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Summary and Recommendations from a SETAC Pellston Workshop on In Situ Measures of Ecological Effects

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Special Section

ABSTRACT

The objective of a SETAC Pellston Workshop held in Portland, Oregon, USA, in November 2004 was to evaluate the use of field-based biological effects and exposure techniques in the hazard and risk assessment of aquatic ecosystems, thereby improving the accuracy and relevance of the decision-making process. This objective was addressed by keynote presentations outlining the state of the science and providing case studies, followed by work-group discussions focusing on 4 main areas: 1) Improving stressor–effect diagnostic capability in the assessment process; 2) maximizing efficiency, quality assurance and quality control, and broad-scale applicability of in situ field bioassays and experimental approaches; 3) determining the ecological relevance and consequences of individual and food chain–based effect measures; and 4) incorporating results from field-based effect methods into a weight-of-evidence decision-making process. Major outcomes from group discussions are highlighted, and future priorities for research in this area are recommended.

Keywords: In situ bioassay Bioassessment

INTRODUCTION

A Pellston Technical Workshop held November 10–12, 2004, in Portland, Oregon, USA, and titled "In Situ-Based Effects Measures: Linking Responses to Ecological Consequences in Aquatic Ecosystems" brought together 31 scientists from 10 countries to evaluate the use of field-based biological effects and exposure techniques in the hazard and risk assessment of aquatic ecosystems. The purpose was to identify opportunities to improve the accuracy and relevance of the decision-making process regarding the presence or absence of ecological hazard and risk. The objective was guided by keynote presentations outlining the state of the science and providing case studies, followed by work-group discussions focusing on 4 main areas: Improving stressor–effect diagnostic capability in the assessment process; maximizing efficiency, quality assurance and quality control, and broad-scale applicability of in situ field bioassays and experimental approaches; determining the ecological relevance and consequences of individual and food chain–based effect measures; and incorporating results from field-based effect methods into a weight-of-evidence-based decision-making process.

Testing of confined organisms in situ has become more common in recent years and has unique advantages over lab-based approaches in ecotoxicology (Figure 1; Burton et al. 2005). For many decades, field surveys of indigenous populations and communities of aquatic organisms have been a cornerstone of ecosystem assessments. Community-based measures have proved useful for describing the state of an ecosystem and for revealing impairments but have proved less useful for identifying the causes of impairments: A necessary follow-up in any management or restoration process. This is because community structure is influence by a variety of factors and processes that operate at different temporal and spatial scales. For instance, the absence of a species from a community may be the result of the direct effect of a stressor on that species, but equally it could be the result of changes in other species in the community that either feed on, are preyed on, or compete with that species (i.e., indirect effects) or to changes in other habitats in the landscape that act as sources of colonists for the community of interest (i.e., metapopulation effects).

In situ approaches permit manipulation of these interacting processes and can be a useful tool for elucidating causal relationships. They offer more realistic and precise control of "stressor" exposure to a defined population of organisms under natural or near-natural conditions and hence improve the linkage between cause and effect. In situ approaches have limitations, but if conducted properly, they can provide improved diagnostic ability with high ecological relevance. Moreover, they can be combined to provide a multispecies, multicompartment assessment of exposure and effects that can be used in a weight-of-evidence approach, supporting the ultimate decision-making process (Adams et al. 2005).

Four work groups focused on different aspects of in situ–based effects testing and applications. In situ approaches discussed at the workshop included the use of caged organisms (Maltby et al. 2002; Burton et al. 2005), colonization substrates (Courtney and Clements 2002), enclosures (Solomon et al. 1990), shore-based microcosms (Culp et al. 2003),

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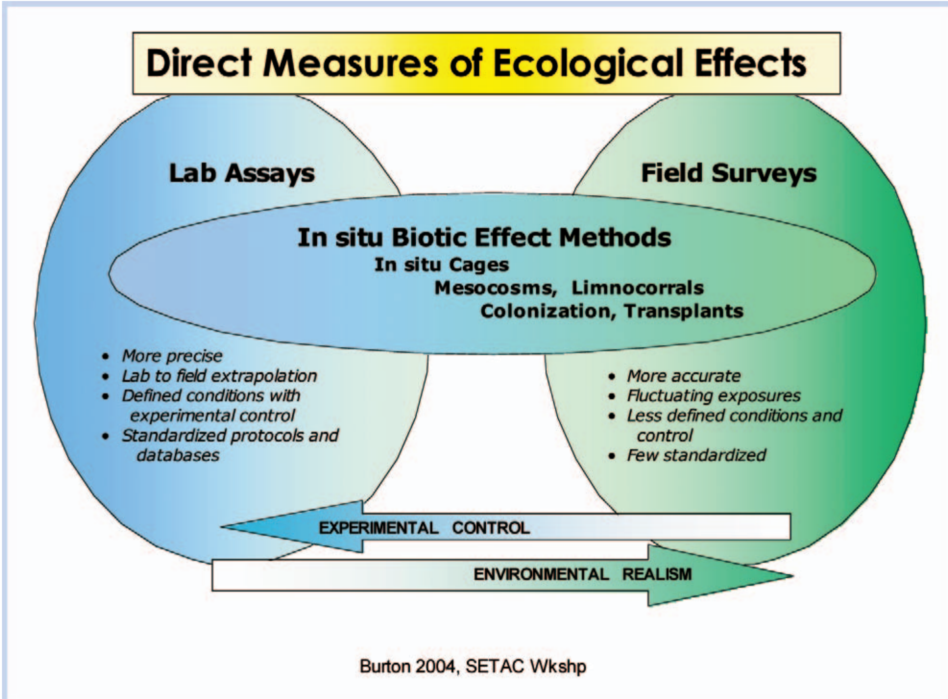

Figure 1. Direct measures of ecological effects.

and online automated biotests (Gerhardt and Schmidt 2002). The questions of each work group were as follows.

Group 1 focused on stressor and effect diagnosis. The questions they addressed were the following:

1. Which approaches are optimal for establishing stressor–effect relationships, and what are their strengths and limitations?
2. What approaches are best suited for dynamic ecosystems or highly variable exposure–effect relationships?
3. Which approaches (or tiered approaches) are best for identifying specific stressors or classes of stressors?
4. What emerging techniques may improve stressor diagnostics?
5. How do short- and long-term exposures affect the assessment process for the various technologies?

Group 2 addressed ways to improve in situ methods and approaches and discussed the following questions:

1. What are the dominant technique-related artifacts, and what is their significance?
2. How can exposure-related artifacts be reduced?
3. What are appropriate quality assurance/quality control performance criteria for these assays to allow for consistent scientific evaluations and interpretation?
4. How can we deploy systems cost effectively?
5. How can the logistic challenges of deployment and monitoring be reduced?
6. What emerging technologies can be utilized to improve in situ methods?
7. How can multiple biological, physical, and chemical techniques be linked for improved exposure–effect characterizations?

Diagnosing ecological relevance was the focus of group 3 and was addressed through the following questions:

1. How can (sub)individual effect endpoints be mechanistically linked to ecological responses? In other words, what is their relevance?
2. Can models provide the linkage between individual responses and ecological effects?
3. How are variable stressor exposures linked to effects?
4. How are individual ecosystem compartments assessed to determine stressor source and effects and then linked into a whole-ecosystem assessment?
5. How does the sensitivity of the commonly used standardized species compare to that of other indigenous species?
6. What are the advantages and challenges associated with use of indigenous and other species currently underrepresented in the risk assessment process?

Finally, group 4 focused on the application of in situ testing into assessment frameworks. Their questions were the following:

1. Can a blend of in situ methods and traditional assessment approaches be used to reduce uncertainty and to establish causality among stressors and effects?
2. How can combinations of in situ techniques (e.g., caged organisms, transplants, mesocosms, physicochemical monitoring) and field survey methods be integrated to produce cost-effective ecological risk assessments?
3. What can be done to improve the linkage between field-based effects results and the decision-making process (i.e., increased information transfer to regulators)?
4. What are appropriate decision criteria (e.g., trigger levels), and how are they incorporated into a decision-making framework that is weight-of-evidence based?

WORKSHOP SUMMARY

The findings of the workshop are presented in 4 work-group papers (Baird et al. 2007; Crane et al. 2007; Liber et al.

2007; Wharfe et al. 2007). These findings are summarized here with additional recommendations.

The 1st workshop paper, prepared by Crane et al (2007), highlights the major advantages of using in situ approaches in ecological risk assessment, namely, the ability to obtain improved realism in exposure and effects measurement and the addition of an important new line of evidence of field-based effects into the risk assessment process. Crane et al. (2007) note that a key challenge for the increased take-up of these methods in the future is the need for a certain degree of method standardization. The 1st steps in this direction have been taken by the development of a standard set by the International Organization for Standardization for the mussel bioassay (ASTM 2002). However, Crane et al. (2007) also recognize that an essential property of in situ effects measures is their flexibility and for responses to be embedded in a local exposure scenario, both of which are often difficult to standardize. In situ effects measures offer a new and fruitful direction in ecologizing risk assessment. That is, these measures permit prediction of exposure and effects to be tested in a local milieu, also permitting both direct effects (toxicity) and indirect effects (altered ecological relationships within the food web) to be assessed simultaneously for the 1st time.

Liber et al. (2007) note that in situ effects measures add value to the problem formulation phase of ERA, specifically in locating environmental compartments where bioavailable contaminants occur. Liber et al. (2007) emphasize the need to have an understanding of the habitat and other ecological and physiological requirements of the test species employed, whether using local or lab-cultured species. They note that it is important not to squander the advantages offered by in situ approaches by placing organisms in overcrowded test chambers or otherwise unsuitable living conditions, leading to results heavily biased by artifacts. Liber et al. (2007) indicate that there have been significant improvements in exposure chambers' design, which has evolved from simple, relatively enclosed systems to more open chambers that permit more dynamic and intimate interaction with the surrounding environment. Innovative designs (e.g., Greenberg et al. 2002) have permitted complex stressor scenarios to be studied and understood. Finally, Liber et al. (2007) make a plea for improved quality control procedures that would allow results obtained by in situ effects measures to be more broadly comparable for large-scale assessment projects.

Baird et al. (2007) tackle the key issue of ecological relevance of in situ effects measures, pointing out that while it might be argued that any response measured in the field is significant, responses must still be interpreted in an ecological context. Baird et al. (2007) present a framework for the interpretation of effects measured by in situ techniques, noting that it is often difficult to interpret suborganismal responses such as biomarkers measured in caged organisms beyond the conclusion that exposure has occurred. In order to assess responses more meaningfully, responses must be shown to link to or directly affect individuals' performance in terms of their contribution to population persistence. Using in situ effects measures in combination with field observations on the physicochemical environment and on the status and trends in local populations of organisms can provide a substantial line of evidence in ecological risk assessment. The use of ecological models such as dynamic mass budget models (Kooijman 2000) is highlighted in this context, with a case study outlined to demonstrate field application of the approach in a regulatory context. Baird et al. (2007) conclude that in situ effects measures are a key advance in ecological risk assessment, leading to the adoption of standardizable yet ecologically meaningful and communicable methodologies.

The 4th workshop paper, prepared by Wharfe et al. (2007), addresses how in situ effects measures can fit within a regulatory and legislative context. Wharfe et al. (2007) note that toxicity testing is now widely recognized as a key piece of supporting evidence in the development and administration of environmental regulations pertaining to toxic substances. In situ effects measures increasingly provide a powerful line of evidence in determining causality and reducing uncertainty in complex field situations. Emerging techniques in the field can confirm that laboratory observations and allow a linkage between field observations on, for example, biological community structure and laboratory toxicity tests. In terms of their application, in situ effects measures are appropriate for large-scale monitoring and assessment programs, such as regional scans and watershed assessments. They also have application in effluent discharge situations (Baird et al. 2007), where in situ methods provide an important feedback loop in the risk assessment process, such as by permitting remediation goals to be set and tracked over time. They are also seen to have advantages in contaminated site cleanup projects and in the generation of information for product registration. Wharfe et al. (2007) conclude that in situ effects measures have a bright future as a regulatory tool and that their potential is only now beginning to be exploited.

WORKSHOP RECOMMENDATIONS

It is clear that in situ effects measures have rapidly developed in the past decade. There are now several measures and approaches that span a range of aquatic habitats, from marine to freshwater, from sediments to wetlands, and that encompass an ever-widening range of species and endpoints. In situ approaches are being continuously revised to improve their ecological relevance.

What has been largely lacking within the field is a move toward the development of standardized approaches that are amenable to quality assurance and quality control procedures. Several experts at the workshop expressed the view that 2 key advantages of in situ approaches—their design flexibility and their ability to use local species for assessment—make standardization difficult. Nonetheless, there was a general consensus that the lack of standardized approaches is a major obstacle to the wider adoption of in situ measures in a regulatory context.

At present, it remains a major challenge for scientists and regulators to realize the potential of these innovative methodologies. The potential of in situ approaches rests on the development of more flexible yet scientifically defensible regulatory requirements and a recognition that the complexities of natural environments lie at the heart of more detailed, higher-tier risk assessments. There was general consensus that the integration of in situ methods into regulatory monitoring programs becomes an important priority for regulatory agencies seeking the development of more targeted and relevant methodologies for ecological risk assessment.

A further recommendation of participants at the workshop was the need for improved linkages between responses observed through in situ effects measures and their ecological consequences in the local environment. Baird et al. (2007)

describe how this can be achieved through the use of ecological models. At present, scientists are at an early stage in this process, and a concerted research effort is needed to examine the wider utility of such models in predicting ecological responses of real populations and communities and how in situ effects measures can be used as a link between the modeling world and the real world.

Finally, workshop participants recognize that there is currently a major gap in regulatory procedures in relation to the problem of interpreting the potential risks posed by complex effluent discharges. In situ effects measures offer an alternative to the more traditional toxicity identification and evaluation approaches. Moreover, in situ methods offer unique advantages by integrating effects in relevant exposure scenarios while still permitting complex toxic interactions between substances and organism receptors to be teased apart using innovative and novel experimental designs and technologies. There was broad consensus that new designs and refinement of current in situ test designs is an area ripe for scientific innovation, with potentially large returns on any research investment.

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