Practical Biological Indicators of Human Impacts in Antarctica

VOLUME 1

"Workshop Deliberations and Recommendations"

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

TABLE OF CONTENTS

Also refer to:

Volume 2 – Background and Appendices

Preface and Acknowledgments

The workshop was 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 Ms. Monica Holder of the Office of the Vice President for Research and Mr. Andrew Greene of the Biology Department of Texas A&M University for their assistance in organizing and convening the workshop.

City of Bryan Proclamation

Executive Summary

Forty-four participants from fourteen countries gathered for two and a half days to discuss the status of biological indicators of human impact in Antarctica. These deliberations were the most recent step in a series of workshops and conferences convened to address national and international requirements for monitoring and minimization of potential human impacts in Antarctica. The workshop participants were provided with a range of informational materials to assist their deliberations including oral presentations, presentation summaries, concept (white) papers, guiding documents, discussion questions, poster presentations, and other background information. The workshop was organized to systematically address the Terms of Reference provided by the sponsors. This is the first of two volumes that report the workshop outcomes. These volumes provide guidance on the inclusion of effective and practical biological indicators of human impacts in monitoring programs in Antarctic.

The workshop participants agreed to a number of recommendations:

- Biological processes and responses are inextricably linked with the physical and chemical environment; therefore biological indicators of human impact can only be understood when closely integrated with a suite of non-biological measurements.
- Long-term biological data sets are fundamental to establishing the natural variability of biological indicators of change and the continuation of long-term data should be supported by National Programs.
- Further work should be undertaken to determine which temperate region protocols could be effectively adapted or customized for use in Antarctica.
- Data quality objectives should guide the choice of biological indicators for monitoring programs rather than relying on the adoption of standard procedures and protocols.
- Operators of National Antarctic Programs should agree on a minimum set of common monitoring parameters to measure potential biological impacts of station operations while producing comparable and compatible data.
- More robust numerical and quantitative models of natural systems are needed for reliable predictions of future biological changes and linkages with their causes.
- All monitoring data should be made widely available through existing National Data Centers.
- The coordination and exchange of information on monitoring among COMNAP, SCAR and CCAMLR should be improved through existing organizational structures and procedures to ensure the highest level of interaction and coordination among all parties.
- To improve communication and information exchange “Monitoring Practice and Science” oral and poster sessions should be organized at the biennial SCAR Science Conference and every fourth year a monitoring workshop should be held during the joint SCAR/COMNAP meetings.
- The monitoring of human impacts must become a routine part of Antarctic station operations and adequate resources must be provided to ensure that these activities are performed at an appropriate frequency and intensity.

- Monitoring programs require an unambiguous definition of a “natural”, control or original state to identify change(s) due to human intervention and to account for natural variability in biological systems. All monitoring programs should explicitly define what comparisons will be used to recognize, assess and interpret the variations observed and whether the change(s) detected is/are considered to be positive or negative.

VOLUME 1 – Workshop Deliberations

The report of the workshop on *"Practical Biological Indicators of Human Impacts in Antarctica"* comprises two volumes. This 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 second volume provides background information 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 reader is also referred to the workshop web site for additional details:

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

1.0 The Antarctic Legal and Regulatory Context

Protection of the environment is a high priority for all nations that operate in Antarctica. The Antarctic Treaty System, with its Agreed Measures for the Conservation of Fauna and Flora (1964) and its Protocol on Environmental Protection (1998), prescribes comprehensive protective measures. All signatories to the Antarctic Treaty pledge to uphold these principles in accordance with international requirements and domestic legislation regarding protection of the environment. The following are brief summaries of the treaties and laws that apply to Antarctica.

The Antarctic Treaty System is the whole suite of arrangements made for the purpose of regulating relations between states in Antarctica. At its heart is the 1961 Antarctic Treaty itself. The original Parties to the Treaty were the 12 nations active in Antarctica during the International Geophysical Year of 1957-58. The Treaty was signed in Washington, DC on 1 December 1959 and entered into force on 23 June 1961. The Consultative Parties comprise the original Parties and States that accede to the Treaty and demonstrate their interest in Antarctica by carrying out substantial scientific activity on or around the comtinent.

The primary purpose of the Antarctic Treaty is to ensure: "in the interests of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord." To this end it prohibits military activity, except in support of science; prohibits nuclear explosions and the disposal of nuclear waste; promotes scientific research and the exchange of information; and holds all territorial claims in abeyance. The Treaty applies to the area south of 60° S.

The Treaty is augmented by measures adopted at Consultative Meetings, by the Protocol on Environmental Protection to the Antarctic Treaty (1998), and by two separate Conventions dealing with the Conservation of Antarctic Seals (London 1972), and the Conservation of Antarctic Marine Living Resources (Canberra 1982). The Convention on the Regulation of Antarctic Mineral Resource Activities (Wellington 1988), negotiated between 1982 and 1988, is unlikely to enter into force.

Within the framework of the ATS, the Convention on the Conservation of Antarctic Seals (CCAS) regulates sealing. The Convention was set up to protect all six species of seal found in the Antarctic following concerns about a possible resumption of commercial sealing. The provisions of the Convention have never been put to use, although it remains in force.

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) came into force in 1982 in pursuance of the provisions of Article IX of the Antarctic Treaty. It was established in response to concerns that an increase in krill catches in the Southern Ocean could have a serious effect on populations of krill and other marine life; particularly on sea birds, seals and fish, which depend on krill for food. The aim of the Convention is to conserve the marine life of the Southern Ocean, whilst allowing for harvesting carried out in a rational and sustainable manner. Achievement of this aim is far from simple – it requires the collection of large quantities of information and the development of appropriate scientific and analytical techniques. A 'precautionary' approach has been implemented to minimize risk associated with unsustainable practices under uncertain conditions. The overarching objective is to manage Antarctic living resources on an ecosystem-scale.

The Protocol on Environmental Protection to the Antarctic Treaty (1998) sets standards for assessing impacts, conserving fauna and flora, managing waste, preventing marine pollution, and setting aside specially protected or managed areas. The Protocol prohibits mineral resource activities other than for scientific research purposes. The Protocol requires monitoring to be taken into account in the planning and conduct of all Antarctic activities [Article 3, 2 (c) (v)]. Environmental monitoring is also required to facilitate early detection of possible unforeseen effects both within and outside Antarctica [Article 3, Items 2 (d) & (e)]. Monitoring is integral to the Environmental Impact Assessment process and is clearly intended to guide the management of activities in order to minimize and mitigate their impact [Article1, 4(b), Annex 1, Article 5]

Environmental monitoring in Antarctica of global, regional and local impacts has been conducted by a number of National Programs over many decades. For example, the gaseous constituents of the atmosphere have been continuously monitored since the International Geophysical Year (IGY) program in 1957/58. In addition, a number of National Programs have conducted studies on the impact of human activities at selected locations on the continent. However, there has been little international coordination of these assessments. At the 1994 Antarctic Treaty Consultative Meeting [ATCM XVIII], COMNAP and SCAR offered to convene technical workshops to provide the ATCM with advice practical, scientifically sound and cost effective monitoring that would meet the requirements of the Protocol on Environmental Protection. COMNAP compiled a summary of existing information on environmental monitoring through a survey of its members. This information was presented as a COMNAP report entitled *"Summary of*

Environmental Monitoring Activities in Antarctica" to ATCM XXI in 1997. In addition there were a series of workshops and reports on various aspects of monitoring programs.

The July, 1996 report, entitled *"Monitoring of Environmental Impacts from Science and Operations in Antarctica",* provided extensive guidance on the design and selection of indicators of chemical contamination and physical disturbance. This was followed by a manual of agreed methods for analytical protocols intended to promote standardization of monitoring efforts and increase inter-comparability across programs. COMNAP sponsored a review of Environmental Impact Assessment procedures to determine if they were effective. These reports culminated with the COMANP report *"Practical Guidelines for Developing and Designing Environmental Monitoring Programs in Antarctica"* in March 2004. This report provided guidance on to design and implement a monitoring program. National Programs have also produced guidance and reference documents describing accepted procedures and protocols for long-term monitoring programs.

2.0 Terms of Reference

In recognition of the responsibility of all nations acceding to the Antarctic Treaty to be stewards of the Antarctic environment and the obligations set forth in the Protocol on Environmental Protection to monitor the impacts of humans in Antarctica, SCAR and COMNAP sponsored a series of workshops. Many facets of monitoring were addressed including physical and chemical indicators of impacts, recommended standard methodologies and design elements, and practical guidelines to implementing monitoring. The next step is to evaluate the state-of-the-art of biological indicators of human impact. The intent is to learn from, and build upon, the experiences of countries in temperate climates in selecting meaningful biological indicators of human impact while at the same time recognizing the unique features of Antarctica. It is also important to realize that the current understanding of complex ecological systems is limited when setting expectations for monitoring activities. While biological resources are often the systems most visible to people, and the most frequently cited as possibly affected by humans, it is not necessarily true that direct monitoring of these elements is the best approach. Biological organisms, and the ecosystems that support them, are often a complex web whose structure and functioning is poorly understood.

It is timely to assess the best practices for biological monitoring and define realistic expectations for monitoring usage in protecting the Antarctic environment.

The workshops Terms of Reference asked the participants:

1. *To consider the range of biological indicators of human impacts that can be appropriately applied in the Antarctic setting.*
2. *To assess the available history and data on biological indicators from the molecular to the ecosystem level and assess the strengths and weaknesses of these methodologies.*

3. *To consider if the monitoring of "key species" is practical and to assess the limitations of monitoring schemes based on these biological representatives.*
4. *To review existing biological monitoring protocols that have been tested, validated and used in temperate climates and determine how they might be adapted to Antarctica.*
5. *To develop a series of recommendations that will assist National Antarctic Programs in establishing meaningful and practical long-term monitoring programs in Antarctica that provide for comparability across programs and optimize the ability of monitoring program results to inform management decisions.*

3.0 Workshop Deliberations

Forty-four participants from fourteen countries gathered for two and a half days to discuss the status of biological indicators of human impact in Antarctica. As described above, these deliberations were the most recent step in a series of workshops and conferences convened to address national and international requirements for monitoring and minimization of human impacts in Antarctica. The workshop participants were provided with a range of informational materials to assist their deliberations including oral presentations, presentation summaries, concept (white) papers, guiding documents, discussion questions, poster presentations, and other background information. Most of this material is available on the workshop web site.

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

Four (4) independent discussion groups of 8 to 12 people were provided with a common set of questions to assist the groups in their deliberations (see Appendices A,B and C). Each group had a designated discussion group leader and a reporter to record the group's discussions. Membership on each group was intended to represent the breadth of expertise and national representation of the overall participants. Each group was asked to provide detailed notes of their deliberations and to distill their discussions into four or five slides for presentation to all attendees. The points to be covered in the presentation were: general discussion items, key findings or lessons learned, conclusions, and recommendations. Each group was also instructed to regularly return to the terms of reference to guide their discussions and to ensure that all relevant topics were addressed by the end of the meeting. The following sections provide a description of what transpired during the workshop leading to a final set of recommendations.

4.0 General Discussion and Key Findings

The basic precepts for monitoring program design outlined in previous workshop reports are relevant when evaluating the utility of biologically based indicators. As in all monitoring, it was emphasized that "monitoring for the sake of monitoring" was not a useful activity. Monitoring must take place within a well defined framework of management goals. The questions or hypotheses that underlie any monitoring must be explicitly stated and defined. The issue or impact of concern, the practices leading to the impact, and the current status of the system being observed must be clearly identified and documented. The objectives should control the selection of indicators and the design of the monitoring program whether biological or not. A clear conceptual framework also avoids monitoring “everything, everywhere” hoping to detect change.

Monitoring is not only undertaken to detect degradation or negative or positive changes, but also to inform management of the efficacy of management actions that are implemented. Monitoring is most useful when directly connected to an Environmental Impact Assessment process with a well-defined mechanism for the provision of feedback to management.

Standard methods are appropriate to improve inter-comparability of data collected across programs and over long time frames. However, standard methods alone do not ensure data quality. Agreed data quality objectives are now the preferred method for ensuring data comparability among programs and over time. If data are produced that conform to standard data quality objectives that are determined by the usage of the data then data will be of high quality regardless of the collection methodology. Data should be independent of their method of collection. Data quality attributes such as reproducibility, precision, completeness and accuracy must be set *a priori* within the context of management’s need for information to inform decision making. For example, if a 50% decrease in a biological population is deemed as a significant change warranting management action, then any agreed protocols to monitor that population must be able to detect change of this magnitude with the appropriate statistical confidence. There is also a need for the establishment of thresholds or quantitative targets that trigger management actions. In these examples, management data needs are used to define data quality objectives which are then used to select appropriate indicators and methodologies tightly coupling monitoring program design with management actions.

While this workshop specifically addressed biological indicators, monitoring programs also need to consider the physical and chemical aspects of monitoring programs outlined in previous workshop reports. Cause and effect for biological indicators can only be understood in the context of the physical and chemical surroundings. For example, for the marine benthos, sediment grain size is a major control of biological community structure regardless of anthropogenic disturbances. The fundamental aspects of monitoring program design detailed in previous workshop reports must be observed regardless of the final choice of indicators or measurements.

The workshop participants concluded that the pressure-state-response model used in monitoring programs elsewhere was applicable in Antarctica. This framework is essential to provide a basis for designing monitoring programs and selecting relevant indicators. In the absence of a management plan and strategy, there is no “ideal” or standard set of biological indicators that *a priori* will address the needs of all situations in Antarctica. Therefore the workshop did not try to construct such a monitoring program but assessed the state of the knowledge and the general principles upon which biological indicators might be used (see Workshop- Volume 2).

The workshop participants noted that while local effects may be the target of operators, regional and global impacts are the context within which local effects occur. Longe range effects were recognized as significant contributors to natural and anthropogenic change observed throughout Antarctica. These global-scale effects include climate change, fishing, and long range transport of pollutants. Local impacts are due to the presence of humans, infrastructure, physical disturbance, local discharges and emissions, and the introduction of non-indigenous species. While some of these impacts may not be the within the remit of National Operators, they cannot be ignored when interpreting long-term trends in data. Changes due to these stressors include:

- Climate – change in temperatures and precipitation patterns;
- Fishing – community structure changes and habitat destruction;
- Pollutants – ozone depletion and UV radiation increases;
- Global transport of persistent organic pollutants (POP's);
- Physical disturbance – habitat loss and alienation; and
- Introductions of non-indigenous species – natural and human introductions such as ballast water discharges, hull fouling and waste disposal practices.

As in previous workshops, issues of temporal and spatial scale were seen as fundamental to monitoring program design. Biological indicators are subject to the same limitations as other indications and the temporal and spatial scales of the impacts being monitored must be defined in order to determine the selection of indicators and sampling designs. Biological indicators may be important as receptors that respond to human impacts and/or they may be used to monitor the value of interest itself.

5.0 Conclusions

The workshop addressed each of the five terms of reference. Workshop participant were asked:

TOR 1: To consider the range of biological indicators of human impacts that can be appropriately applied in the Antarctic setting.

Workshop participants considered the range of biological indicators of human impact and discussed if they could be applied in the Antarctic setting (see Workshop Report – Volume 2). The group agreed that since the previous workshop, the understanding of biological indicators had greatly advanced and that many concepts and indicators used in temperate climates and the Arctic were applicable to Antarctic monitoring. It was also agreed that some practices in other locations were either impractical in Antarctica or required considerable modifications. Concepts such as marine benthic indicators of biological integrity, sentinel indicators as integrators of contaminant exposure, the sediment quality triad, the use of toxicity assays and transplant experiments, and collection of long term data sets were seen as useful approaches to be considered when designing monitoring programs in Antarctica.

The design of a monitoring program, including the use of biological indicators, must first define the issues of concern and establish which pressures (impacts, practices etc.) may be the cause of these issues. The second step is to establish the state of the system under pressure. Finally, monitoring information should inform management actions through appropriate feedback. Monitoring also provides feedback to management on the efficacy of the actions taken by documenting outcomes.

TOR 2: To assess the available history and data on biological indicators from the molecular to the ecosystem level and assess the strengths and weaknesses of these methodologies.

Workshop participants considered the use of a range of biological indicators from the molecular to the ecosystem level. It was considered beyond the capabilities of this workshop to look at all possible biological indicators but it was concluded that successful biological monitoring was being conducted and that the lessons learned from these programs can inform decisions about future monitoring program design in Antarctica. Workshop participants concluded that successful biological monitoring was taking place and that practitioners should make full use of the lessons learned in these existing programs (see Volume 2, Section 1.0).

It was also concluded that many potential biological indicators were not yet viable for the purposes of routine monitoring. Deficiencies included highly variable results, expensive or complex methodological protocols, unclear cause and effect linkages and relationships, incompatibility with natural population levels, and other problems. Criteria for the selection of practical biological indicators for use in monitoring programs are well established and applicable to the Antarctic setting (see Volume 2, Section 2.0).

Molecular-level biological indicators of stress or exposure are many and varied (see Volume 2, Section 3.0). They hold promise for the early detection of impacts as they are usually sub-lethal in their effects. However, they are in generally expensive, utilize complex protocols, linkages to higher level effects are unclear, and cause and effect are not always well understood and/or documented.

While ecosystem-level indicators are holistic in their integration of multiple effects, they are often complex to measure, cause and effect relationships are not well understood, and measurements protocols are time and resource intensive (see Volume 2, Section 4.0).

It was concluded that a general framework utilizing comparable biological indicators was feasible for the detection of local human impacts. The methods chosen and the reporting mechanisms adopted need to be as simple as possible while simultaneously providing high quality/robust data in an understandable format for National Operators. A hierarchical approach is advisable. The environment can best be observed based on its major components: terrestrial biota, vertebrates and the marine benthos. In the terrestrial setting, aerial photography and visual examination can be used to quantify the community structure and the diversity of vegetation. Vertebrates, such as penguins and other seabirds, can be characterized by population size and breeding success close and far from Scientific Bases. Vertebrate data and trends must be juxtaposed on long-term decadal baseline datasets that are already being collected at several locations. The response of marine benthic biota to physical disturbance, toxins and organic enrichment is well established and community level responses can be described and predicted using multi-metric approaches. Well tested and proven approaches include indicators of integrity or health. For example, the sediment quality triad approach and biological indicators of biotic integrity have been widely applied in monitoring programs elsewhere and in Antarctica. The information collected by monitoring programs can contribute to State of the Environment reporting.

TOR 3: To consider if the monitoring of key species is practical and to assess the limitations of monitoring schemes based on these biological representatives.

The concept of “characteristic fauna” was seen as more applicable to the Antarctic setting rather than “keystone species” which has specific ecological meaning that is not well defined in Antarctic food webs. It was concluded that it was highly unlikely that single species or even a simple suite of species would adequately provide the full spectrum of information needed to detect the multi-faceted impacts of humans in Antarctica. While single species may have a role in monitoring programs, it was generally believed that multi-metric approaches were more robust and powerful as monitoring tools in addressing complex disturbance scenarios usually associated with human activities in Antarctica.

Workshop participants concluded that long-term datasets were fundamental for establishing the “normal range” of biological attributes and for understanding and determining the extent of natural variability. Long-term datasets are essential for establishing historical trends in biological indicators and for generating models to predict future responses to changes. Long-term data sets are available in selected locations for sea birds, terrestrial plants, mammals and the marine benthos.

Single species may be appropriate when stressors are known, the species characteristics are well understood, and when natural variability has been or can be established. Examples of potential target species include: penguins, seals, krill, lichen, and mollusks depending on the management objectives being addressed through monitoring.

TOR 4: To review existing biological monitoring protocols that have been tested, validated and used in temperate climates and determine how they might be adapted to Antarctica.

Workshop participants concluded that there were many lessons to be learned from monitoring in areas other than Antarctica. It was also concluded that in some instances the special circumstances of Antarctica did not allow for direct application of methodologies and protocols from elsewhere. However, the basic underlying concepts of biological monitoring are applicable regardless of location and many biological indicators are applicable in the Antarctic context

TOR 5: To develop a series of recommendations that will assist National Antarctic Programs in establishing meaningful and practical long-term monitoring programs in Antarctica that provide for comparability across programs and optimize the ability of monitoring program results to inform management decisions.

A series of specific recommendations were developed by workshop attendees and are detailed below (See Section 6.0). In particular, workshop participants concluded that coordination among operators and exchange of monitoring information could be greatly improved through existing organizations and mechanisms. Better integration and coordination of planning and implementing monitoring programs in Antarctic would benefit all programs.

To be an effective management tool, monitoring needs to be kept simple and information needs to be provided in a non-technical format to National Operators. Standard methods are not sufficient to ensure high quality data production. Data quality objectives must be stipulated based on management objectives in order to produce results that are method and analyst independent.

There are valuable data sets that can inform monitoring activities. Biological monitoring is already being undertaken by various programs. The experiences of others need to be shared in order to communicate which approaches have already been successfully applied in Antarctica.

6.0 Recommendations

Based on the deliberations of the participants and the reports from the discussion groups, ten (10) recommendations were agreed upon by attendees. The recommendations address four areas; 1) the scientific basis for biological monitoring, 2) data management, 3) cooperation and communication, and 4) resources.

6.1 Scientific Basis for Biological Monitoring

Recommendation 1: Biological processes and responses are inextricably linked with the physical and chemical environment; therefore biological indicators of human impact can only be understood when closely coupled with a suite of non-biological measurements.

Biological monitoring data must be interpreted within the context of the physical and chemical environment. Confounding changes in the natural environment must be incorporated when interpreting changes in biological indicators. When designing a monitoring program an holistic approach that takes into account biological and non-biological interactions must be considered. Non-biological indicators are key to discerning cause and effect relationships and for establishing natural variability when interpreting changes in biological indicators of human impact.

Recommendations 2: Long-term biological data sets are fundamental to establishing the natural ranges of biological indicators of change and the continuation of long-term datasets should be supported.

Quantification of the extent and trends in natural variability is crucial to determining the effect of humans on observed changes in biological indicators. Long-term data sets are of critical importance and their value increases with time. Securing the integrity of data sets and documenting their quality is essential for protecting the value of these long-term datasets.

Recommendation 3: Further work should be undertaken to determine which temperate protocols for biological indicators of human impacts could be effectively adapted or customized for use in Antarctica.

A number of biological indicators for monitoring human impacts at the community, population, species and cellular levels are effectively used elsewhere. Only a few indicators have been specifically tested with Antarctic organisms considering the high variability of these settings. Further study is needed to reliably assess the efficacy of methods and approaches within an Antarctic context.

Recommendation 4: Data quality objectives should inform the choice of biological indicators for monitoring programs, rather than relying only on the adoption of standard procedures and protocols.

The approach of adopting standard procedures or protocols is inadequate to ensure data quality. Current best practice relies on data quality objectives allowing the adoption of methods that can meet data acceptance criteria. Adherence to standard methods does not ensure data quality.

Recommendation #5: Operators of National Antarctic Programs should agree on a common set of comparable monitoring parameters to measure the potential biological impacts of station operations while producing comparable and compatible data.

There can be great value derived from a basic continental scale approach to biological monitoring. A network of this scale provides a robust context within which local variability and change can be assessed. The diversity of station surroundings and activities is such that it will be impossible to identify a single biological indicator for use at all sites but it is recommended that the following biological indicators be considered: biodiversity of terrestrial flora, diversity of sea bird species, breeding success of surface nesting species, and marine benthic measurements of biotic integrity.

Recommendation 6: More robust numerical and quantitative models of natural systems are needed for reliable predictions of future biological changes and linkages with their causes.

Monitoring of human impact has so far largely relied upon direct measurement, especially in the case of chemical contamination of habitats. The development of mechanistic models based on an improved understanding of animal behavior, food web connectedness and ecosystem resilience is needed to improve risk assessments and to inform the design of mitigation measures.

6.2 Data management

Recommendation7: All monitoring data should be made widely available through existing National Data Centers.

National Data Centers have been nominated in 16 Antarctic countries and the Joint Committee on Antarctic Data Management (JCADM) is working to extend this. The metadata entries in these Data Centers may not reflect the extent and diversity of the data available. Renewed efforts are required to ensure that individual scientists, environmental officers and operators catalogue their data and make it freely available.

6.3 Communications & Co-ordination

Recommendation 8: The coordination and exchange of information on monitoring among COMNAP, SCAR, and CCAMLR should be improved through existing organizational structures and procedures to ensure the highest level of interaction and coordination among all parties.

With the exception of JCADM, there are few links, formal or informal, among the various Antarctic entities to effectively share the experiences and data derived from monitoring and scientific activities to ensure best practices are utilized. SCAR and COMNAP should consider how to improve information exchange from on-going and future environmental monitoring. The COMNAP Environment Coordination Group (ECG) and AEON should explore ways to more effectively interact with the CCAMLR CEMP Subcommittee.

Recommendation 9: To improve communication and information exchange, "Monitoring Practice and Science" oral and poster sessions should be organized at the biennial SCAR Science Conference. Every fourth year a monitoring workshop should be held during the SCAR/COMNAP joint meetings.

A forum is needed to link scientific knowledge and advances with environmental monitoring requirements and protocols. The existing biennial SCAR/COMNAP meeting offers such a forum where experiences, challenges, and common issues can be explored and data and information exchanged.

6.4 Resources

Recommendation 10: The monitoring of human impacts must become a routine part of Antarctic station operations and adequate resources must be provided to ensure that these activities are performed at appropriate frequency and intensity.

In order to meet the requirements of the Article 3of the Protocol on the Environment states that all National Operators should establish monitoring program capable of assessing the impacts of human activities in Antarctica. Monitoring is a fundamental part of Antarctic logistics and requires adequate resources if effective monitoring is to be undertaken.

Recommendation 11: Monitoring programs require an unambiguous definition of a "natural", control or original state to identify change(s) due to human intervention and to account for natural variability in biological systems. All monitoring programs should explicitly define what comparisons will be used to recognize, assess and interpret the variations observed and whether the change(s) detected is/are considered to be positive or negative.

Changes in biological indicators are only meaningful when compared to an "unaffected state". Change is ideally measured in relation to an "unaffected state" that is known, or believed to be, free of human interference. This "unaffected state" can be defined by the identification and use of similar systems (controls) taking into account variations due to other factors or from historical data (before commencement of an activity). Observations over a gradient of disturbance can also be used to infer or extrapolate to an "undisturbed" state if change occurs in a progressive and predictable fashion. However, in some instances, thresholds may be exceeded that result in non-linear change. Existing databases and meta-databases can provide important reference data and all parties should be encouraged to contribute to this common resource. These data could also be used to identify potential control sites.

Appendix A. Workshop Agenda

Appendix B. Discussion Group Guiding Questions

The following questions were provided to guide the discussions in the break-out groups. The questions were not intended to be restrictive and groups operated as they deeemed. Questions were formulated to ensure that the workshop Terms of Reference were addressed and that meaningful conclusions were drawn in the time allotted.

- Questions were grouped by the topic of the morning's plenary presentations but may be addressed in any order the group deems best.

- Adequate time was allocated to address all of the issues.

- Time was set of aside to develop consensus on the group's report, conclusions and recommendations.

- Each discussion group's report to the plenary included: a summary of general discussion points, key points, findings, conclusions, and recommendations.

A detailed written report of each group's deliberations and a PowerPoint © presentation of the outcomes were products.

Session I: Criteria for the Selection of Biological Indicators

TOR – 1 To consider the range of biological indicators of human impacts that can be appropriately applied in the Antarctic setting.

TOR – 4 To review existing biological monitoring protocols that have been tested, validated and used in temperate climates and determine how they might be adapted to Antarctica.

- What biological impacts are most important to monitor in Antarctica?

- What impacts are most pressing and/or of most concern to the public? To National Operators?

- Is the suite of available biological indicators adequate to address the impact issues of concern? Are more indicators needed? What are these additional indicators of human impact?

- Are the criteria provided for evaluating indicators sufficient?

- Are there Antarctic-specific criteria that should be considered when choosing biological indicators?

- How can the guidance criteria be improved for designing Antarctic monitoring programs?

- Which of the proven biological indicators are judged to be appropriate for Antarctica and why?

- Are there biological indicators that are unsuitable and why?

Session II: Antarctic Experiences in Biological Monitoring

TOR-2 To assess the available history and data on biological indicators from the molecular level to the ecosystem level and assess the strengths and weaknesses of these methodologies.

- Have past monitoring efforts in Antarctica been comprehensive and effective? If not, what was missing?

- Which indicators have provided useful information in the past, and which, if any, have provided unreliable information? Can anything be done to improve the information provided by the unreliable indicators?

- What pitfalls have been encountered in past monitoring activities that should be avoided in future monitoring programs in Antarctica?

- What monitoring protocols used elsewhere can be adapted to Antarctica? What adaptations are needed?

Session III: Biological Indicators Based on Level of Organization

TOR-2 To assess the available history and data on biological indicators from the molecular level to the ecosystem level and assess the strengths and weaknesses of these methodologies**.**

- Are there impacts at higher organizational levels that are not quantifiable given the available biological indicators? Are there reliable indicators that could be used to address these impacts?

- Are there instances in which a multi-metric approach is preferable and/or superior to individual indicator species? Why?

- On the cellular and molecular level, what stress responses are valid impact indicators? Are they easily and cost-effectively monitored?

- Are cellular and molecular indicators predictive of higher level responses at the population, community or ecosystem level?

Session IV: Species-Based Biological Indicators

TOR-3 To consider if the monitoring of keystone species is practical and assess the limitations of monitoring schemes based on these biological representatives.

- Are species-based biological indicators useful for detecting human impact in Antarctica? Which types of impact does this work well for and why? What types of impact does this work poorly for and why?

- Do potential impacts exist that are not quantifiable by the non-species based biological indicators?

- Are there species based indicators that detect these impacts?

- Which keystone species have been monitored in the past? What advantages of using keystone species fro monitoring? What are the limitations?

- Are the time frames for detecting change in higher level organisms compatible with the time frame of decision making?

- How successful have attempts been to extract the impact effects from natural variability? Are there species that are well-studied enough that can compensate for these limitations?

Session V: Conclusions and Recommendations

TOR - 5 - To develop a series of recommendations that will assist National Antarctic Programs in establishing meaningful and practical long term monitoring programs in *Antarctica* that provide for comparability across programs and optimize the ability of monitoring program results to inform management decisions.

- What are your final recommendations regarding biological indicators of Impact?

- Is there basic research that needs to be performed to improve our ability to monitor biological impacts? If so, what is it?

- Is a multi-metric approach preferable to and more powerful than single indicators?

- Are there indicators available that are well enough characterized to devise standard rules to signify when management actions should be taken and what those actions are?

- Is there an “ideal” monitoring program that should be uniformly adopted by all nations or does each situation have its own special aspects that require customized designs for monitoring programs?

Appendix C. Discussion Group Assignments

GROUP 1 Neil Gilbert (NZ), Discussion Group Leader;Kathy Conlan (CAN), Rapporteur

- Guy Denoux, (USA)
- John Hinton (USA)
- Denise Landau (US)
- Hans Ulrich Peter (GER)
- Sandro Torcini (ITA)
- Paul Montagna (USA)
- Torben Iversen (NOR)
- Eric Woehler (SCAR)

GROUP 2 John Shears (UK), Discussion Group Leader; Rebecca Roper-Gee (NZ), Rapporteur

- Gilvan Yogui (BRA)
- Jose Sericano (USA)
- Hans Hei Janssen (GER)
- Giichiro Ohno (JAP)
- Cassandra Shenk (USA)
- Ron Naveen (USA)
- Kevin Hughes (UK)

GROUP 3 – Birgitt Njaastad (NOR) Discussion Group Leader; Rod Downie (UK), Rapporteur

- Steve Sweet (US)
- Lou Sanson (NZ)
- Erik Ropstad (NOR)
- Rodolfo Sanchez (ARG)
- Robert Carr (USA)
- Pamela Toschik (USA)
- Keith Reid (UK)
- Marilu Hastings (USA)
- William Fraser (USA)

GROUP 4 – Polly Penhale (USA), Discussion Group Leader; Ad Huiskes (NETH), Rapporteur

- Terry Wade (US)
- Aimee Hessert (US)
- In-Young Ahn (KOR)
- Joachim Ploetz(GER)
- Mitsuo Fukuchi (JAP)
- Rolf Weber (BRA)
- Philip Lyver (NZ)
- Yves Frenot (FRA)
- Stacy Kim (US)

"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:

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**