab and Schaefer 1990; Danks in press). In some parts of Europe the state of knowledge is much better: for example, more than 93% of an estimated 24,000 species of British insects are known (e.g. Stubbs 1982). However in most tropical areas, and hence globally, knowledge is very much worse, and less than 10% of species — perhaps much less — have been described (cf. Stork 1988).

The pervasive ecological importance of this great variety of insects makes them valuable to assess disturbance or environmental impacts of various kinds (Lehmkuhl et al. 1984; Rosenberg et al. 1986) through assessments of mortality, sublethal effects, population changes, and modifications in community structure. Knowledge of arthropods also is essential to conserve or manage ecosystems, because a skewed focus only on large and conspicuous organisms misrepresents ecosystem dynamics (Kremen et al. 1993; Finnamore 1996a). The high diversity of insects provides potentially high resolution and the opportunity to detect relatively inconspicuous but nonetheless important changes in these systems.

Table 1. Necessary steps in a proper study of insect biodiversity

• Definition of objectives
• Gathering of existing and background information
• Development of a plan for the project as a whole
• Definition of level of detail
• Site selection
• Taxon selection
• Duration of study
• Selection of sampling methods
• Quality control of actual sampling
• Sorting and preparation of samples
• Identification of material
• Data management
• Curation and the disposition of specimens
• Publication and dissemination of information

Insects thus have great potential for understanding ecosystems and as measures of ecosystem health, but the incompleteness of knowledge and the limitation of resources increase the difficulty of work on insect biodiversity. Therefore, careful targeting of any study is essential. Logical steps in planning and conducting the work are listed in Table 1 and outlined in subsequent sections.

Definition of objectives

Any valid scientific study has clearly defined objectives. Therefore, studies of biodiversity should attempt to answer specific questions, and not simply generate isolated lists of species. At the same time, studies of biodiversity are more valuable if they are orientated in a wide spatial, temporal, and social context. In particular, biodiversity studies aim to establish a baseline to assess differences from place to place, under different regimens, or from the present to the future. Such projected comparisons require that procedures be standardized as far as possible, that findings be placed in the context of information available previously, that material be retained for future use, and that information be validly published (see sections below).

Long-term use of the data therefore is one important objective, but it cannot be the only one. Answers to apposite shorter term questions also will drive the design of the study, and these questions have to be asked in an ecological setting (cf. Lehmkuhl et al. 1984): the aim of a study is to find out in some relevant respect what is going on, even though the basic work still is the collection, accumulation and maintenance of large samples of material. For example, valid specific objectives would include the impact of change (artificial disturbance, pollution, etc.) on ecosystem function or persistence, as estimated by the diversity of key trophic groups.

Knowledge of background information

Existing published and unpublished information helps in developing specific study design, as well as for comparison and verification of results. Background knowledge allows gaps to be identified and studies having a specific purpose to be designed (Rosenberg et al. 1979). Some effort will be required to do this, because background information about biodiversity is scattered in a variety of taxonomic, ecological and geographical groupings. Directly relevant information or previously collected specimens may be available, and using this material may be more cost effective than repeating a full sampling program provided that the earlier work was carried out adequately (see below).

By the same token, especially when relatively little data exist already, it is important as soon as possible to summarize in a tidy way ongoing findings as they accumulate, to help capitalize on the core work in subsequent seasons. For example, a valuable baseline of the diversity of old-growth Douglas-fir forests in Oregon was published to bring together the findings of various specialists (Parsons et al. 1991).

The overall plan

The key to an effective overall plan is ensuring that the required funds and personnel will be available over a time frame that is of adequate duration. In particular, resources and expertise for later aspects of a study, such as identification, curation, and publication, must be given deliberate attention. Otherwise, most resources may have been expended (on sampling and sorting, for example) before the later phases, so essential to the completion and wider value of the project, are reached. Many major projects surveying insect diversity in the past lacked adequate follow-through to completion (Rosenberg et al. 1979).

A detailed plan ensures that a project does not overreach itself in early stages, for example by taking too many samples or attempting to inventory too many groups. Of course, sufficient flexibility must be retained to adjust the program in the light of preliminary findings (Lehmkuhl et al. 1984). A specific scientific focus to the plan ensures that usable results can be obtained, and establishment of specific protocols ensures that samples will be adequate, and that specimens will be of a quality that makes them identifiable. For example, insects live in many different microhabitats (and see Site Selection below). These microhabitat differences, and variations in life-cycles (some stages are more difficult to collect), make the species differentially available for sampling. Consequently, any "generalist" assessment of the biodiversity of an area is likely to miss many species. Such potential deficiencies reinforce the need for detailed attention to sampling protocols in relation to study objectives and target groups.

The need for correct early decisions of this sort means that both systematists and ecologists should be involved in the design of projects, or at least that expert review of general plans for biodiversity sampling take place early in project development, to avoid unpleasant later surprises as to the utility of the work. Biodiversity studies cannot be allowed to follow the route of many "Environmental Impact Assessments", carried out without adequate scientific planning to meet political ends rather than scientific or real social objectives (e.g. Schindler 1976), which consequently generated results of low quality. Moreover, any reasonably broad biodiversity study has to enlist the early cooperation of systematics experts; otherwise, identification of the groups that hold the key to meeting the project objectives may not be feasible.

Early attention should also be given to how the results will be used or analyzed. Such considerations influence what is sampled (see below) and how data are recorded. For example, despite some difficulties of interpretation numerical "diversity indices" can give useful shorthand ways of characterizing biodiversity (e.g. Samways 1984; Magurran 1988; Cousins 1991). Which index will be used, if any, may influence how abundance data are to be recorded, for example.

Successful completion of a project requires resources for all elements of that project. For example, expertise for identification and for solving taxonomic problems in key target groups will often have to be purchased. Indeed, increasingly even government agencies (in Canada and elsewhere) are seeking cost recovery for such expert services as identification. In many cases, the necessary expertise will not even be *available* for outside purchase, and will then have to be staffed and developed from the beginning as part of the project.

The cost of sampling and preparation of samples in a project that surveys biodiversity adequately is very high. Scudder (1996) analyzed such costs, as shown for a range of techniques in Table 2. He concluded that employing students at $10 per hour to use only the first 8 methods listed in the table would cost $24,000 per site per season, and identifying the material to family would double the cost. These substantial costs re-emphasize the necessity for long-term planning for resources.

Table 2. Estimate of time required to process samples from one site taken on a typical monthly basis (Scudder 1996)

	Time required (hrs)			
	Processing			
Sampling method	Trap emptying or sampling	Sorting	Preparation	Identification to family[a]
Pitfall traps (6 emptied monthly)	1	6	12	18
Pan traps (6 with 2 x 1 day samples each month)	1	40	80	120
Window traps (5 emptied monthly)	1	35	70	105
Berlese funnel core samples (1 sample per month)	1	8	16	24
Beating (1 hour)	1	6	12	19
Sweeping (1 hour)	1	6	12	19
Searching-walking (1 hour)	1	5	10	16
Searching-crawling (1 hour)	1	6	12	19
Chasing (butterflies) (5 hrs/month)	5	1[b]	2[b]	2[b]
Light trap (moths) (1 night per week)	4	20[c]	200[c]	100[c]

[a]Identification to major families of taxa (except Acari), but see below.

[b]Butterflies collected by an expert, and only voucher specimens processed and identified to species and subspecies by the expert collector.

[c]Moths sorted by an expert and only specimens of special interest processed.

Similarly, funds to curate material and provide resources for its maintenance in appropriate facilities must be arranged for early in the work. Most museums no longer have the means to house specimens provided by various outside sources (e.g. Danks et al. 1987).

In summary, attention to an overall plan for the project as a whole ensures not only that the results will address the project objective, but also that the results will be scientifically valid and so can be built upon for the future (Lehmkuhl et al. 1984; Danks and Ball 1993). Many large-scale studies in the past lacked long-term planning, and so generated only incomplete results that were of no real or lasting benefit.

Degree of detail

Doing the work properly usually requires identification to species. For nearly all objectives it is better to have specific information on carefully chosen groups than family-level information on many. Species-level information is valuable for two main reasons. First, species are the functioning entities in nature, so that ecosystem interactions can normally best be understood using species-level identifications. For example, work on caddisflies of the genus *Ceraclea* (formerly *Athripsodes*) showed that each species has a different tolerance for changes in conditions caused by industrialization (Resh 1976; Resh and Unzicker 1975). Again, seasonal patterns of larval abundance of *Baetis* mayflies suggested recovery from insecticide treatment of their river habitat, but in fact the "recovery" resulted from the presence of a second, and temporally separated, distinct species of *Baetis* (Lehmkuhl 1981).

Grouping species in the same insect family therefore is not usually appropriate. Indeed, a moderate sized family of insects, for example chironomid midges, contains species differing greatly in relative size and feeding habits, a diversity similar to that of the whole of the birds, for example. It would not generally be thought reasonable to group data about all birds (e.g. "kilograms of birds per hectare"); it is not reasonable to do so for insects, despite some past practices stemming from taxonomic difficulties. The first reason for specific identifications, therefore, is biological reality and applicability of data, which ensure that the results and analysis will be usable to answer questions of interest.

A second reason for species-level work is that species names allow information to be associated with each taxonomic entity for future reference (Danks 1988a). All biological information is collected together and retrieved on the basis of species' names; because such knowledge can be referenced effectively, it can be used and developed through time. Therefore existing information can be integrated with the new findings. Identifications only at higher taxonomic levels do not uniquely document diversity or make it possible to use the information for detailed comparisons. Attention to details of habitat, etc. is also necessary for adequate documentation.

The need for detailed identification is obvious in many walks of life: misidentifying even the strain of a pet dog can lead to difficulties if a pup grows ten times larger than expected. The need for detailed identification has nevertheless been overlooked in some projects on biodiversity because those projects were of such broad scope.

Site selection

At a general level (e.g. Danks et al. 1987), choosing accessible sites lowers the cost of sampling. Using discrete habitats that are easily recognized also assists in careful and repeatable sampling. Long-term stability of the sites is especially valuable for repeated sampling over time; long-term stability is increased by formal legal protections (e.g. national parks) or association with stable institutions (e.g. some field stations). Pre-existing and continuing interest by various agencies not only helps to maintain the stability of effort, but also makes available a wider base of information, for example on climate, vegetation type, or other data of value, as in the U.S. Long Term Ecological Research Sites (Callaghan 1984) or potentially with components of the Canadian Environmental Monitoring and Assessment Network (Environment Canada 1993).

At a more specific level, site choice depends on the objectives of the study, because few studies of biodiversity have sufficient resources to complete a full regional inventory of species from all habitats in a range of places. If the initial project focus is on habitat (e.g. forest types), sites should of course be fully representative of each habitat type of interest. If the primary focus is on taxa with particular ecological properties of interest (e.g. herb-feeding bugs), emphasizing habitats favoured by the organisms, as determined by expert advice, increases the efficiency of sampling. In any event, sites and habitats should be characterized through ongoing field notes during sampling. Such reports are very helpful later for interpreting the sample data, because they record site variability and provide other valuable clues. For example, seasonal vegetation development and changes in moisture regimens within a given site affect both the presence and the efficiency of trapping for some species.

Selection of taxa for study

There are so many groups of insects in most habitats and their numbers are so large that with ordinary resources it is impossible to study them all simultaneously. The choice of taxa depends on utility and feasibility. Other things being equal, this choice depends on the objectives of the study, because groups of different diversity, habitat specificity, dispersal ability, feeding habit, and so on would be expected to have different values for answering the questions posed by the study.

Unfortunately, questions of feasibility usually modify the theoretically ideal choice. For example, the practicality of sampling and sorting differs among groups. Most soil-dwelling groups are more costly to sample than groups that live on the ground surface. Moreover, groups collected must be identified. An initial difficulty is that knowledge in some groups is inadequate to allow specific identifications, although in some taxa morphological species or morphospecies (i.e. “species 1”, “species 2”, etc., as yet unnamed) can be recognized reliably by experts. A second difficulty is that, even for some groups that are reasonably well known, considerable expertise may be required to distinguish the species.

The choice of taxa therefore typically is a compromise between scientific relevance and feasibility. Nevertheless, it is unwise to over-emphasize feasibility (as has happened in some previous studies), because the taxonomic coverage may then be confined to groups that provide little useful information about the objective. For example, characterizing forest types, ages or treatments by means of taxa that occur almost exclusively in large clearings or in pools, and so tend to be similar among the different forest types, is unlikely to be successful.

Conversely, a study intended to ascertain what changes in biodiversity occur in grazed meadows compared to ungrazed sites, and how the changes can be minimized, might target otherwise feasible groups expected to signify the relevant changes more clearly. These changes might include the occurrence and vigour of specific plants and allied microhabitats (reflected by selected plant bugs, for example), ground exposure (influencing grasshoppers, which deposit their eggs in bare soil, and soil mites that respond to local soil moisture and other soil factors), general habitat structure (potentially reflected by ground beetles, for example), and food-chain as well as habitat effects (e.g. through study of predaceous wasps). Changes in such species would also indicate if important linkages with other organisms are likely to be disturbed, and suggest further consequences. An informed biodiversity study of this sort then can suggest whether and how mitigation is to be carried out.

It is unwise to restrict studies to only one or two easy-to-identify groups. Not only may such a restriction provide too few data to answer the questions at hand, but it is also inefficient because very little use is made of costly samples containing many other potentially instructive taxa. Such “other taxa” are routinely discarded in most smaller biodiversity studies, rather than being preserved or made more widely available. Instead, work should normally be done on a relevant but taxonomically and ecologically diverse subset of the taxa collected. Predators and herbivores, for example, would be expected to show different patterns and to provide different insights.

Duration of the study

It is not usually possible to sample insect diversity adequately over too short a time frame, both because the temporal development of populations may make individuals available for capture for a relatively short time, and because of natural variations in the occurrence and abundance of individuals.

Most sampling devices or techniques target a single stage of the life cycle, especially the adult. However, some adult insects live for a very short time, and when the population emerges synchronously adults may be present in the field for a week or less. Moreover, different species emerge at different characteristic times of year. The emergence of a species may be early or late in any given season, depending on weather. Its availability for trapping even when present (and so whether it will be captured at any given time) depends on the weather and on its abundance. It turn, abundance depends on population processes governed by natural enemies and many other factors.

These variations mean that a given species may or may not be captured in a sampling program that is too short or insufficiently intensive. In particular, short visits to sites are likely to provide only a small random selection of the real diversity. Even if a longer lived and therefore more reliably encountered larval stage is sampled instead, for example, it will not be possible to identify most of these larvae without a costly program of rearing and taxonomic analysis. Larvae may nonetheless provide more useful information than adults for some purposes. Taking advantage of this fact requires especially careful planning to overcome additional difficulties of sampling and deficiences of taxonomic knowledge.

Consequently, a study of biodiversity must be planned over a time frame of adequate duration. Local diversity cannot be characterized unless the core data are more-or-less complete. “Hit and run” techniques have been recommended as the only practical way of sampling tropical diversity (e.g. Coddington et al. 1992), but are likely to be inadequate except for superficial assessments.

Moreover, most changes in biodiversity of potential interest (colonization, succession, population cycles, etc.) accord with long-term natural events, which can be interpreted only when long-term data have been collected. For example, analysis of ten years of population data on the gall midge *Taxomyia taxi* and its parasitoids failed to demonstrate density-dependent effects; however, extension to a 24-year run of data revealed such effects (Redfern and Cameron 1993). The major events, chiefly climatically driven, that help to govern many ecosystems occur at intervals of several years, which is longer than the normal cycle for the funding of research (Weatherhead 1986).

Selection of sampling methods

Some general principles that govern the choice of sampling methods are outlined here: in essence, methods should be multiple, targeted, cost-effective and standardized. The many details of specific methods are beyond the scope of this synopsis, but have been summarized, with extensive references, by Marshall et al. (1994).

Biodiversity is best assessed through several simultaneous sampling methods. All methods have their strengths and weaknesses, and for most objectives a useful cross section of the fauna will be sampled only by using a number of different techniques (cf. Marshall et al. 1994).

Methods must be appropriate for the targeted taxa and habitats. In addition to typical mass-collecting devices, the sampling set can be supplemented by specific methods for target taxa, as long as the uniformity of the core sampling effort is controlled from one study to another. Also, occasional additional material acquired by supplementary techniques, such as searching streamside vegetation or rearing, generally makes the taxonomic work easier.

The most cost-effective techniques are passive or behavioural ones (e.g. pan trap, pitfall trap, Malaise trap, flight-intercept trap, Berlese funnel); insects come to the trap or collecting vessel, rather than being pursued by the collector. Such techniques yield huge numbers of specimens, leading to good habitat coverage, but creating difficulties of sorting and selection.

It is especially important to standardize methods (see recommendations by Marshall et al. 1994). Only in this way can information from different sites, regions, and times be compared effectively. Such standardization requires careful attention to the number, size and colour of traps, the mesh size of sieves, etc., as well as the day-to-day execution of the sampling (see below). Some attempts to develop standard protocols for sampling insects in particular environments are already underway (e.g. Finnamore 1996b).

Replicating sampling is also important. The need for replication is often overlooked because of the high cost of handling material from multiple traps or sites. However, for both qualitative analysis (species occurrence) and quantitative analysis (numbers of specimens), replication is always essential to answer key questions of interest, which usually take the form of whether the differences in biodiversity between different places or different times are real, or simply reflect sampling variation.

Execution of sampling

Once the appropriate techniques have been selected, they must be implemented carefully in a standardized manner. Passive traps create less sampling bias than active collectors do, but even so pitfall traps that are not flush with the ground surface are less effective than those flush with the ground, for example, and are likely to capture fewer small species. The actual location of traps within a habitat may make a considerable difference to the numbers of specimens trapped, depending on vegetation cover, local wind patterns, and so on. Some of these variations (whether inadvertent or not) may actually be advantageous if enough traps are deployed, because they help to characterize trap-by-trap variation for comparison with real site-to-site differences. Again, the most desirable number and pattern of trapping depends on the target groups and habitats selected in accordance with project objectives. Emptying some kinds of traps (e.g. emergence traps) requires knowledge and practice so that part of the catch is not missed. Therefore, to reduce avoidable sampling errors, technical staff have to be adequately trained in the placement and servicing of traps before the project begins.

Sorting and sample preparation

The sorting and preparation of trap samples of insects is extremely time consuming, taking up to 40 times as long as the sampling itself (Marshall et al. 1994), even before any identifications are undertaken. Moreover, people differ considerably in the time taken to sort a given sample. Depending on experience, different sorters took from 40 minutes to 5.7 hours for removal of specimens of three major groups from one flight-intercept trap sample, in one instance cited by Marshall et al. (1994).

As with sampling itself, strict control and standardization are required to ensure the integrity of data and the long-term preservation of specimens. Differences among technicians (e.g. Corbet 1966) create additional problems in subsampling or other quantitative work. Constant care and attention is required even during prolonged and relatively mundane activity. For example, laboratory protocols (such as dealing with only one trap sample at a time) must be established to avoid cross-contamination of samples or mislabelling of specimens. Adequate preservative-to-specimen volume must be maintained (by increasing container size if necessary when the trap sample is larger) when field preservative is replaced for more permanent storage.

It is particularly important to plan sorting and preparation with identification in mind. Specimens of many groups are much more difficult or impossible to identify if carelessly or incorrectly prepared. Detailed instructions about preparation must therefore be obtained from cooperating systematists as the project is being developed. Of course, groups that require extremely costly preparation (e.g. detailed dissection and slide mounting) would need higher relevance to the project objectives to justify the cost of mounting.

Identification

Securing reliable identification to species is the greatest single difficulty in work on insect biodiversity. Except in the few best known groups, expert knowledge is required to ensure that identifications are accurate, and such expertise has to be planned for from the earliest stages, because it is both extremely limited and in great demand for these and many other activities. Despite the increased interest in biodiversity in recent years, the numbers of professional systematists have declined (e.g. Kosztarab and Schaefer 1990; Wiggins 1992), so that the resources to provide identifications for biodiversity studies simply do not exist. In other words, there is no "black box" into which specimens can be fed for identification.

Because a good taxonomist is a scientist, not a technician, specialists are best able to help if a project has a finite objective and is well planned with their participation. Many details of working with relevant systematists can be optimized to favour identification (some already noted in sections above; and see Danks 1983), as summarized in Table 3.

Table 3. Requirements to optimize identification by specialists

Sort all material from substrates
Organize material into higher taxa
Prepare (preserve, mount, etc.) appropriately
Provide adequate data on mode of collection, habitat, time of year, behaviour, etc. (translate code numbers if necessary)
Whenever possible, supplement mass collections with especially valuable reared, sex-associated, or other high quality material
Provide context so that the level of identification, the need for ancillary information on distributions, and so on will be clear
Pack and ship material using proper methods to safeguard it
Whenever possible, allow specialists to retain specimens of particular interest for their work.
Acknowledge help appropriately (e.g. in published citations)
Allow sufficient time for identifications to be made, and provide a realistic deadline based on when the information is required for analysis and reporting

Care is also required in using the results of expert identification, because so many groups are inadequately known. Even in groups where the adults have been characterized, identification of larvae is very difficult when the taxonomy is based mainly on adults, as in chironomid midges, or of females when species identifications depend on male characters, as in caddisflies.

It is important to understand the meaning of annotated or partial identifications and to retain qualifiers, quotation marks, parentheses and other punctuation, such as poss. (possibly), prob. (probably), nr (near, i.e. related to), grp (group, i.e. belonging to a group of species not distinguishable by ordinary means from this material), and sp. [or n.sp.] 1 or A (species recognized and numbered by the identifier from work in progress, but specific name not available).

Data management

Studies of biodiversity generate extensive data, requiring efficient means of keeping track of the information and making it available. The necessary protocol at the core of data management keeps basic data associated with each specimen and hence with each species. However, the data (rather than the specimens themselves, despite their taxonomic and voucher value) are used for analyses of biodiversity. It is therefore especially important to consider aspects of data management during the planning stages, so that a system can be put into place before any data are collected.

Fortunately, especially because technology has advanced, many specific database systems can be used *as long as the data are properly recorded in a logical manner*. Provided the computerization has been carefully planned, information in a well organized database then can be extracted using a variety of different formats.

A scheme for data management is best developed by considering common or “standard” specimen data, possible additional specific data required for the project at hand (e.g. further details of habitat if these are required to answer the project question), and in a preliminary way how the data will be analysed. Such a preliminary examination helps to avoid inefficient subsequent transcription or splitting of data fields for analysis.

Although standardization of the initial data collected maximizes the availability of information, it is very difficult to ensure (cf. Hellanthal et al. 1990) because of differences in the capture and subdivision of data fields; subsequent work is hindered by computer incompatibilities such as differences in database structure, vocabularies or hardware configurations. However, progress has been made toward developing standard data fields (e.g. Noonan 1990), although some flexibility is needed to respond to unforeseen additional inputs or requirements (cf. Harris 1976).

Computerized information is especially valuable because it can be easily transmitted, and integrated with sophisticated means of analysis such as geographic information systems. However, it is important to remember that, especially relative to the long-term value of the data, the life of digital information is relatively short, both because media (such as diskettes) deteriorate, and because software evolves, making older formats unreadable (Rothenberg 1995).

Curation and disposition of specimens

The specimens obtained from any study document its findings for future reference, allowing both future checking of data and further use. Data in biology essentially are kept and organized on the basis of the species (Danks 1988a). Consequently, voucher specimens are required to validate the specific entities obtained during biodiversity studies, because advances in taxonomy (or errors in original identifications) may require re-examination of the material. These voucher specimens also increase progressively in value as knowledge accumulates and they are used for taxonomic or ecological comparison. Such repositories are of considerable long-term importance for evaluating changes or impacts (e.g. Resh and Unzicker 1975; Danks et al. 1987; Wiggins et al. 1991).

Depending on the objective of a study, vouchers often are best kept associated with the original sites or habitats rather than scattered in a taxonomically arranged collection (Danks 1991). However, such a scheme is time consuming and expensive, again reinforcing the need for a long-term plan for the execution and funding of all aspects of a biodiversity study. When most species can be identified (but not as usefully otherwise) the data can be kept associated instead in an electronic format.

Publication and dissemination of information

Any properly planned scientific project leads to information that is valid, organized and available. In most cases, this means that results should be peer reviewed and properly published, and not take the form solely of internal reports, unedited lists, and so forth. Information made available on the basis of carefully validated specific identifications is most useful.

Information can also be disseminated through computer databases, online information systems, or the Internet. Such dissemination is useful to engender and assist further work and coordination. However, it is very important that the status of any identifications, conclusions or claims that have not been fully evaluated through the focus of expert judgement or peer review and publication be clearly marked as interim.

Conclusions

Five major conclusions emerge from this overview.

1. Any project needs a specific target, choosing the taxonomic and habitat diversity to be sampled through a focus on the project objectives. Indiscriminate or unplanned sampling will not provide answers to relevant questions.

2. Any study must start with a long-term overview of requirements for the whole project, including all stages, from initial planning and wide consultation with a variety of experts, to the disposition of specimens and publication of results.

3. Data of most value for both short-term project and long-term biodiversity goals are based on reliable identification to species. Overcoming the taxonomic impediment for insects therefore is the greatest single challenge for biodiversity studies.

4. Consequently, a key project requirement in addition to funds and their continuity is obtaining systematics expertise. In many cases, such expertise for identification (and indeed for the research required to make identification possible in the groups of most importance to the project objectives) will have to be funded as an explicit and integral component of the project.

5. In turn, the need for taxonomic expertise also requires planning at a level above that of individual projects, involving governmental support, university training, and other infrastructures for systematics.

References

Callahan, J.T. 1984. Long-term ecological research. *BioScience* 34: 363-376

Coddington, J.A., C.E. Griswold, D.S. Davila, E. Penaranda, and S.F. Larcher. 1992. Designing and testing sampling protocols to estimate biodiversity in tropical ecosystems. pp. 44-60 *in* E.C. Dudley (Ed.), The Unity of Evolutionary Biology. Proceedings of the Fourth International Congress of Systematic and Evolutionary Biology, Volume 1. Dioscorides Press, Portland, Oregon. 588 pp.

Corbet, P.S. 1966. A method for sub-sampling insect collections that vary widely in size. *Mosquito News* 26: 420-424.

Cousins, S.H. 1991. Species diversity measurement: choosing the right index. *Trends in Ecology and Evolution* 6: 190-192.

Danks, H.V. 1983. Insect identification. *Newsletter of the Biological Survey of Canada (Terrestrial Arthropods)* 2: 42-43.

Danks, H.V. 1988a. Systematics in support of Entomology. *Annual Review of Entomology* 33: 271-296.

Danks, H.V. 1988b. Insects of Canada. Biological Survey of Canada (Terrestrial Arthropods), Document Series no. 1. 18 pp.

Danks, H.V. 1991. Museum collections: fundamental values and modern problems. *Collection Forum* 7: 95-111.

Danks, H.V. (in press) Terrestrial arthropods in the nearctic region: diversity and resources for study. *in* K.C. Kim (Ed.), Biodiversity and Taxonomy of Insects and Arachnids: A Global Perspective. Universal Book Services, Leiden.

Danks, H.V. and G.E. Ball. 1993. Systematics and entomology: some major themes. pp. 257-272 *in* G.E. Ball and H.V. Danks (Eds.), Systematics and entomology: diversity, distribution, adaptation and application. *Memoirs of the Entomological Society of Canada* 165. 272 pp.

Danks, H.V., G.B. Wiggins, and D.M. Rosenberg. 1987. Ecological collections and long-term monitoring. *Bulletin of the Entomological Society of Canada* 19: 16-18.

Environment Canada. 1993. Ecological Science Centres – what they are and how they will work. Ecological Science Centres [now Cooperatives] News 1(1): 2.

Finnamore, A.T. 1996a. The advantages of using arthropods in ecosystem management. A brief from the Biological Survey of Canada (Terrestrial Arthropods). 11 pp.

Finnamore, A.T. 1996b. The SAGE Project. A workshop report on terrestrial arthropod sampling protocols for graminoid ecosystems. (Available on the Internet at http://www.eman-rese.ca/eman/reports/publications/sage/intro.htm)

Harris, J.W.E. 1976. Storage and retrieval of quantitative British Columbia - Yukon Forest Insect and Disease Survey records. Can. For. Serv. Envir. Canada, Pacific Forest Res. Stn., Victoria, BC-X-120. 30 pp.

Hellanthal, R.A., J. Louton, G.R. Noonan, R.T. Shuh, M.G. Thayer, and F.C. Thompson. 1990. Automatic data processing for systematic entomology: Promises and problems. Report for the Entomological Collections Network, First Annual Meeting, Baton Rouge, Louisiana. 48 pp.

Kosztarab, M. and C.W. Schaefer (Eds.)1990. Systematics of the North American Insects and Arachnids: Status and Needs. Virginia Polytechnic Institute and State University, Blacksburg, VA. Info. Ser. 90-1. 247 pp.

Kremen, C., R. K. Colwell, T. L. Erwin, D. D. Murphy, R. F. Noss, and M. A. Sanjayan. 1993. Terrestrial arthropod assemblages: their use in conservation planning. *Conservation Biology* 7: 796-808.

Lehmkuhl, D.M. 1981. Report on the impact of methoxychlor on non-target organisms in the Saskatchewan River. Appendix III, 165 pp., *in* W.W. Sawchyn, Impact of methoxychlor as a blackfly larvicide in the Saskatchewan River. SRC publ. No. C-805-19-E-82.

Lehmkuhl, D.M., H.V. Danks, V.M. Behan-Pelletier, D.J. Larson, D.M. Rosenberg, and I.M. Smith. 1984. Recommendations for the appraisal of environmental disturbance: some general guidelines, and the value and feasibility of insect studies. A brief. *Bulletin of the Entomological Society of Canada* 16(3), Supplement. 8 pp.

Magurran, A.E. 1988. Ecological Diversity and its Measurement. Croom Helm, London.

Marshall, S.A., R.S. Anderson, R.E. Roughley, V. Behan-Pelletier, and H.V. Danks. 1994. Terrestrial arthropod biodiversity: planning a study and recommended sampling techniques. A brief. *Bulletin of the Entomological Society of Canada* 26(1), Supplement. 33 pp.

Noonan, G.R. 1990. Standard fields and terms for databases about insects. *Insect Collection News* 4: 4-10.

Parsons, G.L., G. Cassis, A.R. Moldenke, J.D. Lattin, N.H. Anderson, J.C. Miller, P. Hammond, and T.D. Schowalter. 1991. Invertebrates of the H.J. Andrews Experimental Forest, western Cascade Range, Oregon. V: An annotated list of insects and other arthropods. Gen. Tech. Rep. PNW-GTR-290. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. 168 pp.

Redfern, M. and R.A.D. Cameron. 1993. Population dynamics of the yew gall midge *Taxomyia taxi* and its chalcid parasitoids: a 24-year study. *Ecological Entomology* 18: 365-378.

Resh, V.H. 1976. Changes in the caddis-fly fauna of Lake Erie, Ohio, and of the Rock River, Illinois, over a fifty year period of environmental deterioration. pp. 167-170 *in* H. Malicky (Ed.), Proc. 1st Int. Symp. on Trichoptera. Lunz am See (Austria), September 16-20, 1974. Dr. W. Junk, The Hague, Netherlands.

Resh, V.H. and J.D. Unzicker. 1975. Water quality monitoring and aquatic organisms: the importance of species identification. *Journal of the Water Pollution Control Federation* 47: 9-19.

Rosenberg, D.M., H.V. Danks, J.A. Downes, A.P. Nimmo, and G.E. Ball. 1979. Procedures for a faunal inventory. pp. 509-532 *in* H.V. Danks (Ed.), Canada and its insect fauna. *Memoirs of the Entomological Society of Canada* 108. 573 pp.

Rosenberg, D.M., H.V. Danks, and D.M. Lehmkuhl. 1986. Importance of insects in environmental impact assessment. *Environmental Management* 10: 773-783.

Rothenberg, J. 1995. Ensuring the longevity of digital documents. *Scientific American* (January): 42-27.

Samways, M.J. 1984. A practical comparison of diversity indices based on a series of small agricultural ant communities. *Phytophylactica* 16: 275-278.

Schindler, D.W. 1976. The impact statement boondoggle. *Science* 192: 509.

Scudder, G.G.E. 1996. Terrestrial and freshwater invertebrates of British Columbia: priorities for inventory and descriptive research. Res. Br., B.C. Min. For., and Wildl. Br., B.C. Min. Environ., Lands and Parks, Victoria, B.C. Working Paper 09/1996. 206 pp.

Stork, N.E. 1988. Insect diversity: facts, fiction and speculation. *Biological Journal of the Linnean Society* 35: 321-337.

Stubbs, A.E. 1982. Conservation and the future for the field entomologist. *Proceedings and Transactions of the British Entomology and Natural History Society* 15: 55-67.

Weatherhead, P.J. 1986. How unusual are unusual events? *American Naturalist* 128: 150.

Wiggins, G.B. 1983. Entomology and society. *Bulletin of the Entomological Society of America* 29: 27-29.

Wiggins, G.B. 1992. Who speaks for systematic biology in Canada? *Bulletin of the Entomological Society of Canada* 24: 197-202.

Wiggins, G.B, S.A. Marshall, and J.A. Downes. 1991. The importance of research collections of terrestrial arthropods. A brief. *Bulletin of the Entomological Society of Canada* 23(2), Supplement. 16 pp.