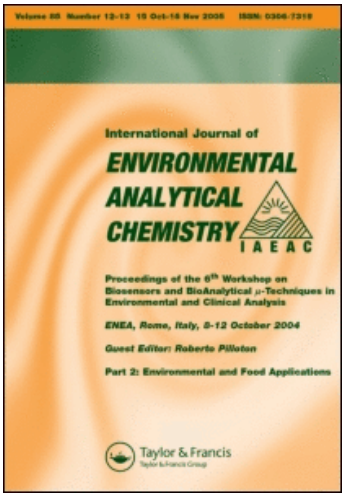

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THE NEED FOR ENVIRONMENTAL MONITORING IN ANTARCTICA: BASELINES, ENVIRONMENTAL IMPACT ASSESSMENTS, ACCIDENTS AND FOOTPRINTS

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The Protocol on Environmental Protection to the Antarctic Treaty (1991) requires the environmental monitoring of human activities carried out in Antarctica. The objective of such monitoring is to collect environmental information which can be used by decision-makers to help prevent or minimise environmental impact. Applied monitoring, driven by practical management needs, is a relatively new field of inquiry for most Antarctic scientists.

This paper examines the background to environmental monitoring in Antarctica, the design of monitoring programmes, the application of monitoring results to environmental management and future research needs. In particular, it highlights the urgent need for international collaboration to validate data, effectively utilise scarce resources and devise standard monitoring protocols for wide application amongst the Treaty countries.

KEY WORDS: Environmental monitoring, Antarctica, Southern Ocean, baseline surveys, environmental impact assessment, pollution.

INTRODUCTION

Basic research monitoring vs applied environmental monitoring

The basic objective of environmental monitoring is to detect and measure change in the environment by collecting time series of data for defined purposes and observing trends in the selected variables[1]. Monitoring encompasses a wide spectrum of activities, but in Antarctica it can be most easily split into monitoring programmes designed to answer either basic research or applied management questions.

In the past, monitoring for basic research purposes has dominated Antarctic science and has concentrated on the measurement in the Antarctic of global change parameters or of global pollutants. The depletion of the ozone layer is perhaps the most famous example of global change detected in Antarctica[2]. In terms of environmental pollution, the discovery of

organochlorine pesticides, such as DDT, in the tissues of Antarctic penguins was significant[3]. As a result of these important studies and others, basic research monitoring is a well-established part of ongoing science in Antarctica.

Of particular importance to the success of this monitoring is that the Antarctic environment is still almost uncontaminated by human activities. Antarctica acts, therefore, as an unparalleled natural laboratory for research into the problems of global change and global pollution. However, scientific research and associated logistics activity, tourism and other human activities within Antarctica could have local or even possibly regional environmental effects and so compromise the global scientific value of the continent.

In Antarctica, applied environmental monitoring concentrates on the detection of local or regional environmental effects caused by specific human activities. Here the aim is to collect environmental information which can be used by decision-makers to help prevent or minimise environmental impact. Applied monitoring, driven by practical management needs, is a relatively new field for most Antarctic operators.

Successful applied environmental monitoring is not about the measurement of many variables at many sites in the vague hope that subsequent analysis will reveal a cause and effect relationship. Monitoring of what ever type is expensive, particularly if carried out for long periods. It should be focused, therefore, on what is essential and necessary.

Antarctic Treaty requirements for applied environmental monitoring in Antarctica

At the XV Antarctic Treaty Consultative Meeting (ATCM), 1990, Recommendation XV-5 on environmental monitoring in Antarctica was agreed. It calls for national Antarctic programmes, individually and collectively, to establish environmental monitoring programmes for activities including:

i) waste disposal;
ii) contamination by oil or other hazardous or toxic substances;
iii) construction and operation of stations, field camps, and related ship, aircraft and other logistic support facilities;
iv) conduct of science programmes;
v) recreational activities, and
vi) activities affecting the purposes of designated protected areas.

The requirement for environmental monitoring is further strengthened by the Protocol on Environmental Protection to the Antarctic Treaty (1991). This calls, under Article 3.2 (d) and 3.2 (e) for regular and effective monitoring to allow assessment of the impacts of ongoing activities, including the verification of predicted impacts, and to facilitate early detection of the possible unforeseen effects of activities.

In 1992, the First Meeting of Experts on Environmental Monitoring in Antarctica was held and this established an initial framework and recommendations for monitoring studies in Antarctica. The Meeting stressed that monitoring studies should be carefully designed, practicable, cost-effective and focused only on what is essential to meet the requirements of the Environmental Protocol.

The Report of the Meeting of Experts[4] was considered at the XVII ATCM, 1992, where Recommendation XVII-1 on environmental monitoring and data management was agreed. This requested the Scientific Committee on Antarctic Research (SCAR) to provide advice to the Treaty Parties on the long-term monitoring programmes needed to assess whether human activities have significant adverse effects on Antarctic birds, seals and plants, and also on emission standards for the burning of fossil fuels and waste incineration so the scientific value of Antarctica is not degraded. In addition, the Council of Managers of National Antarctic Programmes (COMNAP), in consultation with SCAR, was asked to establish environmental impact monitoring studies at a representative set of facilities in different locations in Antarctica.

International co-operation in environmental monitoring

The Antarctic Treaty (1961) has proved an outstanding model of how peaceful international co-operation can be successfully achieved. National Antarctic programmes have for many years supported one another and freely exchanged expertise, equipment, data and personnel. The Protocol on Environmental Protection recognises that co-operation between nations is essential in order to protect the Antarctic environment, and Article 6 of the Protocol calls for the Treaty Parties to co-operate in the planning and conduct of activities.

In order to effectively utilise scarce resources, there is an urgent need for the already widespread international collaboration between national operators to be extended to the field of applied environmental monitoring.

This paper aims to review the design of environmental monitoring programmes, indicate the application of monitoring data to environmental management and highlight urgent future research needs.

THE DESIGN OF ENVIRONMENTAL MONITORING PROGRAMMES

SCAR and COMNAP[5] have suggested that a sequence of steps be used in the design of an environmental monitoring programme (Figure 1).

Objectives

The specific objectives of both basic and applied environmental monitoring programmes need to be clearly established before field measurements begin. Abbott and Benninghoff[6] suggest that in general for Antarctica, the objectives can be defined as follows:

i) to further understanding of the structure, variability and interactions within and between natural systems;
ii) to collect baseline information on the environment or ecosystem in order to detect, measure and monitor future environmental changes;

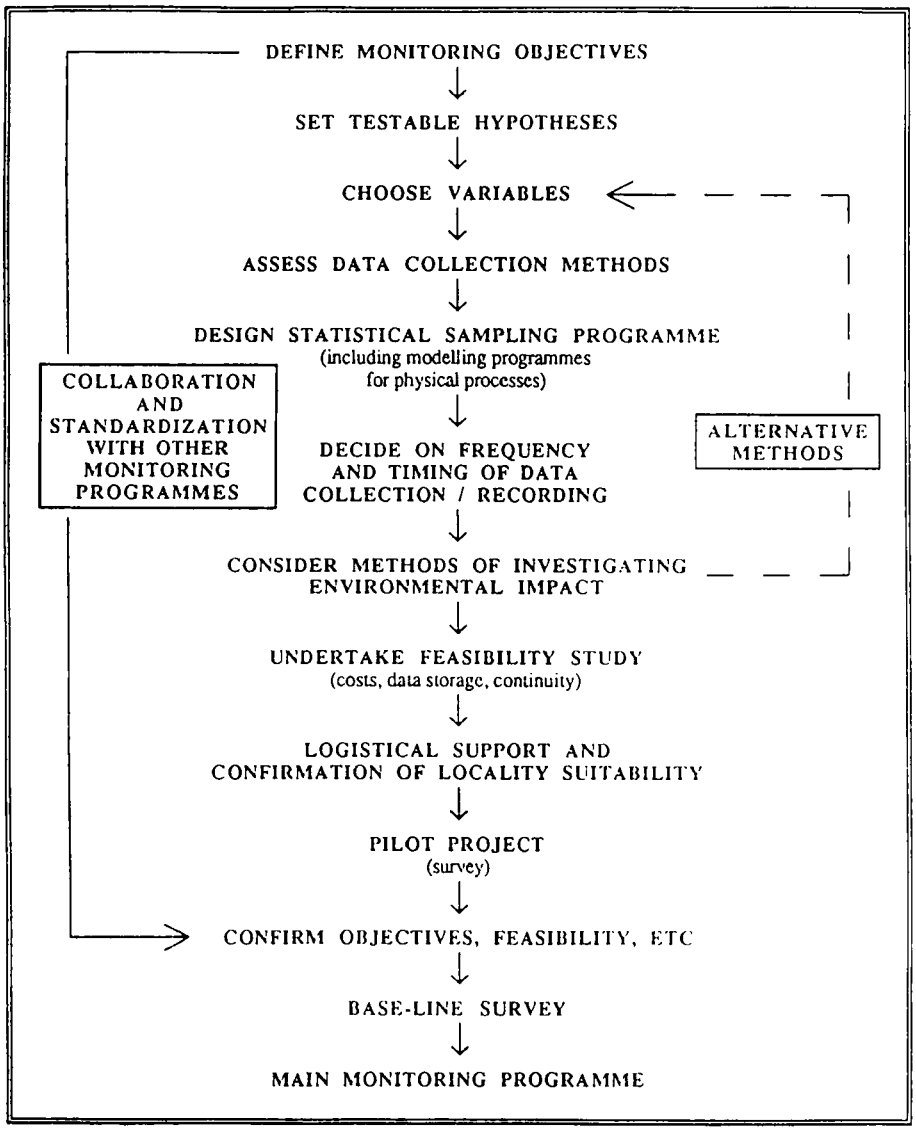

Figure 1 Flow diagram of the steps to be used in the design of an environmental monitoring programme[5].

iii) to verify predictions made on the expected changes in environmental or ecosystem processes under a given perturbation;
iv) to detect unforeseen effects of human activities on particular variables;
v) to evaluate the effectiveness of existing regulatory mechanisms, conservation measures and management procedures;
vi) to establish whether the environment or ecosystem is in a healthy state.

Testable hypotheses

All monitoring programmes need to be based on valid and testable scientific hypotheses. All too often this rigorous framework is forgotten and monitoring is carried out with everything and anything being measured with no real idea what the results mean or how they might be constructively used.

In the Antarctic, where we know so little about the environment or its dependent ecosystems, hypotheses need to be clear, simple and testable. For example, pollution of the marine environment may be a major issue arising from a proposal to build a new coastal research station. As part of a wider monitoring programme, oil pollution could be examined. An appropriate hypothesis might be that oil spills at the base will cause increased levels of hydrocarbon contamination (*n*-alkanes and polycyclic aromatic hydrocarbons (PAH)) in benthic organisms and sediment nearby. A sampling programme can then be designed and indicator variables and survey sites identified.

The formulation of hypotheses is an important step in the intuitive production of dynamic models of environmental processes. Models, calibrated using monitoring data, are likely to become increasingly important in Antarctic environmental management since they can be used to guide action on the 'best' way to respond to change in an environmental system. Different project scenarios and management strategies can be explored using a model before implementing a particular course of action. This attribute is very useful in Environmental Impact Assessment (EIA) where different options need to be explored to find the one with the least impact. For example, a computer dispersion model was used to compare the mixing characteristics of an existing surface wastewater discharge and a number of different wastewater outfall options at the USA McMurdo research station, Ross Sea, Antarctica[7].

Selection of indicator variables

To monitor all biotic and abiotic components of Antarctic ecosystems that might be affected by human activities would be prohibitively expensive. Thus a more rational approach is to identify and select indicator variables, which are chemical, physical or biological parameters that might be expected to respond in a measurable and predictable way to an environmental impact.

The selection of indicator variables is clearly a crucial part of designing a monitoring programme, but is very difficult to do given our incomplete knowledge of Antarctic ecosystems. There are, as yet, no universally agreed systems for defining which particular variables should be considered of key importance. However, as experience of applied environmental monitoring increases it may be possible to agree on a general framework of 'Valued Ecosystem Components' (VECs)[8].

A VEC is an environmental parameter which, if altered from its existing state, is important in evaluating the impact of human activities. Possible VECs might be: soils, plant species, breeding birds, ecological communities or protected areas.

A list of VECs can be compared against a list of human activities to form a matrix of interactions which can be subjectively scored for severity of environmental impact. Those

VECs which show the greatest effects can be considered as likely monitoring variables[5]. Figure 2 shows an example of an impact matrix produced for the construction phase for a proposed emergency airstrip on Marion Island, Prince Edward Islands[9].

Alternatively, special workshops can be convened at the start of the monitoring programme to help identify VECs. The use of workshops has been adopted recently in Svalbard for the applied environmental monitoring of industrial activities in the region, particularly for oil and gas developments[10]. This is a cumbersome approach, but its value may well lie in highlighting the key features in each ecosystem that can be used as the basis for an improved selection protocol in the future. The use of VECs is rapidly developing in Canada, the USA and European countries, and a version of the developments may well prove appropriate for Antarctica.

The design of a sampling scheme and choice of analytical techniques

The next stage is to design the sampling scheme. It must be able to distinguish between natural background levels in a chosen indicator variable and the levels induced by human activity. This can be done most effectively by using impact and control sites.

Impact sites are located in the area where maximum impact is expected to occur. Control sites should be as similar as possible to the impact sites, except that they must be located in an area where an impact is not expected to occur. Several sampling points must be established within each site, because the differences between the locations can only be measured when the variability within each is known.

Figure 3 shows an example of how impact and control sites could be used to monitor the effects on benthic biota of a proposed sewage treatment plant. Here the impact site would be located in the immediate vicinity of the outfall and in the centre of the predicted waste plume, and the control site would be in an area which is clear of any sewage effluent.

It may be impossible to find control sites. This may occur if the indicator variable is rare or has only a very limited distribution in the target area. In such a situation, the only option is to monitor the response of the impact site over time. The first survey at the impact site acts as the baseline and control and subsequent surveys acts as different treatments. The validity of such comparisons is highly dependent on knowing the natural variability of the indicator being studied.

Analytical techniques should be relatively simple and easily standardized so that they can be widely applied. For physical and chemical monitoring studies it is essential that measurements are referenced to internationally accepted standards and that collaborating laboratories exchange samples and standards to ensure consistency. Accuracy and repeatability should be covered by quality assurance agreements. Duplicates, spikes and blanks should all be routinely incorporated into laboratory analyses. SCAR and COMNAP[5] have suggested that acceptable data would normally be considered as those more than ten times the value of the blank or the detection limit.

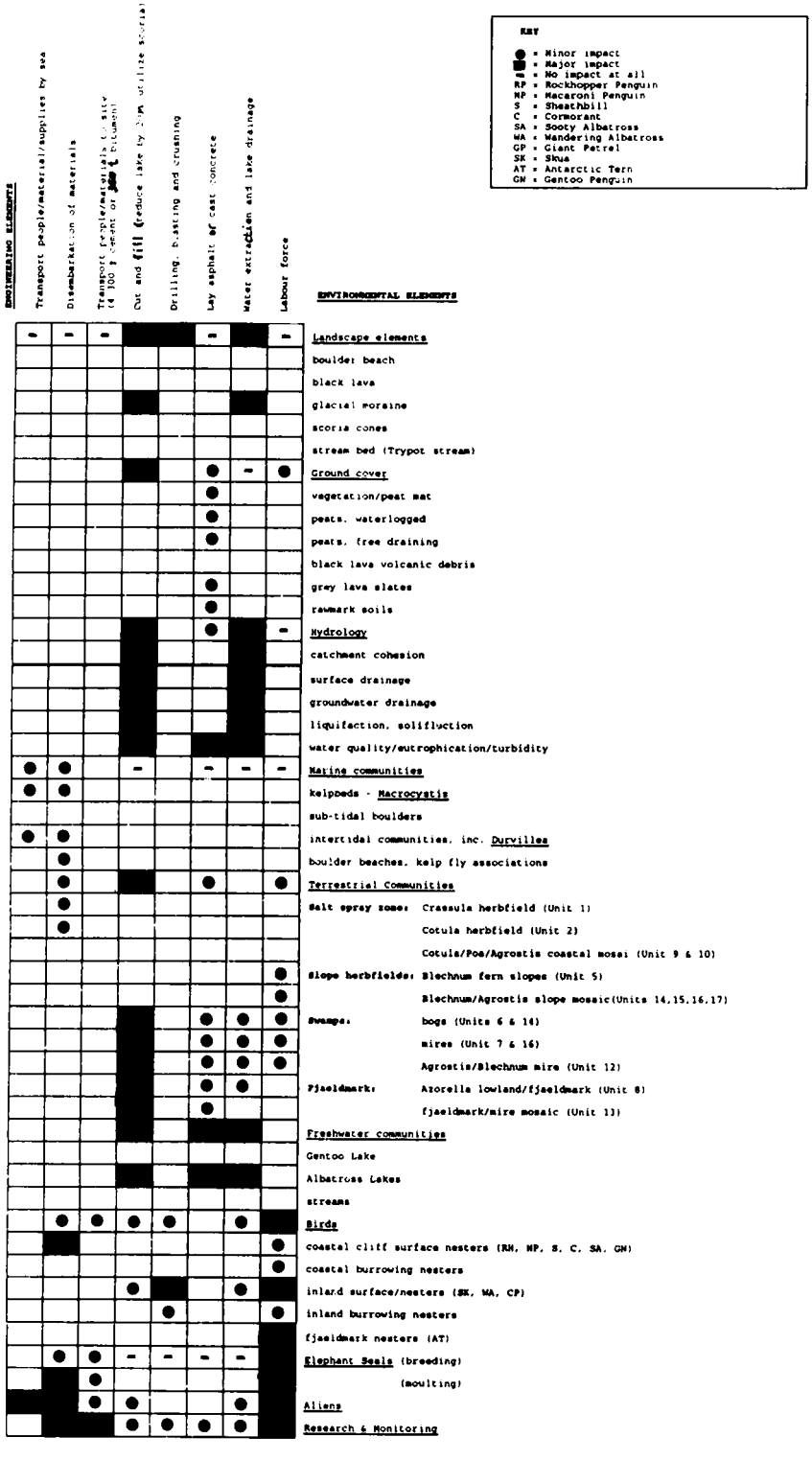

Figure 2 Impact matrix for the construction of a proposed emergency airstrip on Marion Island, Prince Edward Islands[9].

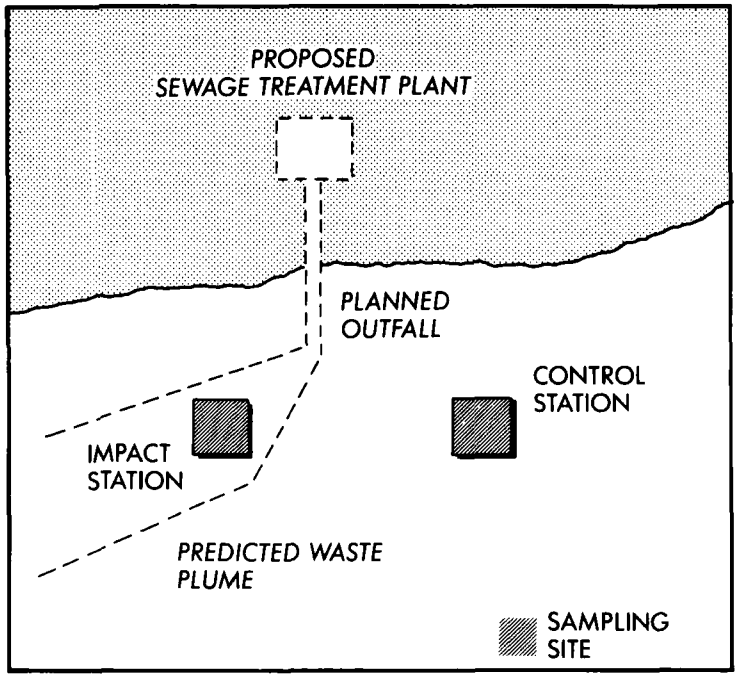

Figure 3 An example of how impact and control sites can be used to monitor the effects on benthic biota of a proposed sewage treatment plant.

Management and storage of data

The success of any monitoring programme will depend, in part, on the establishment of an effective system for managing the data. Monitoring may need to be undertaken for long periods of time, during which the people initially involved in establishing the programme may change. Therefore, there needs to be careful coordination of the programme so that records are not only deposited safely but are accessible and understandable to successive researchers.

Recently, attention has been drawn to the potential of using Geographical Information Systems (GIS) to store, integrate, visualise and analyze different environmental datasets for different variables within a specified area. Sequential datasets can also be handled and interrogated. GIS systems, therefore, are a powerful tool which could help in the management of the environmental impacts of human activities in Antarctica[6].

Regular review

Monitoring programmes should be subject to independent scientific review and have completion dates. The review should examine whether the programme objectives are being

met, if there are any gaps in the data, the effectiveness of the sampling techniques and if the programme is cost-effective. At intervals during the life of any long-term programme, reports should be published giving a preliminary evaluation of the monitoring data. Applied monitoring studies are not easy to publish in basic scientific research journals. SCAR and COMNAP[5] have suggested that the new Committee for Environmental Protection, established under the Environmental Protocol, should initiate a publication series to ensure that applied monitoring studies, including raw data where necessary, are made publically available.

THE APPLICATION OF APPLIED ENVIRONMENTAL MONITORING TO ENVIRONMENTAL MANAGEMENT

Baselines

Baselines can be defined as the collection of essential measurements which establish descriptions of selected environmental indicators. The baseline data acts, therefore, as a datum from which any subsequent observed changes can be measured and compared.

At present, the main scientific activity in Antarctica involving the establishment of baselines is the determination of global datum levels for various classes of pollutants. The Italian National Research Programme has been particularly active in this field and is currently monitoring the presence of halocarbons, PCBs (polychlorinated biphenyls), chlorinated pesticides and radionuclides in a wide range of Antarctic material, including water, snow, soil, plants and fish[11].

At present, pollutants are being surveyed by different research groups from different countries and in different areas in the Antarctic. There is clearly a potential problem in the coordination of data collection and analysis, and this is exacerbated when the accuracy of the results is sensitive to the sampling methods used, the possibility of contamination before analysis, or the limits of detection of different analytical procedures. The need for quality assurance is paramount. Scientists need to be certain that levels of a compound measured as parts per million by one group in a particular area of the Antarctic are significantly different from levels in the same compound measured as parts per billion by a different research group elsewhere in the Antarctic, or the rest of the world. Agreed and standardised protocols, cross-laboratory intercalibrations and pooling of data are all essential if Antarctic baselines are to be scientifically acceptable.

Environmental Impact Assessment (EIA)

EIA is a procedure which attempts to identify and predict the potential impact of a specific human activity on the environment. The objective of using applied environmental monitoring in EIA is to assess and verify the actual impact of an activity, to validate any predictions made before the activity began and to provide useful information so that decision-makers can prevent or minimise any damage.

The Protocol on Environmental Protection to the Antarctic Treaty (1991) requires that EIA must be applied in the planning and operation of all activities in Antarctica, ranging from major capital projects to small scientific investigations. If an activity is likely to have a minor or transitory impact an Initial Environmental Evaluation (IEE) must be produced, if the activity is likely to have more than a minor or transitory impact then a Comprehensive Environmental Evaluation (CEE) is required. Following an IEE, monitoring is discretionary, whilst after a CEE, it is mandatory.

In 1989, the British Antarctic Survey (BAS) carried out a CEE for its proposal to build and operate a crushed rock airstrip at Rothera Point, Adelaide Island[12] and included results from baseline monitoring studies and special on-site surveys. In addition, the CEE recommended an enhanced environmental monitoring programme at Rothera to establish the actual impact of the project. Therefore in 1990, before the airstrip construction began, BAS started sampling a series of key environmental indicators. Parameters sampled include airborne dust, hydrocarbon levels in soil, the breeding success of birds and heavy metal accumulation in lichens. The BAS intends to publish a written account of the actual environmental effects of the construction and operation of the airstrip once the results of the monitoring programme have been fully collated and analyzed.

Very few of the IEEs or CEEs so far produced have recommended even very limited environmental monitoring programmes. This may be due to lack of expertise or shortage of funds. However, monitoring has two major benefits. First, monitoring can provide early warning of damage and so enable decision-makers to take action before any major impact occurs. Second, it can be used to improve knowledge about the impacts of various activities on specific environments. Unfortunately, written accounts of the actual impacts of past activities in Antarctica are lacking. The lack of information makes impact prediction a very uncertain task and means that the effectiveness of mitigation measures is unknown. Combined, these benefits mean that environmental monitoring, if well designed, could be very cost-effective.

Accidents

An accident, such as an oil or chemical spill, can sometimes be utilized to provide an unplanned opportunity for applied environmental monitoring. Here monitoring can be used to describe the distribution, fate and environmental effects of the pollutant. Such information can be vital when deciding between different clean-up options.

The grounding of the resupply vessel, *Bahia Paraiso*, in Arthur Harbour, Antarctic Peninsula in January 1989 led to a 600,000 litre diesel fuel spill and provided a tragic, but unique, opportunity to study the environmental impact of oil pollution in the Antarctic. The US National Science Foundation (NSF) responded quickly to the incident and established a wide-ranging monitoring programme. Initially, environmentalists argued that the fuel spill could damage Antarctic marine ecosystems for a century because the fuel would only degrade slowly in the cold polar climate[13]. However, scientific investigations by NSF revealed that the actual pollution effects were limited and in less than two years, and at many locations within a few weeks, the hydrocarbon burden of sediment and intertidal organisms

had returned to background levels. The high energy marine environment, severe storms and the high volatility of the fuel released all combined to limit the environmental impact of the spill[14].

Opportunities for the monitoring of accidents should be exploited to the full. However, such monitoring can have its drawbacks since the establishment of ecological cause and effect can be extremely difficult, even after the most severe pollution and when using well studied indicators. This dilemma has been well illustrated by Eppley[15] who reviewed the strong disagreement between US biologists over whether massive chick mortality of the South Polar skua on Anvers Island, in January 1989 was caused by natural factors or the *Bahia Paraiso* oil spill. One group of biologists blamed the spill, claiming that breeding skuas neglected their chicks while cleaning themselves after becoming coated in fuel oil during feeding. Other biologists were not convinced, pointing to massive chick mortalities elsewhere on the Antarctic Peninsula, and blamed the deaths on storms coincident with the spill or a regional shortage of Antarctic silverfish, the bird's main prey item. The controversy shows the inherent difficulties in determining the effect of an oil spill on species populations, particularly when numbers and breeding success show wide natural variation.

The problems associated with the monitoring of accidents suggests that Antarctic operators should ensure that monitoring protocols are developed, not at the time of an incident, but as an integral part of spill contingency plans.

Footprints

A major requirement to improving the environmental management of human activities in the Antarctic is to discover their exact imprint or 'footprint' on the environment.

'Footprints' need to be established for two good reasons. First, in recent years there has been considerable argument between scientists and environmentalists as to the extent of human impact in the Antarctic[16]. Second, there has been controversy over whether contaminants, especially heavy metals, detected in the Antarctic are derived from the atmospheric fall-out of global pollution or local sources[17]. For both debates, the arguments will only be settled by examining hard data, and so quantified 'footprints' need to be established for a range of localised human activities, such as airstrips, bases and field camps.

ATCM Recommendation XVII-1, agreed in 1992, asked COMNAP, with the help of SCAR, to establish research programmes to record how the imprint of a typical series of facilities in different locations affect the Antarctic environment. At the BAS, a 'footprint' study has already been carried out at the Halley V research station, Brunt Ice Shelf and involved the measurement of heavy metals in surface snow samples at varying distances from the base. Results show that elevated heavy metal levels were found near the station due to fuel usage and waste burning, with background levels being reached at a maximum distance of 10 km away from the station[18].

There is also considerable debate concerning the environmental impact of abandoned research stations and field camps. Unfortunately, at most of these sites no baseline work was ever undertaken, but they still offer an opportunity to investigate the persistence of pollutants over long time periods. For example, low levels of organochlorine compounds have been

discovered in moss and lichen samples collected near to the abandoned stations at Port Lockroy and Prospect Point on the Antarctic Peninsula[19].

A good location in Antarctica to examine recovery rates or long-term residual effects might be the Dry Valleys in Victoria Land. Here a baseline already exists, since detailed microbiological assessments were carried out at a number of sites during the Dry Valley Drilling Program, both before and after drilling[20, 21]. The proposal by the USA to establish a Long Term Ecological Research (LTER) site, which links long-term monitoring with research, in the Dry Valleys is clearly a very important new initiative.

RESEARCH NEEDS

The need to establish firm linkages between pollutants and biological effects

A theme of many national Antarctic programmes is the collection of baseline data on the concentration and distribution of man-made compounds in the Antarctic. This in itself is of limited value if the results are not compared to other data elsewhere in the world and if sources and transport routes cannot be determined. With the sophisticated analytical equipment now available it is relatively easy to measure even low-level concentrations of toxic and hazardous compounds, but unfortunately scientists have almost no idea of the biological effects of these compounds on Antarctic ecosystems. Chemical measurements of pollutants need to be matched by experimental and field data on the effects of pollutants on organisms and biological systems[22]. For example in Canada, herring gulls have been used extensively as bio-indicators of organochlorine contamination in the Great Lakes[23]. As yet very little ecotoxicological research has been carried out in Antarctica, although, the New Zealand Antarctic Research Programme has started an investigation into the toxic and sub-lethal effects of exposure to oil on Antarctic fish[24].

Increased international collaboration

Monitoring programmes, of what ever type, are expensive since they require long-term commitment of resources. This highlights the need for increased international collaboration so that monitoring is not duplicated unnecessarily, costs are reduced and that valuable data is available throughout the scientific community.

International cooperation could be developed very effectively in the following areas:

i) the development of quality assurance standards, particularly for laboratory practice;
ii) the design of model monitoring protocols for different indicator variables;
iii) the pooling of funding to allow regional or continent wide monitoring;
iv) the development of an Antarctic Data Directory of monitoring datasets as advised by ATCM Recommendation XVII-1 agreed in 1992.

CONCLUSION

Until recently, few Antarctic scientists considered applied environmental monitoring, particularly of human activities within Antarctica, to be either necessary or a legitimate use of scientific funding. With the advent of the Protocol on Environmental Protection to the Antarctic Treaty (1991), environmental monitoring is now a mandatory requirement for all planned and ongoing activities likely to have more than a minor or transitory impact on the Antarctic environment.

The objective of applied environmental monitoring is to provide relevant environmental information so that it can be used by decision-makers to prevent or minimise environmental impact. Since Antarctic operators often undertake similar activities, it is in everyone's interest to pool and exchange monitoring data. However, to be of use data must be comparable and this requires the urgent adoption of internationally recognised protocols for field sampling techniques, chemical analyses and data analysis and curation.

Applied environmental monitoring, if designed around testable scientific hypotheses, should be seen as a scientific opportunity not a political hindrance. If used responsibly it will contribute greatly to improved environmental decision-making, and to the basic understanding of the Antarctic environment.

References

1. R. E. Munn, *Global Environmental Monitoring Systems (GEMS): Action Plan for Phase 1. SCOPE Report 3.* (Scientific Committee on Problems of the Environment, Toronto, 1973), 132pp.
2. J. C. Farman, B. G. Gardiner and J. D. Shanklin, *Nature*, **315,** 207–210 (1985).
3. W. J. L. Sladen, C. M. Menzie, W. L. Reichel, *Nature*, **210,** 670–673 (1966).
4. Antarctic Treaty Consultative Parties, *First Meeting of Experts on Environmental Monitoring in Antarctica* (Antarctic Treaty Consultative Parties, Buenos Aires, 1992), 37pp.
5. SCAR and COMNAP, *Environmental Monitoring in Antarctica: a Discussion Document* (SCAR Secretariat, Cambridge, 1992), 23pp.
6. S. B. Abbot and W. S. Benninghoff, in: *Antarctic Ecosystems, Ecological Change and Conservation* (K. R. Kerry and G. Hempel, eds. Springer-Verlag, Berlin, 1990) pp 394–403.
7. S. F. Railsback, *Polar Rec.*, **28,** 149–154 (1992).
8. G. E. Beanlands and P. N. Duinker, *An Ecological Framework for Environmental Assessment in Canada* (Institute for Resource and Environmental Studies, Dalhousie University, Halifax, 1983), 142pp.
9. G. Heymann, T. Erasmus, B. J. Huntley, A. C. Liebenberg, G. de F. Retief, P. R. Condy, and O. A. van der Westhuysen, *An Environmental Impact Assessment of a Proposed Emergency Landing Facility on Marion Island* (Department of Environmental Affairs, Pretoria, 1987). 209pp.
10. R. Hansson, P. Prestrud and N. A. Oritsland, *Assessment System for the Environment and Industrial Activities in Svalbard* (Norwegian Polar Research Institute, Oslo, 1990), 267pp.
11. P. Cescon, ed. *Annali Chim.*, **81,** 277–613.
12. Natural Environment Research Council, *Proposed Construction of Airstrip at Rothera Point, Antarctica—Final Comprehensive Environmental Evaluation* (Natural Environmental Research Council, Swindon, 1989), 56pp.
13. Anon, *New Scient.*, No. 1651, 31 (1989).
14. M. C. Kennicutt II and S. T. Sweet, *Mar. Pollut. Bull.*, **25,** 303–306 (1992).
15. Z. A. Eppley, *Mar. Pollut. Bull.*, **25,** 307–312 (1992).
16. R. Laws, *New Scient.*, No. 1762, 4 (1991).
17. C. F. Boutron and E. W. Wolff, *Atmos. Environ.*, **23,** 1669–1675 (1989).
18. E. D. Suttie and E. W. Wolff, *Tellus*, **44,** 351–357 (1992).
19. E. Bacci, D. Calamari, C. Gaggi, R. Fanelli, S. Focardi, and M. Morosini, *Chemosphere*, **15,** 747–754 (1986).

20. R. E. Cameron, F. A. Morelli and R. M. Johnson, *Antarct. J. U.S.*, **7**, 187–189 (1972).
21. R. E. Cameron, R. C. Honour and F. A. Morelli, in: *Adaptations within Antarctic Ecosystems* (G. A. Llano, ed. Smithsonian Foundation, Washington D.C., 1977) pp. 1157–1176.
22. M. A. Champ, D. A. Flemer, D. H. Landers, C. Ribic and T. DeLaca, *Mar. Pollut. Bull.*, **25**, 220–226 (1992).
23. P. Mineau, G. A. Fox, R. J. Norstrom, D. V. Weselof, D. J. Hallett and J. A. Ellenton, in: *Toxic Contaminants in the Great Lakes* (J. O. Nriagu and M. S. Simmons, eds. J. Wiley and Sons, New York, 1984) pp. 426–452.
24. W. Davison, *N. Z. Antarct. Rec.*, **10** (2), 7–8 (1990).