

**RECOMMENDATIONS FOR THE APPRAISAL OF
ENVIRONMENTAL DISTURBANCE:
SOME GENERAL GUIDELINES, AND THE VALUE
AND FEASIBILITY OF INSECT STUDIES**

and

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particular, proposals and sampling plans should be developed with the best available expert scientific advice, including peer review. Second, the plans should be framed to ask *specific* questions.

Such a broad approach to planning was used for recent studies on the effect of methoxy-chlor on insect communities in the South Saskatchewan River.

- Specialists in pesticide chemistry, river entomology and fisheries were asked to review the available data and, if deemed necessary, to suggest appropriate studies.
- A detailed and specific set of guidelines, objectives, and priorities was agreed upon by the scientific advisory group; these could be used as a basis for establishing a contract for the study. (Within the guidelines, alternative courses of action were possible since results of one stage might not be anticipated and would affect future work).
- Those doing the work knew exactly the objectives and priorities, and could conduct the study and prepare the report accordingly. Resources could therefore be applied effectively to answering questions and testing hypotheses.

Consequently, the results (Lehmkuhl 1981) satisfied all parties involved, including the funding agencies, the scientific workers and outside reviewers of the report.

Planning must therefore include the means to conduct the study properly. Careful conduct of the fieldwork, and accurate identification of the insect species collected, can usually be done only by qualified scientists: appropriate personnel should therefore be involved in such studies.

RECOMMENDATIONS

Although decisions based on environmental assessments are influenced by many social and economic factors, usable results from the studies depend critically on good science. This brief suggests that good entomological science for environmental monitoring and evaluation can be assured by accepting the following general principles:

1. Planning the work:
 - a. Obtain an overall view of the problem and its ecological setting. At an early stage in developing study plans, consider the points of view of all interested parties and therefore the nature of the scientific data required for policy decisions.
 - b. Develop a general plan for the whole study. This includes adequate time frames for completion, and corresponding personnel and budgets.
 - c. Develop a scientific programme with defined goals, including hypotheses to be tested (merely compiling lists of taxa is not an adequate objective). State the objectives of the study, including lists of priorities, but allow the flexibility to respond to any unexpected interim results.
 - d. Obtain scientific input at all levels from experimental design to interpretation of results. In particular, arrange for peer review of study plans.
2. Conduct of the work:
 - a. Use available expert personnel, so that the scientific work reflects state-of-the-art quality.
 - b. With entomological material, generally work at the species level.
 - c. Have identifications made or confirmed by qualified persons or compared with authentic specimens and literature.
3. Subsequent responsibilities:
 - a. Arrange for scientific peer review of the results.
 - b. If possible, publish key results in a cohesive way in the scientific literature to add to the store of valid, organized and available knowledge.
 - c. Deposit series of properly prepared specimens in at least one recognized repository so that they will be available for reexamination or further analysis.

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SOME GENERAL PRINCIPLES

Problems with earlier work, and lessons drawn from the examples just cited, suggest ways in which environmental appraisals using insects might best be planned and executed.

Value of information at the species level

One general principle that emerges from the studies just cited is that meaningful studies require detailed knowledge at the species level. While species level data are relatively uncommon in environmental monitoring and appraisal, this does not demonstrate the lack of need for such detail, but rather shows that many studies are of less than desirable quality.

For example, interpreting population change requires a knowledge of the ecology of individual species. Whether changes observed are due to life-history events, environmental heterogeneity and dispersion patterns in the population, artifacts of the sampling protocol, or results of the process of concern can only be ascertained by detailed knowledge of the life history and ecology of the species under study.

Each species of insect has much information associated with it. The key to this information is identification to species. A family or generic name is not adequate, because examples can be found in all groups in which species of the same genus or family differ considerably in certain features. Therefore order, family, genus, and subgenus often give little information regarding the range of ecological conditions under which a given species is found. Thus studies based on identifications above the species level often have little value in ecology or the appraisal of disturbance.

Work at the species level was once frequently precluded by taxonomic difficulties. However, with more experienced and more highly trained personnel available and the rather considerable progress in taxonomic and basic ecological work in the last decade (compare references cited in Danks 1979), this is no longer true. Taxonomically, many groups are now feasible subjects for species-level studies, and expertise exists within Canada to provide specific identifications.

In essence, the reason for species level work is that the species is the most universally valid biological currency by which information can be organized. Such information can be cross communicated and developed. Because it is available to other workers, a progressively more comprehensive picture of biota in relation to environmental conditions can be built up. By this means each environmental study can best contribute not only to the case at hand, but also to the future development of environmental appraisals. Such a fund of organized relevant knowledge is based on accurate identifications: voucher specimens of material on which information is based should therefore be preserved.

Need for stating questions in an ecological context

A second principle that emerges from these examples is that impact studies should be set in an ecological context. Ecological systems, composed of the physical, chemical and biotic environments, can be understood in terms of structure and function, described by a substantial body of ecological theory built up over many years. Together with more formal conceptual models, such theory analyzes or hypothesizes the relationships among ecosystem components (e.g. Minshall *et al.* 1983 for streams). Moreover, taxonomy has reached the level where significant numbers of organisms in the system can be identified to the species level, and laboratory and field studies provide information on distributions, tolerances, and requirements of many individual species. In addition, the fact that there are day-to-day and year-to-year variations in biotic and physical elements of the system, even in undisturbed habitats, means that any human disturbance operates in a framework which itself is characterized by variation (e.g. Stanford and Ward 1983).

Therefore, monitoring and appraisal, even of a limited disturbance, requires a broad understanding of the system. In other words, plans for a study of the effects of a disturbance should recognize the ecological setting of the system which is being disturbed.

Need for a broad approach to planning

Previous examples also show that in any piece of work, including applied ecological investigations, useful results are produced only if studies are carefully planned from the earliest stages. Explicit prediction or planned monitoring of effects reflects the long-term, holistic thinking characteristic of good science. By the same token, decisions about overall strategy, which outline what should be measured, what sorts of changes are significant, and when and where the study should be conducted, are needed before details of the study are developed. There are therefore two main requirements for the general organization of the work. First, all interested parties should cooperate in developing an appropriate plan. In

Various deformities of the larvae of chironomid midges, including distortion of mouthparts and thickening of the exoskeleton, have demonstrated the existence of industrial or agricultural contamination of water (Warwick 1980b, Hamilton and Saether 1971, Koehn and Frank 1980). Such sub-lethal effects can serve as an early warning of major ecological damage caused by chemical overload by pesticides or heavy metals.

Detailed observations of the behaviour of caddisflies exposed to sub-lethal pesticide concentrations showed that larvae left their cases and—even though surviving the pesticide—did not return to the cases (Symons 1977), exposing the larvae to predation and other mortality factors.

Other studies confirm that knowledge of insect life cycles is often necessary to understand what has happened. In monitoring the effect of methoxychlor treatments, apparent "recovery" of *Baetis* mayflies proved to be hatching of related species within the genus (Lehmkuhl 1981); "disappearance" of *Isoperla* stoneflies was caused by normal life cycle phenomena as well as treatment (Lehmkuhl 1981).

Insects thus demonstrate that concepts basic to good science, such as experimental controls and detailed analysis of data, are necessary for the appraisal of environmental disturbance.

Community structure

Changes can also be assessed by the analysis of diverse and easily sampled insect communities. Although general indices such as species richness reflect broad or severe disturbances, the structure of insect communities tracks changes in more detailed ways. For instance, mild localized pollution in the littoral zone of lakes can be recognized by the mass occurrence of species which are not typical members of the normal community, for example, larvae of certain chironomid species (*Cladotanytarsus*) in Okanagan Lake, B.C. (Saether 1979, 1980). At a larger scale, studies of benthic insect communities in lakes have led to a well developed system of lake typology (Saether 1975, 1979, 1980, Warwick 1980a; review by Wiederholm 1984) which shows how a characteristic fauna integrates information about the fertility of the lake. Changes caused by nutrient enrichment, for example, can therefore be readily detected.

The structure of insect communities may also change after pesticide treatments: low numbers of predators after river treatment by methoxychlor led to a preponderance of certain prey species; and hence to an unusual community structure (Lehmkuhl 1982). Analogous changes in the natural predator-prey balance were documented much earlier in sprayed apple orchards, forcing a revision of previous practices in the use of chemical pesticides.

Insects can also be used to show long term effects. In Britain the melanic form of the moth *Biston betularia* became locally prevalent because on soot-darkened substrates it was less conspicuous than the normal form to bird predators, thereby showing the influence of industrial pollution over many years (Kettlewell 1961, 1973). The sensitivity of insects to changed conditions has also allowed some long-term effects of pesticide application to be recognized. McNeil *et al.* (1979) discovered that the jack pine sawfly was susceptible to very small doses of fenitrothion (applied against spruce budworm) which had built up in needles of the host plant through repeated annual applications. The same insecticide depressed yields of blueberries for several years because native bee pollinator populations had been decimated; the populations took several years to recover after fenitrothion use was discontinued (Kevan and Laberge 1979, Kevan and Opperman 1980). Aquatic invertebrates provided a better indication of stream water-quality than did routine chemical monitoring because they exhibited long-term responses to sporadic urban runoff of organic materials and silt (Whiting and Clifford 1983).

On a still longer time scale, historical events such as land clearing have been traced in detail through the analysis of chironomid head capsules preserved in lake sediments (Warwick 1980a). In the Bay of Quinte, Lake Ontario, the chironomid fauna responded to initial colonization of the lake basin by Europeans by developing a composition characteristic of enriched nutrient conditions. Subsequent activities caused massive erosion in the watershed, and mineral sedimentation returned the structure of the fauna to one less characteristic of rich waters. As the erosion stabilized, the suppressed effects of still greater nutrient inputs were realized. Such a history allows prediction of the sort of changes that result from similar environmental disturbances. This is possible both for testing past effects and forecasting expected changes.

Insects thus provide several means to evaluate historical and community changes in a broad framework. Especially credible estimates of environmental changes are obtained when information has been integrated over time and space in this way.

USE OF INSECTS IN MONITORING AND EVALUATING ENVIRONMENTAL DISTURBANCE

To offset the problems just outlined and to take advantage of recent advances, some examples of ways in which insects can demonstrate environmental changes are briefly noted. On this basis, general guidelines for studies which appraise the effects of such changes are put forward.

Insects and their relatives comprise three-quarters of all living animal species. In Canada alone, there are over 66,000 species of terrestrial arthropods (Danks 1979). Furthermore, this diversity includes many closely related species which may respond uniquely to environmental conditions and disturbances.

Insects have figured in various attempts to measure the results of environmental disturbances such as cultivation, land clearing, forest fires, dam construction, or pipeline construction, and the pollution of habitats by fertilizers, pesticides, nutrient enrichment, sewage disposal, chemical waste disposal, radioactivity and acid rain. However, most of these studies have been completed at a low level of biological resolution, or the projects were chiefly organized by engineers or chemists rather than biologists, and have shown only well-known principles already established for other organisms and in other ways: disturbances lead to community changes; very severe disturbances lead to substantial mortality and usually to reductions in diversity. These conclusions provide no understanding of events, and hence are of illustrative but little predictive value. Examples cited below show several ways in which insects can be used more precisely to detect and interpret the significance of environmental perturbations. Insects are particularly useful in this regard because they possess many readily measurable biological characteristics, and they are ubiquitous and diverse. Moreover, because insects display species specific physiology, behaviour and other traits that are fixed genetically (without much of the lability of response seen in vertebrates, for example), they are especially useful indicators of particular conditions. However, it is precisely the informative diversity of insects that demands careful and detailed work if useful results are to be obtained.

General mortality responses

Insect mortality or changes in abundance can provide a measure of the effect of various environmental pollutants.

Laboratory experiments have demonstrated that some species of arthropods are excellent indicators of contamination. For example, mortality of the oribatid mite *Humerobates rostrilamelatus* is closely correlated with sulphur dioxide concentrations (Andre *et al.* 1982) and this mite responds more rapidly to air pollution than do most plants.

Other studies in field situations have proved that insects can indicate the severity of pollution. For instance, populations of the species of carabid beetles studied by Freitag *et al.* (1973) decreased, for example by a factor of more than 4 in *Agonum decentis*, toward the source of pollution from a pulp mill. Other field studies show that environmental impacts frequently are more subtle, and not all species are affected in the same way, as for various soil mites exposed to pesticides (Smith *et al.* 1980). Populations of some species may even increase as a result of chemical contaminants. Species of chironomid midges and mayflies are not all necessarily harmed by oil pollution, but each species responds differently (Rosenberg and Wiens 1976, Rosenberg *et al.* 1980): some species increase in number and others decrease, and changes in abundance of these species could therefore be used to identify small spills or chronic low-level contamination by oil and its derivatives. Similarly, species of *Ceraclea* caddisflies each change differently in occurrence and abundance in response to environmental deterioration, allowing the different species to be used as indicators of water quality (Resh 1976, Resh and Unzicker, 1975).

Susceptibility of soil Collembola to insecticides and fungicides varies widely from one species to another, and varies among fungicide analogs (Tomlin 1975, 1977), showing that toxicity data cannot easily be extrapolated from one species to another or between related chemicals. Since the fertility of the soil depends partly on activities of such arthropods (e.g. Biological Survey of Canada 1982), these results suggest ways in which detailed studies of soil arthropods will reveal changes not shown by other, larger, organisms.

Sub-lethal effects

Although direct mortality has attracted most attention in studies of non-target organisms, other features such as insect life cycles and behaviour provide valuable insight into environmental effects and their measurement.

INTRODUCTION

Society's concern with the consequences of technological development has led to the necessity of monitoring and assessing the impact on natural environments of proposed or existing developments. It is widely agreed among those working on such projects that there are problems with current practices and procedures in a wide range of studies which attempt to interpret or predict the effects of environmental disturbance.

Problems in the particular case of formal Environmental Impact Assessments have been commented on at length by Beanlands and Duinker (1983), Rosenberg, Resh *et al.* (1981), Munn (1975), Lash *et al.* (1974) and others.

This brief* indicates that many of the scientific problems in environmental studies of all kinds can be overcome. The brief considers the use of insects in such studies, and demonstrates:

1. That successful work requires coordination among all parties interested in a given technological development, and expert scientific advice at all stages from early planning to publication of results.
2. That insects can be used effectively in the monitoring and appraisal of environmental disturbance.
3. That such studies should usually pose questions in an holistic setting and in the context of current understanding of ecological systems.

REASONS FOR DISSATISFACTION WITH MANY STUDIES

In many studies involving entomology, the organisms are not identified to species, scientific objectives and investigative designs are not well defined, time allowed is inadequate, and results therefore do not increase our ability to predict impacts in similar or subsequent situations. Communication among participants is often inadequate. Key scientific results, and information on appropriate expertise, may be overlooked.

Many of the early inadequacies were unavoidable during the developing phases of applied ecological studies. These included lack of suitably trained and experienced people, lack of standardized methodology, uncertainty regarding objectives, and, most importantly, lack of basic scientific knowledge, all of which hindered the usefulness of early work. To a large extent, these early difficulties have been overcome. Qualified personnel exist, and advances have been made in many aspects of the methods used, from study design to field work and report compilation. However, there are still problems in defining the actual objectives in data collection and interpretation, and in the dissemination of information.

A major difficulty has stemmed from the fact that the separation between scientific and human value judgments has not always been fully appreciated. The possible result of a disturbance can be measured or predicted; but value judgments are required to decide whether it is "significant" in terms of human values, or when compared with the "benefits" of the proposed development. Science can only describe the system and the changes that might occur. Social and political processes must determine if any changes in the ecological system are acceptable. Projects should therefore be designed so that the differences between the scientific and the political processes are evident, and so that facts that pertain to the required judgments are obtained. Matthews (1975), Beanlands and Duinker (1983) and others have discussed such social and political aspects for the more specific case of Environmental Impact Assessments.

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Abstract

This brief considers the development of proper scientific standards for the monitoring and appraisal of environmental disturbance. Insects are useful in various ways for such evaluations, as demonstrated by examples. The objectives of any such study should be defined by consultation among all interested parties. The complete study should be planned by defining scientific objectives in an ecological context, with the help of peer review of the plans. Data collected should be related to specific questions that have been formulated about the influence of a given disturbance on the system. Scientific answers should be the best attainable at the present state of knowledge; this requires expert personnel for design, analysis and identification of species. Because of their diversity in natural systems, and because they are not well-known, insects usually have not been identified to species in past studies of this kind. However, problems of identification can now usually be overcome with expert help: species identifications are normally necessary because species are the only taxonomic units by which information on the functioning of natural systems can be organized. Some recommendations summarizing these conclusions are presented.

**Récommandations sur l'évaluation de la dégradation de l'environnement:
quelques lignes directrices générales, valeur et faisabilité des études sur les insectes**

Résumé

Le présent mémoire porte sur l'élaboration de normes scientifiques pertinentes pour la surveillance et l'évaluation de la dégradation de l'environnement. Les insectes sont utiles à maints égards pour ces évaluations, ainsi que le démontrent les exemples cités. Les objectifs de toute étude de ce type devraient être définis par consultation entre toutes les parties intéressées. Il faudrait planifier l'étude complète en définissant les objectifs scientifiques dans un contexte écologique et en faisant examiner les plans par des pairs. Les renseignements recueillis devraient se rapporter à des questions spécifiques concernant l'influence d'une altération donnée sur le système. Les réponses scientifiques devant être les meilleures qu'on puisse recueillir dans l'état actuel des connaissances, il faut donc confier à des spécialistes la conception de l'étude, l'analyse et l'identification des espèces. A cause de leur diversité dans les systèmes naturels et parce qu'ils sont mal connus, les insectes n'ont habituellement pas été identifiés au niveau de l'espèce lors des études de ce type déjà effectuées. À l'heure actuelle toutefois, avec l'aide de spécialistes, on peut ordinairement résoudre les problèmes d'identification; il est normalement indispensable d'identifier les espèces, car elles sont les seules unités taxonomiques qui permettent d'organiser l'information recueillie sur le fonctionnement des systèmes naturels. Certaines recommandations résumant ces conclusions sont présentées dans le présent document.

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