“Practical Biological Indicators of Human Impacts in Antarctica”

VOLUME 2
Background and Appendices

March 16-18, 2005
Bryan/College Station, Texas

TABLE OF CONTENTS – Volume 2

Also refer to:

Volume 1 - Workshop Deliberations and Recommendations

Preface and Acknowledgments

The workshop was co-funded by The National Science Foundation Office of Polar Programs (NSF-OPP), the Council of Managers of National Antarctic Programs (COMNAP), and the Scientific Committee on Antarctic Research (SCAR). The workshop was co-hosted by the Office of the Vice President for Research, Texas A&M University and the British Antarctic Survey.

The workshop was attended by 44 participants from 14 countries (see Volume 2 - Appendix C.).

The organizers would especially like to thank Monica Holder; Vice President for Research Office, Texas A&M University; and Andrew Greene, Biology Department, Texas A&M University, for their assistance in organizing the workshop.

City of Bryan Proclamation

VOLUME 2– Background and Appendices

The report of the workshop on "Practical Biological Indicators of Human Impacts in Antarctica" is organized into two volumes. This second volume provides background information to inform the reader including: assessments of the status of various biological indicators of human impact, summaries of the oral presentations, a list of participants, and other supporting materials. The first volume provides the Antarctic legal and regulatory context for monitoring activities, the terms of reference and charge to the workshop, and the workshop's deliberations and recommendations. The reader is also referred to the workshop web site for additional details.

(http://vpr.tamu.edu/antarctic/workshop/workshop.php)

1.0 Antarctic Experiences in Biological Monitoring – Lessons Learned

Environmental monitoring activities conducted in Antarctica have been routinely summarized by COMNAP/AEON. The summaries illustrate the existing level of Antarctic monitoring, help to increase awareness of monitoring activities and help to coordinate information gathering at multiple operator sites. The AEON surveys provide references for those planning monitoring programs in Antarctica. The information is useful for identifying gaps in current Antarctic environmental monitoring studies. The document provides an indication of the types of studies undertaken and the range of impacts and parameters being monitored. Accessibility of existing data sets is essential to the success of new environmental monitoring regimes developed to fulfill the requirements of the Environmental Protocol. The range of monitoring activities listed is diverse although the most common types of monitoring studies undertaken include:

- Atmospheric pollutants associated with station activities
- Quantity and quality of sewage and waste water discharges
- Levels and fate of hydrocarbons in soil and/or water
- Population counts and/or breeding success of Antarctic birds
- Heavy metals in plants, soil and sediment
- Contamination and pollutants in freshwater lakes
- Photography at fixed sites/intervals at stations/field sites

These materials are available online at:

http://www.comnap.aq/comnap/comnap.nsf/P/Pages/Environment?Open

2.0 Selection Criteria for Biological Indicators

Indicators are designed to inform us quickly and easily about something of interest. They act as proxies to communicate information about conditions and over time about changes and trends. Indicators are needed because it is unnecessary and impossible to measure everything. Monitoring indicators over time can help to determine whether problems are developing, whether action is desirable or necessary, what action might yield the best results, and how successful past actions have been. The best indicators capture the essence of the dynamics of environmental systems and changes in their functioning in a way that can inform management decisions.

Indicators can be quite different depending on whether the primary purpose is to assess impact at local or regional scales, i.e. most indicators are spatial scale dependent. Ecological indicators that describe the state of ecosystems have been elusive, in part due to the innate complexity of ecological systems. Some indicators are less useful than others because the measures used are not clearly linked to underlying ecological processes, making it difficult to interpret changes in those indicators. In other cases, data requirements are so complex and extensive that the indicators would be too expensive to use. These limitations have challenged scientists and managers for many years.

Attributes that are considered important for assessing the utility of biological indicators of human impact are summarized below.

Criteria for evaluating indicators:

1. General Importance
    - Does the indicator provide information about changes in important and relevant ecological or biogeochemical processes?
    - Does the indicator provide information about major environmental changes that affect wide areas?
2. Conceptual Basis
    - Is the indicator based on a well-understood and generally acceptable conceptual model of the system to which it is applied?
    - Is the indicator based on well-established scientific principles?
3. Reliability
    - What experience or other evidence demonstrates the indicator’s reliability (prior use)?
4. Temporal and Spatial Scales
    - Does the indicator inform us about regional or local ecological conditions and processes?
    - Are the changes measured by the indicator likely to be short-term, long-term, transitory, or cumulative?
    - Can the indicator detect changes at appropriate temporal and spatial scales without being overwhelmed by variability?
5. Statistical Properties
    - In the areas of accuracy, sensitivity, precision, and robustness, has the indicator been shown to serve its intended purpose?
    - Is the indicator sensitive enough to detect important changes but not so sensitive that signals are masked by natural variability?
    - Are the statistical properties understood well enough that changes in its values will have clear and unambiguous meaning?

   - What level of change is regarded as significant enough to trigger management action?
6. Data Requirements
   - How much and what kinds of information are necessary to permit reliable estimates of the indicator to be calculated?
   - How many and what kinds of data are required for the indicator to detect a trend?
7. Skills Required
   - What technical and conceptual skills must the collectors of data for an indicator possess?
   - Does the collection of input data require highly technical, specialized knowledge if the data are to be accurate, or is data collection a relatively straight forward process?
8. Data Quality
   - Are the data used to calculate the indicator of environmental quality accurate?
   - Is the documentation of sampling and analytical methods clear enough for future investigators to understand how each indicator was calculated?
9. Data Archiving
   - Has an archive system for monitoring data been established to provide interested parties access to the data?
10. Robustness
    - Is the indicator robust enough to yield reliable and useful data in the context of natural variability?
    - Is the indicator relatively insensitive to sources of interference?
    - Are technological changes likely to render the indicator irrelevant or of limited value?
    - Can time series of measurements be continued in compatible form when measurement technologies change?
11. International Compatibility
    - Is the indicator compatible with indicators being developed by other nations and international groups?
    - Is there a need for inter-laboratory cross calibration?
12. Cost Benefits and Cost-Effectiveness
    - If resources for monitoring are limited can the information provided by an indicator be obtained for less cost in another way?

In general, indicators need to be understandable, quantifiable, and broadly applicable, providing information about key attributes of the system being monitored. In the ideal situation, it is best if the information and advice can be conveyed to the public and policy makers in clear non-technical language.

Combinations of Indicators – Biological Integrity

Multiple attribute (or multi-metric) approaches can more be used to more carefully examine human impacts. One example is the fish Index of Biotic Integrity (IBI) (Karr, 1981 and Karr et al., 1986). Combinations of attributes, or measurements in the form of an index provide valuable assessment tools. The multi-metric approach defines an array of measurements representing a measurable characteristic of a biological assemblage that changes in a predictable way with increased or decreased environmental stressors (USEPA 1996, USEPA 1997). Multi-metric indices can be used as an overall indicator of biological condition. Each assemblage in the aquatic community might have differing responses to pollution or degraded conditions. Thus, assessment methods that target multiple species and assemblages are capable of detecting a broad range of stresses and reflect the condition of a large segment of the ecosystem. However, there is not yet a complete understanding of how some measurements respond, either quantitatively or qualitatively, to perturbation in general and to particular stresses. To provide for an effective assessment, the variables selected to determine biological integrity should:

- Address societal concerns - Biological measurements are often related to the properties of biotic systems that are of concern to society, such as alien species, fish production, and biological diversity.

- Reflect environmental stress levels - Biological measurements and the measurements developed from them must be sensitive to environmental stress, and the response must be interpretable.

- Have low uncertainty - Variability should be understood and measurement error should be controllable.

- Be focused on what is essential – effective assessment is not necessarily about the measurement of many variables at many sites.

- Be cost-effective - The cost incurred in measurement should be proportional to the value of the information obtained.

- Be environmentally benign to measure - Sampling methods that disturb or alter habitats and organisms should be avoided.

Assessment of biological integrity typically focuses on a few broad but integral classes of ecological properties (e.g., Barbour et al. 1992, Karr 1991) that respond to anthropogenic impacts (e.g., Schindler 1988, Schindler et al. 1989), including:

- Health - Individuals or populations.

- Species structure and composition - The number and kinds of species in an assemblage. Species structure includes both diversity and the presence of stress-tolerant species.

- Trophic structure - The relative proportion of different feeding levels, such as filter feeders, scavengers, or predators.

- System function - The productivity and material cycling of the system.

Multi-metric assessment typically includes several measurements of at least three properties (eg. species structure, trophic structure, and system function). Individual and population health measurements are used less often because they are not yet well developed for invertebrates and plants. Assessment of biological impacts depends on an ability to define, measure, and compare biological condition between similar systems. Impairment is judged by departure from an expected condition. This requires a functional definition of biological integrity as the condition of the community inhabiting unimpaired habitats as measured by community structure and function metrics (USEPA 1990). This definition of biological integrity makes the explicit assumption that natural, undisturbed systems are healthier than those changed by human activities. Because biological integrity is defined relative to unimpaired conditions, it must also be measured relative to those conditions. The four classes of ecological properties listed above are measurable relative to natural or unimpaired conditions. Minimally impaired systems typically form the basis for defining reference conditions for biological assessment.

3.0 Biological Indicators Based on Level of Organization

Perturbations of the environment can be expressed at many levels of biological organization from the molecular (inducible enzymes, DNA damage) to the individual (lesions, tumors) to the community (reproductive success, biological assemblages) to the ecosystem (shifts in guilds – Figure 1-1). The utility of these responses for monitoring purposes varies greatly from indicator to indicator for a wide variety of reasons from the complexity of the measurement to the ambiguity of the cause and effect relationship to the time frame over which the response is fully expressed. A full review of the entire spectrum of possible indicators of impacts at all levels of biological organization is beyond the scope of this summary. However, a review of the best studied and most useful indicators at various levels of organization are illustrative of potential indicators that one might consider in designing monitoring programs.

Living organisms are composed of cells that carry out large numbers of chemical reactions to maintain and perform their functions. Perturbations of the environment by human activities often interfere with these cellular reactions, leading to impaired cellular functions or viability (USEPA, 1991). For example, a contaminant introduced into an aquatic environment might induce effects at the enzyme level that alters cellular function. This can also be caused by various environmental stressors like changes in water temperature. These changes then affect cell integrity, ultramicroscopic structure and other functions such as energy expenditure or the secretion rate of a hormone. When these changes are severe enough, histological lesions occur due to cell death and the organ function may ultimately be affected.

Gene Function Enzyme Activity Membrane Permeability	Cell Integrity and Metabolism	Histological Lesions	Organ Function	Homeostasis	Growth and Reproduction	Ecology and Behavior

Figure 1.1 : Levels of biological complexity in the study of the effect of some environmental factors, including pollution. The extent of complexity increases as one progresses from left to right (Heath, 1995).

When homeostasis is altered some organs show compensatory changes to bring the internal condition back toward normal. Chronic exposure/stress may depress growth and reproduction. Pollutants that affect the nervous system can also alter the organism's behavior and many substances cause alterations in the functions of the nervous system. Changes in the functioning of a group of organisms in an ecosystem can cause effects on other organisms producing a higher level response (Heath, 1995). The ability to predict these effects and to extrapolate effects from laboratory to population and community levels has become an important part of biological indicator science. Physiological and biochemical indicators of organismal health including sub-lethal effects are often monitored. By using biological indicators, it is possible to identify environmental problems before the health of aquatic systems is seriously altered (Jimenez and Stegeman, 1990). For the determination of both the exposure and effect of a pollutant on an organism, biochemical alterations can serve as markers. Chemically induced changes in biochemical systems represent an effect of the chemical on these systems. Biochemical system alterations in organisms are often more sensitive indicators than those at higher levels of biological complexity. Changes at the molecular level will underlie effects at higher levels of organization. Biochemical disturbances, depending on the function of the systems affected and the nature of the response, can indicate whether additional effects (e.g. at the organ level) are likely to occur (Stegeman *et al.*, 1992).

The so-called biomarker approach where "early-warning" molecular, physiological and/or behavioral responses of organisms are determined is considered a powerful tool for monitoring programs. New techniques allow the detection of the effects of complex mixtures of stressors. Many are diagnostic of causes, provide information on the bioavailability of contaminants and allow more accurate assessments of potential ecological damage. Cellular and molecular indicators provide the greatest potential for identifying individuals and populations for which conditions have exceeded compensatory mechanisms leading to chronic stress, which, if unmitigated, may progress to severe effects at the ecosystem level. Biochemical and physiological indicators of contaminant stress can be categorized as general versus specific sensitivity to compounds, regulatory versus regulated parameters, indicators of exposure versus indicators of effect, or by category of biochemical and physiological function. The general categories of biochemical and physiological function include:

- Osmoregulation indicators are useful as indicators of general organism health rather than diagnostic tools for identification of specific pollutants - i.e., plasma ion concentrations, ATPase activity, and histological and histopathology examination.

- Metal sequestration and regulation such as metallothionien levels
- Oxidative metabolism plays a central role in catabolic energy production and adenylate can be a biochemical indicator of contaminant stress; inducible prophylactic enzymes such as superoxide dismutase, catalase, and glutathione peroxidase serve a vital role in protecting the cell from oxidative stress and are useful indicators of contaminant stress in aquatic organisms; and xenobiotic metabolism associated with the cytochrome P450 monooxygenases (MO).
- Maintenance of energy status using adenylate energy charge
- Reproduction: biochemical reproductive parameters such as vitellogenin, the major yolk protein in salmonids, .blood levels of vitellogenin, reproductive endocrine function, and steroid hormone levels.
- Neurotransmission, such as the neurotransmitter acetylcholinesterase (ACHe).
- Interactions with genetic material such as DNA adducts and DNA damage.
- Immunology, including immunosuppression.

Monitoring of biological assemblages is commonly used to assess changes in the environment. A common method of evaluation is to compare biological variables from test sites to those from reference sites. Typically, a test sample is considered to be impacted if one or more biological indicators are "significantly" different from those of the reference conditions. The key to such a strategy is the clear understanding of reference conditions. Benthic impacts from contamination have typically been broadly defined to include both organic enrichment (nutrients) and contaminants which often occur together in runoff and effluent. Many studies have reported organismal responses to contamination, organic enrichment, or other disturbances.

Biological assessments provide integrated evaluations. They can identify impairments of aquatic life from contamination of the water column and sediments from unknown or unregulated chemicals, non-chemical impacts, and altered physical habitat. Resident biota function as continual monitors of environmental quality, increasing the likelihood of detecting the effects of episodic events (e.g., spills, dumping, treatment plant malfunctions, nutrient enrichment), toxic non-point source pollution (e.g., agricultural pesticides), cumulative pollution (i.e., multiple impacts over time or continuous low-level stress), or other impacts that periodic chemical sampling is unlikely to detect. Impacts on the physical habitat such as sedimentation from storm water runoff and the effects of physical or structural habitat alterations (e.g., dredging, filling, channelization) can also be detected.

The most well studied assemblages are marine benthic biota which respond to many types of physical, chemical, and biological stressors. Natural variations occur due to variable freshwater flow, salinity, and sedimentation, as well as historic and recurring anthropogenic influences including nutrient and organic enrichment, and contamination. It is difficult to identify a benthic response to contamination because toxic responses often co-vary with many other environmental factors (Nichols, 1979; Peterson *et al.*, 1996; Swartz *et al.*, 1986; Spies *et al.*, 1988). In general, large amounts of information about changes in the benthos in space and time and corresponding changes in environmental and contaminant factors are required to detect trends and determine causality (Luoma and Carter, 1991). Identifying truly unimpacted reference locations which could serve as true "reference" locations for biological comparisons is an important requirement. "Ambient" reference locations must be identified.

The benthic index of biotic integrity (BIBI) is an index that measures the "health" of benthic communities. The BIBI provides a means for comparing the relative condition of benthic invertebrate assemblages across habitat types. It also combines several benthic community measures indicative of habitat "health" into a single number that measures overall benthic community condition. Community measures, or attributes, that are components of the BIBI include species abundance, biomass, the Shannon diversity index, the abundance and biomass of pollution-indicative species, and the abundance and biomass of pollution-sensitive species.

4.0 Taxa Based Biological Indicators

Biological indicator taxa may be used to assess the health of an environment. While indicator taxa is a term that is often used, it is somewhat inaccurate. Indicators are usually groups of taxa that are used to assess environmental condition. Within each group, individual taxa can be used to calculate metrics or groups of taxa or individual orders to assess environmental quality conditions. A review of all of the various taxa that might serve as biological indicators in Antarctica is beyond the remit of this workshop. Interested parties are referred to the workshop web site and other primary literature for further information on specific taxa.

5.0 References

Barbour, M.T., J.L. Plafkin, B.P. Bradley, C.G. Graves, and R.W. Wisseman. 1992. Evaluation of EPA's rapid bioassessment benthic metrics: Metric redundancy and variability among reference stream sites. Environmental Toxicology and Chemistry **11**:437-449.

Clark, R.B., 1989. Marine Pollution, 2nd Ed., Clarendon Press, Oxford.

Collins, G.B. and Weber, C.T. 1978. Phycoperiphyton (algae) as indicators of water quality. Transactions of the American Microscopial Society **97:** 36-43.

Cormack, D., 1983. Response to Oil and Chemical Marine Pollution, Applied Science, London.

Crowder, A.A., and D.S. Painter. 1991. Submerged macrophytes in Lake Ontario: current knowledge, importance, threats to stability, and needed studies. Canadian Journal of Fisheries and Aquatic Sciences **48**:1539-1545.

Heath, A.G. 1995. Water Pollution and Fish Physiology. 2nd Ed. CRC Press, Inc., Boca Raton, Florida.

Jimenez, B.D. and Stegman, J.J. 1990. Detoxification Enzymes as Indicators of Environmental Stress on Fish. In: Biological Indicators of Stress on Fish, Adams, S.M., ed., American Fisheries Symposium **8**:67-79. Bethesda, Maryland.

Karr, J.R. 1981. Assessment of biotic integrity using fish communities. Fisheries **6**:21-27.

Karr, J.R., K.D. Fausch, P.L. Angermeier, P.R. Yant, and I.J. Schlosser. 1986. Assessing biological integrity in running waters: A method and its rationale. Illinois Natural History Survey, Special Publication 5.

Karr, J.R. 1991. Biological integrity: A long-neglected aspect of water resource management. Ecological Application **1**:66-84..

Longwell, A.C. 1977. A genetic look at fish eggs and oil. Oceanus **20:** 45.

Luoma, S.N. and J.L. Carter. 1991. Effects of trace metals on aquatic benthos. In Metal Ecotoxicology: Concepts and Applications, edited by M. Newman and A. McIntosh, CRC Press, Boca Raton, FL. pp. 261-300McCall, P.L. 1977. Community patterns and adaptive strategies of the infaunal benthos of Long Island Sound. J. Mar. Res. **35**(2): 221-266.

Nichols, F.H. 1979. Natural and Anthropogenic Influences on Benthic Community Structure in San Francisco Bay. U.S. Geological Survey, Pacific Division, AAAS. pp. 409-426

Patterson, D.L., Holm, E.J., Carney, K.M., and Fraser, W.R. 1996. Effects of tourism on the reproductive success of Adelie penguins at Palmer Station: Preliminary findings. Antarctic Journal of the United States, Review 1996.

Peterson, C.H., M.C. Kennicutt II, R.H. Green, P. Montagna, D.E. Harper Jr., E.N. Powell, and P.F. Roscigno. 1996. Ecological consequences of environmental perturbations associated with offshore hydrocarbon production: A perspective on long-term exposures in the Gulf of Mexico. Canadian Journal of Fisheries and Aquatic Sciences **53**:2637-2654

Schindler, D.W. 1988. Effects of acid rain on freshwater ecosystems. Science **239**:149-158.

Schindler, D.W., S.E.M. Kasian, and R.H. Hesslein. 1989. Biological impoverishment in lakes of the midwestern and northeastern United States from acid rain. Environmental Science and Technology **23**:573-580.

Spies, R.B., D.D. Hardin, and J.P. Toal. 1988. Organic enrichment or toxicity? A comparison of the effects of kelp and crude oil in sediments on the colonization and growth of benthic infauna. Journal of Experimental Biology and Ecology **124**:261-282

Stegeman, J.J., Brouwer, M., Di Guilio, R.T., Forlin, L., Fowler, B.A., Sanders, B.M., and Van Veld, P.A. 1992. Enzyme and Protein Synthesis as Indicators of Contaminant Exposure and Effect. In: Biomarkers: Biological, Physiological, and Histological Markers of Anthropogenic Stress. Hugget, R.J., Kimerle, P.M., Mehrle Jr., P.M., and H.L. Bergman, eds. Lewis Publishers, Boca Raton, Florida.

USEPA. 1990. Biological criteria: National program guidance for surface waters. EPA 440/5-90-004. U.S. Environmental Protection Agency, Washington, DC.

Swartz, R.C., F.A. Cole, D.W. Schults, and W.A. DeBen. 1986. Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. Marine Ecology Progress Series **31**:1-13

USEPA. 1991. EPA Toxicology Handbook. Fifth Printing, Government Institutes Inc., Maryland.

USEPA. 1996. Biological criteria: Technical guidance for streams and small rivers. EPA 822-B-96-001. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

USEPA. 1997 (draft). Revision to rapid bioassessment protocols for use in streams and rivers: Periphyton, benthic macroinvertebrates, and fish. EPA 841-D-97-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Appendices

- **A.** **Summaries of Oral Presentations**
- **B.** **Poster Abstracts**
- **C.** **Participants**