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"How to" and "why": assessing the enviro–social impacts of pesticides

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Abstract

A typology is proposed to distinguish among three quite different types and applications for pesticide impact assessment tools (which are also known as "pesticide risk indicators"): (1) decision support systems for farmers and other property managers; (2) "ecolabeling" or "green labeling" systems designed to influence consumer opinion and market behavior; and (3) indicators of impact and risk used by governments, industry and academia to assess policies and programs. These types are differentiated by their objectives, decision makers, factors or variables considered, arena of activity, scale and unit of analysis, handling of an economic dimension, format of results, and method or approach. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

It has become widely acknowledged that pesticide weight and volume are not adequate proxies for assessing the risk of non-target impacts of pesticides. Thus since the mid-1990s diverse user groups and research communities have been thinking about how best to measure and track these risks. This paper gives an overview of pesticide assessment systems, providing some mental tools for negotiating their uneven terrain. It touches on several key issues regarding measures of the non-target impacts of pesticides:

- What indicators and measures should be used?
- Is pesticide risk reduction the same as integrated pest management (IPM)?
- Is it a guarantee of improved environmental quality and public health?
- Should toxicology be the centerpiece of a risk measure?
- How can situation-specific factors that affect exposure be incorporated into user-friendly pesticide assessment tools?
- How do pesticide risk indicators connect with (1) "real science" (2) consumer behavior in the marketplace, and (3) public policy?

To address these issues, a typology — or way of categorizing pesticide risk indicators — is proposed to distinguish among three quite different applications for these tools:

- Decision support for farmers, farm advisors and other property managers in choosing among pest control options and evaluating the impacts of their choices;
- "Ecolabeling" or "Green Labeling" systems designed to influence consumer opinion and market behavior;
- Research, evaluative and policy tools generated and used by government, industry and consumer groups, and academia.

The paper focuses more on the "what" and "why" questions than on the technical particulars of "how", which requires far more patient attention to detail and data than possible here. Specific methods used in a number of pesticide assessment systems are detailed in several other publications, some of whose authors and organizations now also provide updates on the World Wide Web (Levitan, 1997, 1999; Levitan et al., 1995; Levitan and Kovach, 1998; Day, 1998; Reus et al., 1999).

2. Why assess the impacts and risks of pesticides?

The quantity of pesticides used worldwide is at a record high — 4.7 billion pounds were used in 1995 — and

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continues to grow. Despite the fact that many newer pesticides are used at very low volume per unit area, total usage in the US, for example, is more than double the amount applied 35 years ago when Rachel Carson wrote *Silent Spring* (1962).

At the same time, a lot more is known about the impacts of human activities. Some of the impacts have been positive (thus the relatively well-to-do are living long and healthy lives), but also more is known about toxins and resource degradation. The task of identifying the greatest risks in our multifactorial environment is both complex and value-laden. The development and application of comparative risk indicators is a functional and useful step toward risk reduction.

Hazardous toxic chemicals are one such source of risk, and pesticides are among the chemicals of greatest concern and ubiquity: Half of the 640 chemicals tracked by the US Toxics Release Inventory, for example, are pesticide ingredients (US EPA, 1996).

However, pesticide risks cannot be adequately assessed either by simply quantifying the amount of pesticide used or by counting the number of pesticide applications because different chemicals have quite different potencies, fate and transport characteristics, and non-target effects. Thus risk-weighted indices of usage are being developed as a more powerful measure of negative environmental impacts. Their objective is to facilitate and monitor the shift to more benign pest control products and practices, and thus reduce risks to public health and other aspects of the environment. The intent is to avoid shifting risk from less potent chemicals used at higher volumes to more potent chemicals used at lower volumes. This objective can be characterized under the rubric of "sustainable agriculture" or "pollution prevention" or "risk reduction" — In any case, it answers the question: "why assess pesticide impacts?".

3. Nomenclature

"Pesticide risk indicators" has come to be the most widely used term describing this field, but a number of other terms also cover some of the same ground (Table 1). This diverse nomenclature is an outcome of having many disciplines, languages of communication, and networks of concern involved with pesticide risk reduction efforts, ranging from international groups like the OECD, the European Union, and the World Wildlife Fund to local extension educators who advise individual farmers.

In some nations, pesticide regulation and risk reduction efforts are within the purview of departments of the environment; in others the work is under the aegis of agriculture agencies. The process of assessment is often more specifically under the wing of program evaluation or risk communication or economics. In addition, the development and interest in pesticide risk indicators often slides between disciplinary boundaries. "Architects" of assessment systems often carry out this work as an aside to their daily responsibilities.

Table 1
Array of terms used to describe "pesticide risk indicators"

Environmental impact assessments
Environmental risk indicators for pesticides
Integrated pest management measurement systems
Measures of adoption of integrated pest management
Measure of success of integrated pest management
Pesticide decision support systems
Pesticide environmental impact indicators
Pesticide hazard rankings
Pesticide impact assessment models
Pesticide impact assessment systems
Pesticide indexes
Pesticide program evaluation
Pesticide ranking and scoring systems
Pesticide risk analysis
Pesticide risk yardsticks

Many of the indicator systems have been published only in the "gray literature" of reports, handouts, spreadsheets, databases and bulletins. Prior to the recent advent of the World Wide Web and e-mail, information about this gray literature circulated slowly by word-of-mouth. Now that the field is about 10 years old, increasing numbers of descriptions and/or results of evaluations are also being published as books and journal articles. However, even these publications are not easy to locate by means of traditional scientific literature searches because they are described by quite different key words and search terms, and appear in the journals of disciplines ranging from plant science to toxicology, artificial intelligence to agriculture. This diversity is reflected in a listing of pesticide risk indicators that is posted and periodically updated at the Environmental Risk Analysis Program website (*http://www.cfe.cornell.edu/risk/PesticideRiskIndList.html*).

4. Pesticide impact assessment systems vs. pesticide risk indicators

In part the differences in nomenclature and terminology simply depend on which terms are familiar within a particular discipline, but they also reflect differences in disciplinary orientation and methodological approach. The term "pesticide impact assessment system" cuts somewhat of a wider swath than does "pesticide risk indicator," ranging from complex simulation models — such as are produced by systems ecologists and soil scientists who track pesticide fate and transport — to the succinct summaries of trends and highlights generally known as "indicators."

"Pesticide impact assessments" that evolved from one of the bio-physical disciplinary heritages are likely to retain the systems perspective and resultant depth and complexity, as well as the related terminology. On the other hand, assessment systems that evolved within the framework of policy analysis and risk communication are often instead attempting to provide a simple measure or an indicator of trends, efficacy, success, failure, etc. i.e., they give an "indication" but do not attempt to simulate a complex reality.

Whatever term is used, the objective of the models (or tools, or systems) is to assess impacts/risks of pesticides on one or more human health or other environmental endpoints, either by comparing among pest control alternative, comparing with a hazard threshold, or comparing risks over time (i.e., trends) or across space (i.e., impacts in different regions or different uses). The goal of the systems, from whatever methodological approach, is to provide information to encourage and/or evaluate risk reduction. The challenge is to develop tools which retain scientific validity — which is a strength of assessment systems, while at the same time develop tools which are easy to use and to understand — which are strengths of risk indicators. When understood in this light and within the limitations of each approach, better use can be made of the results.

5. Impacts, hazards and risks

There is also a semantic distinction between the terms *impacts*, *hazards* and *risks*, as used to describe consequences of pest control activities. The word *hazard* is intended to convey only the type of harm and perhaps its severity e.g., "lethal toxin to amphibians," while *risk* conveys a probability of harm that takes both the hazard and the chance of exposure into consideration.

Although "pesticide risk indicators" are increasingly incorporating some measure or indicator of exposure, and thus conveying more information that a listing of hazards, they are generally constrained by their structure and the available input data to be less than an assessment of risk probability under any specific realistic scenario. To capture this approximation of hazard potential and risk characterization, and to acknowledge that risk indicators are typically not quantitative analyses of risk as understood in the field of risk analysis, the term impacts or impacts/risks is preferred.

6. Types of risks relating to pesticides

A number of different types of risks are associated with pesticides, any one or more of which may be tracked by a particular assessment system, including the risk of:

- unintended adverse effects on non-target biota (note that input data and results will differ depending upon which groups of biota are assessed);
- exposure, i.e., risk of pesticide residues on food, in water, in soil, in air (this type of information is often generated from fate and transport models);
- pest resistance of pest controls;
- disease or loss of food and fiber because pests are not controlled;
- harm to natural or agro-ecosystem (i.e., adverse effects of pesticides on beneficial organisms);
- greater cost for pest control than the cost of pest damage — a criterion used in IPM to decide whether intervention is worthwhile;
- consumption and degradation of resources as result of using a pesticide (e.g., ozone depletion, in part caused by the fumigant methyl bromide) or of using an alternative pest control measure (e.g., soil erosion from tilling to control weeds rather than using an herbicide.

Table 2
Comparison of "most hazardous" pesticides, as ranked by three assessment systems

CHEMS-1 (Swanson et al., 1997)	California (Pease et al., 1996)	EIQ (Kovach et al., 1992)
1 terbufos	1 methomyl	1 disulfoton
2 **trifluralin**	2 aldicarb	2 parathion
3 hexachlorobenzene	3 carbofuran	3 propoxur
4 anthracene	4 **2,4-D (+salts)**	4 oxydemeton-methyl
5 chlorothalonil	5 mevinphos	5 fenamiphos
6 **2,4-D**	6 **dimethoate**	6 **dimethoate**
7 1,3-dichlopropene	7 **trifluralin**	7 paraquat

Assessing each of these types of risk requires asking a different set of questions. They require models which rely on different assessment endpoints and input data. The results generated by different indicators should not, therefore, be expected to be identical. Table 2 lists the top pesticides as ranked by three assessment systems. Although all three lists are generated by composite models of hazard to public health and non-human biota, only 2,4-D, trifluralin and dimethoate are on more than one list. The reason is that the three assessment models take different approaches to incorporating indicators of exposure, and assign greater weight to different aspects of the environment. Both the Environmental Impact Quotient (EIQ) developed by Kovach et al. (1992) and the California Policy Seminar system developed by Pease et al. (1996) focus on agricultural pesticide uses, but the EIQ is a farmer decision support system particularly sensitive to impacts on beneficial insects and farmworkers. In contrast, the Chemical Hazard Evaluation for Management Strategies (CHEMS-1) developed by Swanson et al. (1997) is a screening system for all chemicals, intended to err on the side of caution and flag chemicals requiring more rigorous observation or testing.

Table 3
Typology of pesticide risk indicators[a]

Criteria	Category of Pesticide Risk Indicator		
	Decision support	Ecolabel	Policy analysis
Objectives	Inform re: potential environmental and economic consequences of pest management decisions	Encourage production and purchase of goods that meet a set of environmentally-sensitive criteria	Monitor trends in pesticide use and risk; warn about hazards/potential risks
Decision maker	Property owner, manger (e.g. farmer)	Group providing accreditation; consumer	Researchers, advocates, policy-makers
Factors or variables considered	All factors taken into account in making the decision	Set of factors deemed important by group conferring the ecolabel	Single or multiple factor(s) relevant to specific policy or issue
Arena of activity	Site of pest control activity	Marketplace	"At the roundtable"
Scale of analysis	Field or enterprise	Farm or food processing facility	Production region, nation, world
Unit of analysis	Pest management incident or strategy	Output from a facility (e.g., the apples from a farm)	Total quantity of pest control products
Economic dimension	When included, typically just production costs	Choice exercised by consumer; price premium and/or increased market share for producer	Cost to society, market externalities
Format of results	Link process with result in workbook or computerized expert system	Separate decision process from result with ecolabel on product	Tabular or graphical results summary
Method or approach	Interactive decision-tree	Checklist of criteria	algebraic equation or screening checklist

[a] Characteristics of each category are generalized and idealized. Concepts and "shorthand terms" used in the table are elaborated in the text.

The point being made, and illustrated by Table 2, is that the strength of pesticide risk indicators is in assessing relative risk based on the given measure of any one system. Indicators are not suited, for the most part, to assess absolute risk, nor for results to be extrapolated beyond the hazard or risk endpoints evaluated by the model.

7. Typology

The typology proposed for differentiating among categories of pesticide assessment models provides a handle for appreciating the nuanced differences among the systems. By understanding why different data and variables may be more appropriate for indicators used in different situations, one can also understand why results may differ. In this typology, the three categories (Decision Aids, "Ecolabels," and Research and Policy Tools) are principally differentiated on the basis of their objectives and intended application, but typically also fall out using the other criteria in Table 3.

Objectives of assessment systems can be further delineated between those that are prescriptive (ex ante) and those which are descriptive (ex poste); in other words, whether they project or advise about future action, or describe and evaluate past actions.

A full discussion of the complexities and ramifications of the choice of assessment variables is beyond the scope of this paper (see Levitan, 1997), but two types of variables are differentiated: (1) behavioral or "input" factors and (2) impact or "output" factors. Indicators of impacts include many pesticide test endpoints, such as single species toxicity test results (e.g., the LD_{50}), estimates of exposure, measures of residues on food and in the environment, sublethal effects (e.g., impacts on reproduction, the endocrine system), secondary impacts on habitat and food sources, and impacts at higher levels of ecological organization (e.g., impacts on species richness, biomass, ecosystem productivity). Assessments based upon impact criteria have been constrained by data limitations, gaps and inconsistencies.

Behavioral data are frequently easier to collect via surveys and interviews and by observation. Examples of behavioral variables include whether the pest control manager practices integrated pest management (IPM); the number and types of IPM techniques that are used; and verification that pesticide sprayers have been calibrated. Assessments based on behavioral indicators are not similarly constrained by data gaps because data points are observational. However there remains a potential gap between "what was done" and "what difference it made" that can only be closed by validating the relationship between behaviors and impacts. Systems based on behavioral indicators assume a positive relationship between certain sets of behaviors and impacts. For example, behavioral assessments are generally predicated on the assumption that IPM and organic methods are more benign in their environmental impacts than post World War II "conventional" chemical pest control strategies. Assessments based on impacts data are essential for undergirding, supporting and challenging these implicit assumptions about the effects and significance of certain behaviors.

With these caveats, each of the three major types of assessment tools, Decision Aids, "Ecolabels," and Research and Policy Tools will be described in terms of the nine criteria listed above.

7.1. Decision aids for farmers/growers and other property managers

The objective of these assessment tools is to inform people who make pest management choices about the potential environmental and economic consequences of their decisions. The site of the problem is the arena of activity — i.e., the buildings and grounds where pest control is needed. These are typically field scale indicators, used "on-site" not only by farmers and farm advisors making decisions about agricultural pesticides, but also by other property managers, including homeowners, lawn maintenance companies, golf course managers, foresters, etc. Thus the scale of analysis is typically the enterprise. The unit of analysis is likely to be either the pest management incident, a discrete pest control application or practice, or else the compendium of decisions made during one or more production seasons — which together constitute a pest control strategy.

The value of assessment tools for farmers and other property managers depends on their utility in providing valid information and "advice" that is pertinent to specific pest management decisions. The problematic is how to integrate and inform the many factors contributing to each management decision. To be useful, the decision support system must somehow consider or allow for all factors that the property manager must (or should) take into account in making the decision. After all, only one decision about what to do can be made at any single decision point. Thus, the decision maker must optimize for multiple attributes, including safety, effectiveness and economic value. The decision integrates the manager's personal concerns for applicator safety and the agro-environment, with altruistic or regulated interests in protecting human health and the broader environment, and business interests in production costs and in securing a market niche. Farmers do not have the luxury of basing their decision on a single criterion, such as choosing one pest control because one indicator shows it is safer in the short run and another pesticide because a different risk indicator shows it has lower chronic risk. An economic dimension is either explicitly among the assessment criteria, or else production costs borne by the property manager must be implicitly understood to play a role in the decision-making process.

Field-scale decision supports should be sensitive to "situation-specifics" — a term coined to cover both site and management variables — because impacts and costs are both very responsive to the details of reality. Thus these decision support systems must have accurate input data for all types of site conditions (e.g., soil type, rainfall, wind and temperature) as well as data for managerial variables such as use of irrigation, time of spraying, actual costs for labor and materials for alternative pest control options, etc.

The challenge of course is how to incorporate such detailed and variable data into a useful field tool. Two very different approaches have been used successfully:

- Data are provided from some very large datasets. The impediments to this approach are its data and equipment-intensive requirements, and the fact that situation-specific variables are limited to those in the model, which are not likely to include management variables. In the attempt to be multi-factorial, these data-driven models typically become too complex and cumbersome to provide useful decision support for the non-professional.
- Data are provided by means of an interactive interview or questionnaire answered by the pest control manager, and delivered in the format of a workbook or computerized expert system based on a "decision-tree model." Unlike stand-alone rankings of pesticides by risk, this format permits "if-then-else" routines that can be extremely sensitive to situation-specific variability. For inputs that cannot be gleaned from the experienced insights of the property manager, the "decision-tree model" is informed by an array of information drawn from the scientific literature (e.g., toxicological hazard data for pest control options, expert judgements about risk thresholds, algorithms regarding pesticide behavior in soils and water).

Since these are decision support systems for a group of real people, they must be flexible and non-dogmatic, as well as responsive to the given situation. The more successful on-site pesticide risk decision support tools are an intimate interlinking of process and result, whereby the "answers" regarding pesticide risk depend upon responses given in the process of looking for an answer. In other words, pesticide risk indicators that use the decision-tree approach cannot stand apart from the process.

The decision support approach has been used both as a "self-education tool" as well as an evaluative tool.

Because there is no one "best answer" for all situations, this methodological approach can run into some difficulties when "results" are linked with a benefit to the producer, such as IPM accreditation. Unfortunately a nuts-and-bolts discussion of this issue (and possible ways around it) is beyond the scope of this short paper.

7.2. Ecolabeling systems to influence consumer opinions and purchases

Ecolabels, which are also called "green labels," bring environmental impact assessment to the marketplace by encouraging the production and purchase of goods that meet a set of environmentally sensitive criteria, such as criteria about acute toxicity of pesticides. The concept and application of ecolabels has mushroomed in recent years, such that ecolabels are affixed to many manufactured goods as well as to agricultural and forest products. The environmental factors considered by the assessment are whatever set of factors is deemed important by the accrediting group that confers the ecolabel.

The term "ecolabel" is generic for this market mechanism; i.e., it is not specific to any one set of environmental standards or any one certification program. Thus ecolabels are the "front end" for many different assessment criteria and assessment systems. Consumers are generally far more familiar with the label (e.g., "organic produce") than they are with the particulars of the labeling criteria. Consumers of certified organic food in the United States, for example, are not likely to be aware that certain pesticides (such as rotenone or sulfur) are permitted and may have been used on their organic food.

Two groups of decision-makers affect and are affected by ecolabels: the accrediting body and the consumer. The arena of activity is the marketplace, both the retail market place where the consumer decides whether to pay the price premium sometimes associated with these products in exchange for a personal or societal benefit, and the wholesale marketplace, where market share may be decided if distributors choose to preferentially handle ecolabeled products. With vertical integration and pre-market negotiation, the reality (and often the intent) is that the production arena is also affected by ecolabeling decisions i.e., the incentive of the ecolabel entices farmers to avoid or reduce use of more hazardous pesticides. The economic dimension comes into play for consumers in weighing their purchasing options, and for producers who may be motivated by promise of a price premium or increased market share.

The scale of analysis is typically the production unit (e.g., a farm or food processing facility or company). The unit of analysis is the product (e.g., apples) from that facility. The approach or method used for ecolabel assessments is typically a checklist, indicating whether the specified criteria have been met. A key point about ecolabels is that the label — which is the format of the assessment results — always stands separate from the decision process. In other words, an ecolabel is either conferred or it is not. There is no opportunity to account for mitigating circumstances, unless there is a method for incorporating them into the accrediting process. In other words, the farmer does not have opportunity to explain to the consumer: "but I sprayed early in the morning so the pesticide didn't harm the honeybees and other pollinators" or "oops, we had an accident, and the farmworkers breathed in sulfur dust." The label does not have a place to clarify that in a particular farm-field depth to water is greater than assumed by the pesticide leaching model, and therefore pesticides are less likely than predicted by the model to leach into the groundwater. This segregation between process and output differs from the previously discussed decision-tree models used for farm-scale decision tools, where process is intertwined with output.

7.3. Policy, evaluative and analytic tools used by governments, industry, and academia

In this typology a range of assessment systems used for many distinct purposes fall under the rubric of policy tools. Key and over-riding objectives of policy tools are to monitor trends in pesticide use and risk, and to warn about hazards and potential risks. More specifically, the types of policy tools include:

- screening systems that enable regulatory agencies and industry to quickly assess preliminary data for danger signals about new or potential pest controls;
- analyses by regulatory agencies and environmental watchdog groups that evaluate pesticide use and risks over time, or compare risks of different pesticides or pest management options;
- evaluations of risks from individual pest control products and practices, used as the basis for restrictions and warnings (see, for example, the WHO and US EPA human health acute toxicity warning labels, both discussed in Levitan, 1997);
- criteria for pesticide usage tax programs;
- evaluations of the success and/or relative or absolute costs and benefits of programs and policies (e.g., to determine whether pesticide taxes, regulations of spray buffers around fragile areas, or investment in improved pesticide application technologies is most effective in reducing risk at least cost);
- assessments of the adoption of IPM on farms and in schools, used in part to set IPM research and extension priorities;
- evaluations of the success of IPM in meeting its objectives to control pests in a cost-effective and more environmentally benign manner.

The types of decision-makers targeted by policy tools are as different as this list of objectives. They include research and outreach teams working in academia, extension, and the budget offices of government and foundations, as well as policy-makers at all levels of government and in the environmental research and activist communities. The arena of activity for policy tools could be said to be "at the roundtable," in contrast to the farmer's field and the marketplace. The unit of analysis is generally large — e.g., the total quantity of pest control products used in a state, a nation, or internationally.

The scale of analysis is generally similarly large. Thus, many of the situation-specific details of importance in making pest management decisions at the field scale wash out at this larger scale. Because results of the analysis generally will not differ on the basis of situation-specific variables, risk indices used for policy purposes may be presented in a tabular format — as tables in a scientific paper or on a pesticide label, for example — and published separately from the decision-making process. The method is typically to calculate results either using an algebraic equation or a screening checklist.

Development of risk indicators for policy purposes is perhaps an easier row to hoe than developing holistic pest control decision aids for farmers because policy objectives are often more narrowly defined. For example, there is worldwide concern about decline in amphibian populations. If herpetologists were to synthesize existing data and create a pesticide classification scheme based upon the hazard to frogs, this assessment would be an important pesticide policy tool with regard to amphibians. It would, however, be but a small addition to the array of information needed for a farm-scale decision support tool. Conversely, data collected for the broader scale of policy analysis — for nations, industrialized countries, etc. — are frequently too generic to be useful to farmers in making site-specific decisions. For example, the pesticide regulatory community relies on mortality data from tests on adult honeybees as the indicator of adverse effects on beneficial organisms, but a farmer also needs information, about the impacts of pesticides on the predatory mites and insects that keep pest populations small.

There is an opportunity in developing policy tools to consider economic cost in a broader social context than is typical for farm-scale decision tools, where production or management costs are the primary economic focus. Policy tools perhaps have an obligation to consider costs to society, for example, to remediate environmental problems or to pay for incentives to reduce risk.

Interdisciplinary and multiple-purpose collaborations are breaking down firm lines of distinction between the three types described here. For example, interactive farm decision tools which involve parameters and criteria beyond pesticide use (e.g., to include nutrient management), are being developed in collaboration with agricultural processors and distributors. Producers who get approvals from those higher on the distribution chain are then guaranteed a market share and may also gain an "ecolabel accreditation." Horticulturalists, toxicologists and other scientists influence these market processes by working collaboratively with agribusiness and producers to select criteria, parameters and thresholds for farm decision tools and ecolabels.

8. Current and emerging issues

The following quote was written when thinking about emerging issues and impediments just a few years ago, but at a much earlier stage in the development of pesticide assessment systems:

> Systems for assessing pesticide impacts on the environment (also called "pesticide risk indicators") will proliferate as more complete datasets and indicator prototypes are produced and shared via electronic media, and as the pioneering efforts described in this review circulate, are critiqued, linked, and improved. Palpable improvements will result from collaborations among systems developers, practitioners, policy makers, ecotoxicologists, ecologists and others to develop indicators which incorporate complex realities into tools that are simple-to-use and understand....Demands for guidance (and also for "easy answers") from impact assessment tools will continue to mushroom, particularly in the form of ecolabels in the marketplace (Levitan, 1997).

While much of this has come to pass, other issues of concern then remain of concern now, albeit perhaps better understood. With the maturation of the field, the relationship between pesticide risk indicators and statistical and biological complexity has brought new challenges to the fore: The many faces of uncertainty and variability are increasingly recognized as important factors in risk analysis, with the corollary that they should in some way be reflected in risk indicators. The limitations of assessments based on impacts of single doses of single pesticides on single individuals of single species are also increasingly recognized, especially given that adverse ecological impacts often result from cumulative effects of mixture on distributed functions at all levels of biological complexity. "Risk" indicators originated with simple hazard categorizations, evolved to include sometimes crude estimates of exposure based on dosage, but have barely dabbled in the complex arena of bioavailability. It remain to be seen how well risk indicators are able to account for these more interactive, ecological factors.

An issue not discussed elsewhere is a frequent pattern among members of multidisciplinary groups working together to develop risk indicators: each discipline quite fully appreciates the complexities of its own area, but cannot fathom that other disciplines face the same levels of complexity. Each group is sensitive to problems of over-simplification within their own disciplinary expertise, as they deal with the pressure to develop "user friendly" assessment tools, but assumes that quite simple hazard indices are sufficient for risk measures in other fields.

This caution is perhaps of particular import for assessment systems which purport to cover both economic and environmental effects, but there are also creative tensions between exposure and hazard characterizations, and between toxicological and other risks (e.g., the risks of habitat loss, reduction in biodiversity, pest resistance to pest controls, resource consumption and degradation, etc.). The implicit question here is whether pesticide risk indicators are assumed to focus exclusively or primarily on toxicology, or if they should be developed to give comparable emphasis and weight to other domains of risk.

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