Importance of Insects in Environmental Impact Assessment

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ABSTRACT / Insects are particularly suited for use in environmental impact assessment (e.i.a.) because of their high species diversity, ubiquitous occurrence, and importance in the functioning of natural ecosystems. Examples are given of the use of insects in the predictive phase of e.i.a., in the monitoring and assessment phase, and in the much rarer instance of an e.i.a. that includes both of these phases. The importance of working at the species level to understanding the results of e.i.a. is emphasized.

The term *environmental impact assessment*, or variations of it, has come to have a variety of meanings over the last several years (for example, see Rosenberg and others 1981, Beanlands and Duinker 1983, Hirst 1984, Larkin 1984). Here, we adopt the following, simple definition: environmental impact assessment (e.i.a.) is the process of doing predictive studies on a proposed development, and analyzing and evaluating the results of this development (Lash and others 1974). Thus, scientifically based e.i.a.'s are composed of two distinct parts: (a) a predictive phase, which is meant to predict the effects of expected impacts before development occurs, and (b) a monitoring and assessment phase, which is meant to measure and interpret environmental effects during construction and after the development has been completed (Rosenberg and others 1981). Numerous publications are available that deal with e.i.a. methods (Rosenberg and others 1981, Beanlands and Duinker 1983).

Because the e.i.a. process is usually ended once development is complete, there are few examples of e.i.a.'s for which both predictive and monitoring phases are available. Unfortunately, the monitoring and assessment phase is usually deleted (Rosenberg and others 1981, Larkin 1984), although its importance in evaluating the predictions made cannot be overestimated (Rosenberg and others 1981, Beanlands and Duinker 1983, Hecky and others 1984).

Insects are well suited for use in e.i.a. for several reasons. They offer an enormous potential choice of species to work with: some 90,000 species are known from North America alone (Borror and others 1976, Danks 1979). Insects occur in almost every imaginable habitat, and are often abundant and easily sampled. In particular, they are important in the ecological functioning of natural ecosystems through diverse activities ranging from decomposition of organic matter to provision of food for fish and wildlife. In fact, insects play roles as predators, parasites, herbivores, saprophages, and pollinators, among others, which indicate the pervasive ecological and economic importance of this group of animals in both aquatic and terrestrial ecosystems. Environmental perturbations impinge on these roles, and insects often respond to these perturbations in characteristic fashion, so that insects are useful objects of study in e.i.a.

This presentation is intended to inform practitioners of environmental impact assessment of the value of using insects in such activities. To date, this use has been largely overlooked or avoided for a variety of reasons: (a) Most insects are small and cryptic in their coloration and behavior, so that during an e.i.a. they do not receive the attention given to more conspicuous animals such as fish, birds, or mammals, which also often have direct economic value (for example, fish which are harvested). The lack of attention given to the ecological and economic importance of insects and their usefulness in e.i.a. must change. (b) An apprehension may exist that the costs of using insects outweigh the benefits (Resh and Grodhaus 1983).

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Certainly, the analysis of collections of insects often is labor-intensive and time-consuming, but new approaches are being developed to deal with this problem (see, for example, Resh and Price 1984). (c) The development of taxonomic keys to provide the species-level identifications needed for work in e.i.a. has been slow in North America (Resh and Grodhaus 1983), although the situation is improving (Lehmkuhl and others 1984). This problem cannot be solved by ignoring it. (d) Guidelines for the use of insects in appraising environmental disturbance generally are lacking, although publications such as that by Lehmkuhl and others (1984) help to fill this need.

Most of the following examples of the use of insects in e.i.a. come from aquatic ecosystems. In part, this is because of our collective experience, but also e.i.a. appears to have received more attention in aquatic than in terrestrial habitats (see Majer 1983, Beanlands and Duinker 1984). However, the principle of using insects in e.i.a. is the same for aquatic and terrestrial habitats.

Use of Insects in Predicting Effects of Impacts

The effects of a development can be predicted by analogy with similar natural or man-made disturbances (the "case-history approach"), or through experimental work. Often, we are able to learn a great deal about the effects of a development by studying similar projects that have already been completed. This is useful in helping to predict the effects of a proposed project. For example, analysis of case histories indicates that the formation of a reservoir produces predictable responses in the aquatic insect fauna (McLachlan 1974, Wiens and Rosenberg 1984). Members of the fly family Chironomidae are, typically, the first and most abundant colonizers of new temperate reservoirs. Usually, they are followed by other invertebrate groups such as Oligochaeta (freshwater oligochaete worms) and Mollusca (snails and clams) (Wiens and Rosenberg 1984). A single zoobenthic species will often predominate during the initial years of a new reservoir. For example, *Chironomus plumosus* populations "exploded" in Dnieper and Kuibyshev reservoirs in Russia, as did *C. transvaalensis* populations in Lakes Kariba and Volta in Africa (see Wiens and Rosenberg 1984 for references). These typical responses have become part of a "reservoir paradigm" (see Baranov 1961, Hecky and others 1984) that was developed from studies of numerous reservoirs, and which has become useful in predicting the environmental effects of reservoir formation.

Insects also can be used to inform us of events that occurred long ago. For example, the study of chironomid head capsules in sediments of the Bay of Quinte, Lake Ontario, provides a fascinating glimpse into the effects of man's activities over the past 2800 years in the Bay of Quinte watershed (Warwick 1980a). Initial colonization of this area by Europeans caused the development of a chironomid fauna that was characteristic of eutrophic conditions. As a result of subsequent large-scale deforestation, massive erosion and mineral sedimentation caused a reversion to more oligotrophic conditions, and the chironomid fauna changed to one typical of these conditions. Once the erosion began to stabilize, the suppressed effects of continued eutrophication were manifested and the fauna once again changed. This case-history study shows that examination of fossil and subfossil chironomids not only may allow reconstruction of past events, but also may provide information useful in forecasting the kinds of changes that can be expected from similar environmental perturbations in a watershed.

"Prediction-by-analogy" from case-history studies is not always accurate (see below). However, experimental manipulations may allow more precise prediction. For example, as part of the Alberta Oil Sands Environmental Research Program (Smith 1981), Lock and others (1981a and b) used limestone bricks treated with synthetic crude oil to simulate the effects of an oil spill on the benthic insects (and other invertebrates) in the Muskeg River, northern Alberta. One set of bricks was placed in the river for four weeks to allow an epilithic community to develop before treatment, whereas the other set of bricks was treated without being preconditioned. The preconditioned bricks revealed little or no response by the benthic community, compared to the ones treated dry, which suggests that in the event of an oil spill the benthic community on rocks in mid-channel having a well-developed growth of periphyton would be affected less than the benthic community of the river edge, where dry rocks could be contaminated by oil and subsequently submerged (Lock and others 1981b).

Another example of the contribution of experimental manipulation, using insects, to prediction in e.i.a. comes from studies in a terrestrial system. Grasshoppers play an important role in energy transfer and nutrient cycling in rangelands. Therefore, as part of research assessing potential impacts of coal-fired power plant sitings in the northern Great Plains of the USA (Lewis and others 1976, Preston and others 1981), the effects of controlled exposures to SO_2 on grasshoppers were investigated. In one experiment (McNary and others 1981), plots in a northern mixed-grass prairie were given long-term exposure to levels of SO_2 that simulated power plant emissions, and total grasshopper density and density of the migratory grasshopper *Melanoplus sanguinipes*, the most abundant species, were measured. A further study (Leetham and others 1981) examined the direct effects on life-cycle components of continuous exposures of *M. sanguinipes* to low levels of SO_2 in the laboratory. Leetham and others (1984) then examined feeding preferences of grasshoppers on untreated and SO_2-treated leaves of the forage grass *Agropyron smithii* Rydb. The understanding gained by such studies helped to predict that long-term exposures of northern mixed prairies to SO_2 emissions from energy development in this region would likely have no adverse impacts (Lauenroth and others 1984). The approach used, including detailed experimental study of specific potential effects on given species, is a good example of prediction in e.i.a.

Useful insights can be developed by combining case-history and experimental approaches. For example, as part of the Mackenzie Valley pipeline study (Berger 1977), Rosenberg and Snow (1977) combined case-history studies and experimental manipulations to develop a conceptual model for predicting the effects of sedimentation on aquatic insects of lotic watersheds in the Mackenzie and Porcupine River drainages of northern Canada. This model states that river discharge, sediment carrying capacity, and susceptibility of the watershed to erosion determine whether or not the biota are harmed by sedimentation and, if so, the duration of the effect. Unfortunately, the model remains untested.

Use of Insects in Monitoring and Assessing Effects of Impacts

The measurement and interpretation of environmental effects during construction and after project completion are necessary to indicate excessive impacts that require immediate mitigation, to validate predictions originally made, and to provide information useful in future e.i.a.'s (Rosenberg and others 1981). Monitoring and assessment thus provide the experience and data required to advance the scientific basis of e.i.a., and information on insects can be particularly valuable in this regard.

The use of biota in monitoring and assessment is important because physical and chemical measurements provide information only on conditions that exist at the time the samples are taken, whereas biological surveillance reflects conditions that have been integrated over a longer period. For example, aquatic insects have been used in water-quality monitoring activities since the early 1900s (for example, see Hawkes 1979, Whiting and Clifford 1983), and they form the basis of the classical system elucidating lake trophic status (see Wiederholm 1984b for review).

Table 1 gives selected examples of the use of insects in monitoring and assessment activities, and indicates the tremendous range of their possible use (see also Newman and Schreiber 1984). References in Table 1 can be consulted for details of methods. Insects can be used in bioassays (toxicity testing, bioaccumulation, behavioral studies, morphological abnormalities), and population and community analyses (Resh and Grodhaus 1983). However, for these types of use, it is important that organisms are identified to species (Table 1). For example, Resh and Unzicker (1975) showed that, of 89 genera of benthic macroinvertebrates for which water quality tolerances were established for more than one species, these species fitted into different tolerance categories in almost 70% of the genera examined. The largest group of genera (31.5%) belonged to a category in which the species showed completely different responses to pollution (decomposable organic wastes). Furthermore, Resh and Unzicker (1975) demonstrated the wide variety of water quality tolerances of species within the trichopteran (caddisfly) genus *Ceraclea* (formerly *Athripsodes*).

It is also important to have detailed life-history information before the results of monitoring and assessment of a population can be adequately interpreted. This, too, relies on species-level identification. For example, in monitoring the effects of methoxychlor treatments for blackfly control on nontarget organisms in the South Saskatchewan River, Lehmkuhl (1981) showed that the apparent recovery of *Baetis* mayflies was, in reality, a hatching of related species within the genus. The disappearance of *Isoperla* stoneflies, caused by late-spring methoxychlor treatment, preceded by several weeks, and replaced, their normal midsummer disappearance caused by natural life-cycle events. In addition, reduced numbers of *Isoperla* species resulting from the treatment led to higher numbers of certain prey species, and hence to an unusual community structure in the river (Lehmkuhl 1982).

The results of monitoring and assessment activities with insects are also valuable in revealing interactions and long-term changes. For example, McNeil and others (1979) discovered that the jackpine sawfly, *Neodiprion swainei*, was susceptible to the very small doses of fenitrothion (which was applied for control of spruce budworm) that had accumulated in jackpine needles through repeated annual applications. Fenitrothion was also indirectly responsible for depressed yields of blueberries for several years in the Canadian maritime provinces because it had decimated popula-

Table 1. Selected examples of the use of insects in monitoring and assessment activities.

Type of monitoring	Organism(s) involved	Toxicant or environmental disturbance being monitored	Comments	References
Bioassays				
Toxicity testing	Larvae of *Brachycentrus numerosus* (Trichoptera)	Fenitrothion pesticide	72- and 96-h LC_{50}'s revealed that *B. numerosus* was relatively resistant to fenitrothion, whereas 30-day tests showed a much greater sensitivity and low margin of safety in the field.	Symons and Metcalfe (1978)
	Eggs and larvae of *Tanytarsus dissimilis* (Chironomidae)	Heavy metals (Cu, Cd, Zn, Pb)	LC_{50} concentrations were as much as 1600× lower than for other aquatic insect exposures because of (a) exposure of more than one life stage and (b) species-specificity.	Anderson and others (1980)
	Nymphs of *Hexagenia rigida* (Ephemeroptera)	Permethrin pesticide	Results indicated that permethrin concentrations that can be expected to occur from field applications may be toxic to nontarget organisms such as *H. rigida*.	Friesen and others (1983)
Bioaccumulation	Nymphs and adults of various species of *Halobates* (Heteroptera)	Cd and other heavy metals	Sea-skaters may be useful for monitoring Cd on the open ocean.	Cheng and others (1976, 1979), Schulz-Baldes and Cheng (1980)
	Imagos of *Hexagenia bilineata* (Ephemeroptera)	Polychlorinated biphenyl (PCB, Aroclor 1254)	Adult *H. bilineata* may be useful indicators of chemical residues because they are abundant and easily collected, and the nymphs, which inhabit soft substrates, are exposed to, and accumulate, sediment-borne residues.	
	Eggs of *Triaenodes tardus* (Trichoptera)	10 pesticides	"Passive biological systems such as caddisfly eggs can accumulate significant quantities of pesticide from water. . . ." (p. 305).	Belluck and Felsot (1981)
	Adult *Apis mellifera* (Hymenoptera)	As, Cd, F	Honey bees are effective biological monitors of arsenic, cadmium, and fluoride over large-scale geographic areas.	Bromenshenk and others (1985)
Behavioral testing	Adult male *Acheta domesticus* (Orthoptera)	Parathion, dieldrin, sevin pesticides	Altered acoustical and sexual behavior of crickets resulted from treatment with low levels of these pesticides.	Young and Stephen (1970)
	Larvae of *Hydropsyche angustipennis* (Trichoptera)	Fenethcarb pesticide	Measurable changes in net-building behavior, caused by the insecticide at sublethal concentrations, were seen. See also Besch and others (1979) for effects of copper, and Petersen and Petersen (1983) for environmental monitoring of heavy metal and toxic chemical wastes.	Besch and others (1977)

Table 1. Continued.

Type of monitoring	Organism(s) involved	Toxicant or environmental disturbance being monitored	Comments	References
	Nymphs of *Ephemerella walkeri* (Ephemeroptera)	8 herbicides	When an avoidance maze was used, no avoidance by the insects was observed for any of the herbicides at concentrations simulating field applications. However, mayflies may receive a lethal exposure before attempting to avoid a chemical.	Folmar (1978)
Morphological abnormalities	Larvae of Chironomidae	Industrial effluents (including heavy metals), agricultural chemicals	Some larval mouthparts are deformed, and head capsules and body walls are thickened. The incidence of deformities rises dramatically in waters affected by industrial effluents and agricultural chemicals. See Warwick (1980b) for review.	Hamilton and Saether (1971), Koehn and Frank (1980), Warwick (1980b), Wiederholm (1984a)
	Nymphs and adults of *Corixa punctata* and *Sigara dorsalis* (Hemiptera)	Dichlobenil herbicide	Unpigmented adults and nymphs were found in herbicide-treated ponds. Pigmentation was inhibited during ecdysis in nymphs exposed to the herbicide, but upon elimination of residues, pigmentation returned during the following ecdysis.	Tooby and Macey (1977)
	Eggs and nymphs of *Acheta domesticus* (Orthoptera)	A chemical impurity in acridine, a component of coal gasification and liquefaction wastes	Cricket embryos developed extra head structures such as compound eyes, branched and extra antennae, and extra heads. The number and severity of abnormalities increased with increasing concentrations of the teratogen, and many of the defective embryos survived to become adults.	Walton (1981)
Population analyses	20 species of Carabidae and one species of Silphidae (Coleoptera)	Fallout from kraft mill flue exhausts (Na_2SO_4)	Populations of beetles were used to indicate condition of the leaf litter ecosystem near the mill. Populations decreased within 2.4 km of the exhaust stack, but increased with distance from the mill.	Freitag and others (1973)
	Larvae of Chironomidae, nymphs of Ephemeroptera	Small spills or chronic low-level contamination by crude oil and its derivatives	Numbers of *Cricotopus bicinctus, C. varipes*, and *Ephemerella aurivillii* should increase in response to contamination by oil, whereas numbers of *Nilotanypus fimbriatus, Heptagenia* (*flavescens?*), and *Stenonema vicarium* should decrease.	Rosenberg and Wiens (1976), Rosenberg and others (1980)
	14 species of ants (Formicidae)	Mirex bait (for control of the fire ant *Solenopsis invicta*)	Effects of mirex application on nontarget species of ants were followed. Some species were affected immediately (e.g.,	Summerlin and others (1977); see also Majer (1983)

Table 1. Continued.

Type of monitoring	Organism(s) involved	Toxicant or environmental disturbance being monitored	Comments	References
			omnivorous and predaceous species) while others were unaffected. Recovery of populations was also monitored; some reached levels higher than before treatment, while others were lower a year later.	
	Larvae of *Gumaga nigricula* (Trichoptera)	Geothermal energy development	The density of *G. nigricula* and its dominance of the macroinvertebrate fauna increased along a gradient of thermal, silt, and chemical (sulfates, ammonium, heavy metals) inputs where long-term geothermal energy development has occurred.	Resh and others (1981)
Community analyses	Lake Chironomidae	Lake trophic status	The fertility of lakes, and changes in it, can be determined by examination of chironomid communities. Lake types from ultra-oligotrophic to dystrophic have characteristic assemblages of chironomid fauna. Eutrophication results in predictable changes in chironomid communities, and there is a good correlation between lake type, based on chironomid communities, and mean concentrations of total phosphorus/mean depth and total chlorophyll/mean depth.	Saether (1975, 1979, 1980), Warwick (1980a); see Wiederholm (1984b) for review
	Stream macrobenthic invertebrates (mainly species of insects)	Stream pollution (introduction of organic matter or nutrients, effects of dams)	A biotic index was developed from Wisconsin streams as a rapid method of evaluating water quality. It uses insects (mainly), amphipods, and isopods. Species are assigned pollution tolerance levels of 0 (species in unaltered streams of very high water quality) to 5 (species in severely polluted streams). The index is calculated from the formula: $\text{B.I.} = \frac{\sum n_i a_i}{N}$ where n_i is the number of individuals of each species; a_i is the tolerance value assigned to that species; N is the total number of individuals in the sample.	Hilsenhoff (1977, 1982); see also Hellawell (1978) and Hawkes (1979) for reviews
	Mainly species of stream insects	Stream pollution by heavy metals (Cu, Cr, Zn)	Heavily polluted habitats appear to be dominated by Chironomidae,	Winner and others (1980)

Table 1. Continued.

Type of monitoring	Organism(s) involved	Toxicant or environmental disturbance being monitored	Comments	References
			moderately polluted habitats by Chironomidae and Trichoptera, and minimally polluted/ unpolluted habitats by Trichoptera and Ephemeroptera. The proportion of Chironomidae in samples may be a useful index of heavy-metal pollution.	

tions of native bee pollinators, and these populations took several years to recover after fenitrothion use was discontinued (Kevan and Laberge 1979, Kevan and Oppermann 1980).

The Complete e.i.a.

As mentioned above, there are few e.i.a.'s for which both predictive and monitoring and assessment phases are available. However, one such example is the Southern Indian Lake reservoir study in northern Manitoba. Zoobenthos (which includes aquatic insects, aquatic oligochaete worms, snails, clams, freshwater shrimp, and the like) responded differently than predicted to reservoir formation in Southern Indian Lake, offering valuable insights into the reservoir paradigm and the hazards of prediction-by-analogy (Hecky and others 1984, Wiens and Rosenberg 1984).

The reservoir paradigm predicts an initial rapid increase in available nutrients, which results in increased standing stocks and productivities in all biotic communities (Baranov 1961, Hecky and others 1984). In addition, for zoobenthic organisms, a single species often predominates in the initial years after reservoir formation, and there is usually a succession of colonizing species (see above). However, in Southern Indian Lake, only increased standing stocks of zoobenthos were observed, and the expected relative abundances and successional events did not occur following reservoir formation (Wiens and Rosenberg 1984).

The pre-impoundment e.i.a. done on Southern Indian Lake (Underwood McLellan and Associates Ltd. 1970) was based on the reservoir paradigm (Hecky and others 1984). This e.i.a. modified the reservoir paradigm, in view of the potential for extensive shoreline erosion in Southern Indian Lake, and predicted a reduction in zoobenthos in nearshore and offshore zones due to sedimentation (Hecky and others 1984). Underwood McLellan and Associates (1970) also predicted a reduction in profundal zoobenthic production due to thermal stratification and oxygen depletion in the hypolimnion, two other aspects of the reservoir paradigm. As a result "important fish food organisms such as amphipods [freshwater shrimp], sphaeriids [fingernail clams] and mayflies may be reduced or eliminated" (Underwood McLellan and Associates 1970:62; brackets ours). However, as previously mentioned, lakewide average standing stocks (no./m^2) of profundal zoobenthos have increased since impoundment (Wiens and Rosenberg 1984 and unpublished data), although production estimates were not made. Furthermore, the low-level flooding of Southern Indian Lake did not result in oxygen deficiencies or thermal stratification in the first six years after impoundment (Patalas and Salki 1984, Rosenberg and Wiens unpublished data), although evidence of the latter appeared in 1983 (Patalas and Salki unpublished data). Since impoundment, standing stocks of freshwater shrimp (*Pontoporeia brevicornis* grp.) have increased dramatically, fingernail clams have remained essentially unchanged, and mayflies (*Hexagenia limbata, H. rigida*) have declined (Wiens and Rosenberg 1984 and unpublished data).

Much of the information on which the reservoir paradigm was based originated from experiences with damming rivers that flowed through valleys. Thus, the type of information provided by the Southern Indian Lake study is valuable to modify predictions of the effects of reservoir formation when a reservoir is created by flooding an extant lake that is subject to extreme shoreline erosion, rather than by damming a river valley. The Southern Indian Lake study is currently trying to unravel and understand the many biotic changes that have occurred in the lake. The aquatic insects are an integral part of these changes and of our understanding of them.

Conclusions

The most valuable information for prediction, and for monitoring and assessment, is based on *understanding* why changes will occur or have occurred, because this allows informed judgments to be made about present or future impacts. The intention of this article is to show that insects offer one way to understand the functioning of ecosystems. This understanding is seen, from the examples reviewed here, to stem most clearly from identifications of individual species. We emphasize, too, that the *proper* use of insects is required. "Quick-and-dirty" studies based on inaccurate or very broad identifications will, unfortunately, yield quick-and-dirty information, whereas properly designed programs of research can answer the questions asked in the course of an e.i.a.

We do not dispute that approaches other than those based solely on a knowledge of species may be possible in e.i.a. In fact, currently, there is debate about whether changes in species composition or aspects of ecosystem function (such as alterations in nutrient pathways) are better measures of environmental perturbation (Kimball and Levin 1985). Typically, supporters of the use of functional approaches have two concerns: (a) that the presence of a high number of species results in functional and structural redundancy, and (b) that it is impossible to study all species, especially in a group as diverse as the insects, because of constraints of expertise, time, and cost. However, in response to the first concern, "under some circumstances, changes in producer species composition are more sensitive indicators of stress . . . than such functional changes as alterations in nutrient pathways; they may also be better early indicators of ecosystem stress because functional redundancies buffer processes against change" (Kimball and Levin 1985:169). With regard to the second concern, there is substantial support for limiting studies of environmental perturbation to key species (Beanlands and Duinker 1983, Kimball and Levin 1985). Surely, therefore, the two approaches are complementary. As Schindler (1987) stated: "After 16 years of manipulating whole ecosystems, I do not believe that changes in ecosystem function, such as production, decomposition or nutrient cycling, can be properly interpreted without analogous information on the organization and structure of the biotic communities."

We cannot deny that there are difficulties in using insects as part of an e.i.a. However, problems associated with the use of any physical method or biotic group in e.i.a. will not be resolved by avoiding them, and concerted efforts are necessary to solve these problems. The fact needs to be emphasized that insects provide valuable information to an e.i.a. (see Table 1) because they are so diverse and are integrated into ecosystems in so many ways.

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