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Editorial

IN DEFENSE OF WHOLE-COMMUNITY BIOASSAYS FOR RISK ASSESSMENT

Ecological risk assessment of toxic substances in its most general form involves two basic processes: (1) determining the effects of exposing an organism(s) to a toxicant and projecting the subsequent effects to natural systems, and then (2) deciding whether the predicted consequences are acceptable. Stage 2 relies absolutely on adequate projections obtained in Stage 1. The critical need for understanding the potential impact of introduced toxicants makes it difficult to determine the best approach to gain needed insights. In this context, environmental regulation of pesticides and other toxicants has traditionally relied heavily on standard laboratory approaches for assessing ecological risk. At its simplest and seemingly most efficient level, determining the toxicologic impact on single species using acute bioassays helps to ascertain the susceptibility of nontarget organisms to introduced chemicals. The crucial question remains, does this approach permit adequate projections to natural systems? While the widely applied, standard approach provides useful data, we feel that it falls short of allowing adequate projections to natural systems. Priority must be placed on whole-system responses to toxicants via community-level or higher bioassays. Understanding whole-system effects requires evaluating dynamic responses at the population, community, and ecosystem levels, and perhaps at the landscape level as well. Responses at these levels address the core of ecological risk assessment and the challenge of extrapolation in ecotoxicology.

Natural ecological systems are indeed complex, offering many potential responses to natural and anthropogenic perturbations. Even individual responses to toxicants vary, from among classes within a phylum to among clones within a species [1]. Both endogenous and exogenous factors interact to provide a rich set of possible community structures and dynamics that differ according to the amount of environmental stress impacting the system. Capturing key signals that describe central processes or consequences will continue to be a major challenge in the rapidly changing field of ecotoxicology.

Good risk assessment policy requires approaches and protocols that abstract essential features while streamlining the assessment process. How can we achieve an appropriate balance between simplifying assessment and obtaining sufficient insight at reasonable cost? In our opinion, single-species bioassays generally miss the essence of the problem, even though they are quick, rather inexpensive to obtain, and straightforward to interpret (as far as they go). More emphasis must be directed at community-level responses. The inadequacy of single-species bioassays in predicting higher level responses was addressed over a decade ago at a SETAC symposium [2]. Since then, several volumes have been devoted to reaffirming and refining this notion across a wide variety of biologic systems [e.g., 3–5]. Where do we go from here?

Despite prevailing notions to the contrary, community dynamics are relatively well defined in a general sense, even if the exact nature of specific interactions are unknown for targeted sites and species combinations. The most important features of community organization that thwart our best efforts to predict responses to pesticides are the seemingly emergent properties that must be addressed. Thus, reducing the size of individual species populations or removing species from natural communities may lead to unanticipated community-level responses. Equally significant, the same perturbation may lead to alternate responses, depending on variations in ambient environmental conditions. The range of possible responses at this level becomes a vexing issue when attempting to assess risk, so much so that we are constantly lured to simpler and more rapid tests that provide repeatable responses. We do this at significant peril. After all, unless we can predict approximate responses in natural situations, the risk assessment exercise is without meaning.

Must higher level studies be emphasized in risk assessment? A recent symposium, "Methods for Monitoring Effects of Pesticides," convened by Michael Marsh at the 1994 SETAC Annual Meeting, again addressed this issue. Based on a diversity of approaches, a clear message emerged from the participants: While analyses of single species provide important information for risk assessment, such studies cannot stand alone to provide appropriate insights for assessing the impact of toxicants on natural systems. Symposium speakers addressed a range of approaches for assessing risk from pesticides. Single-species approaches (Susan Gardner-Arroll and Allan S. Felsot) varied and included both laboratory and field-based methods to assess pesticides. These methods emphasized nontarget impacts. Clearly, much can be learned from such approaches using well-established methods. Other participants emphasized system-level properties that likely affect the expression of responses to xenobiotics in natural systems (Barry Gruessner, Susan Gardner-Arroll, Anthony Joern, Brian Mauer, Wayne Landis, and Lawrence Kapustka). The critical features underlying responses in natural systems revolve around the network of interactions among coexisting species that comprise a community and ultimately direct ecosystem processes. In addition to the obvious direct effects of one species on another, a variety of less obvious responses also exist with well-defined, if often unpredictable, effects on natural communities. Indirect effects, higher order interactions, thresholds, bottlenecks, synergistic interactions among species, and historical legacies abound in natural systems. These features often lead to sudden, unexpected, and even nonintuitive shifts in system dynamics at the community level. Metapopulation dynamics and chaos each provide new views of population responses that will revolutionize our outlook if they operate with regularity. Recent publications in all leading ecological journals document the ubiquity and variety of these responses in a diversity of natural and controlled systems. The repertoire of these responses depends on the "wiring" of the system acting in association with environmental state variables that alter individual species responses, both qualitatively and quantitatively. For example, responses to perturbations by communities in oligotrophic lakes may prove very different than responses to the same disturbance in meso- or eutrophic lakes [6–8]. In addition, responses may not reflect simple additive effects because bottlenecks and thresholds often determine responses of the system [9,10]. Equally important, communities may respond very differently to acute stresses compared with chronic stresses, as described in "press" versus "pulse" experiments [11]. Ecotoxicologic risk assessment must position itself so that complex, system-level responses to potential chemical toxicants can be recognized and evaluated to provide appropriate options to policy makers.

Recognizing emergent responses in natural systems to toxicant inputs presents a significant challenge. What are the critical data needed to facilitate risk assessment of xenobiotics in natural systems? What are the expected fates of both target and nontarget species from such exposure? Do we have the technology and methodology to confront such issues? Regarding the last question, we believe that existing approaches are feasible, cost-effective, underutilized, and offer realistic opportunities to address the first two questions when they are properly phrased. Numerous studies have documented the success of smaller scaled experimental systems, such as microcosms or mesocosms, in predicting the impacts of toxicants to higher levels of ecological organization [12–14]. Toxicant persistence and actual exposure levels are among key factors that apparently determine the degree of reliability of such estimates [15,16]. A growing number of reports indicate that mesocosms and microcosms can indeed reveal the indirect effects of toxicants or mixtures of toxicants on whole communities [17–19]. Nevertheless, any attempts to extrapolate from lower to higher levels of ecological organization must be made after careful consideration of factors such as relative temporal scale, community complexity (e.g., number of trophic levels), prior exposure history, and the frequency and duration of other community disturbances.

Appropriate methods exist to expeditiously assess community-level responses. The use of artificial confinement systems to contain and assess whole-system responses to pollutants has a relatively long history of success, especially in aquatic systems. Mesocosms are powerful tools for developing predictions of toxicant impacts through replicated, robust experimental designs using whole-community assemblages. We believe that this approach has much to offer and that novel approaches within this arena will continue to emerge as needs increase. Similar mesocosm approaches are feasible for terrestrial systems, as indicated by the large number of experimental field studies performed on existing or newly constructed communities. In addition, increased effort should be aimed at developing new methods to assess risk of natural systems to pollutants and pesticides. The emerging field of restoration ecology, for example, will contribute significant new methods for experimentally assessing and predicting community development, with goals parallel to those of environmental risk assessment. Finally, community modeling will also continue to contribute significant tools for studying systems less amenable to whole-system manipulation, as evidenced by the significant insights gained from individual-based models of forest ecosystems [20,21].

These issues become increasingly significant in light of recent decisions by the U.S. Environmental Protection Agency (EPA) to discontinue mesocosm studies on the basis that "they do not provide substantial information for making risk decisions beyond that already revealed by lower tiered studies" [22]. In fact, regulatory managers plan to make decisions regarding ecological risk earlier in the data-gathering process, often with less data than are currently required; decisions will be made in the absence of the higher tiered requirements (i.e., inclusion of mesocosm or long-term studies) whenever possible. Yet, several presentations in the present symposium again raise the real need to understand spatially explicit and indirect or higher order interactions at the community level to assess pesticide impact on whole communities. Clearly, answers to satisfy these needs will not come from single-species studies This raises the legitimate need for further meaningful dialogue, not only between the fields of ecology and toxicology, as pointed out by Clements and Kiffney [23] in a recent SETAC editorial, but also between these fields and regulatory agencies. Clements and Kiffney [23] also aptly identified the need for more ecotoxicologic studies at higher levels of biologic organization. Interestingly, the Ecological Society of America recently completed a workshop on pesticide assessment (August 1994) dealing with many of these same issues considered in this SETAC symposium; results will be published in *Ecological Applications*.

Adaptive management approaches using all tools presently available should greatly bolster risk assessment and policy development for natural systems in all their complexity, if implemented in a rigorous fashion [24]. Although many fundamental questions remain to be addressed using this proven methodology, we are optimistic that risk assessment can profitably exploit whole-community studies. Hence, we feel we can get closer to our goal of predicting general responses to perturbation from toxicants in complex systems. Consequently, we find it ironic that the EPA recently decided to abandon community-level bioassays, given the existence of an already productive and proven community-based approach to the problem. More discussion and research on incorporating such approaches are clearly warranted. In our opinion, the policy needs of pesticide risk assessment require a community- and ecosystem-centered approach. To this end, we must refine the questions and goals so that regulatory managers will have the information required for critical analysis and policy development in a useful package.

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