SCIENCE AND ENVIRONMENTAL MANAGEMENT IN THE McMURDO DRY VALLEYS SOUTHERN VICTORIA LAND, ANTARCTICA

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Scientific research is the principal human activity in the McMurdo Dry Valleys. Concerns have been expressed recently that with an increasing level of activity, and the advent of tourism into the region, there is a need for more formal approaches to environmental management. A recent National Science Foundation workshop called for developing a management plan, utilizing zoning to manage human uses, and for developing a Geographical Information System to archive and make accessible an up-to-date record of environmental data for the area. The support of the science community for these proposals is critical to sustain the long-term scientific and environmental values of the region.

This article was first published as: Harris, C.M. 1998. Science and environmental management in the McMurdo Dry Valleys, Antarctica. In Priscu, J. (ed) *Ecosystem Processes in a Polar Desert: the McMurdo Dry Valleys, Antarctica*. Antarctic Research Series, Vol. 72, American Geophysical Union, Washington.

INTRODUCTION

Scientific research and its associated logistic support is the principal human activity in the McMurdo Dry Valleys. As the papers in this volume illustrate, extensive research has been undertaken in a wide range of disciplines in the dry valleys over the last 40 years, especially by United States and New Zealand scientists [*Hatherton*, 1990]. Scientists generally access the region from McMurdo Station (United States) or Scott Base (New Zealand), located on Ross Island some 80 km distant from the dry valleys (Figure 1). The level of research activity has increased since 1993 with the selection of the McMurdo Dry Valleys as a site in the United States National Science Foundation (NSF) Long Term Ecological Research (LTER) Program [*Wharton*, 1993]. In recent years Italy also has become more actively engaged in scientific research in the area, and the first visit by tourists to the Dry Valleys was in 1993 [*Vincent*, 1996].

The environment of the dry valleys has extremely high, internationally significant, scientific, environmental, aesthetic and wilderness values. The environment is sensitive to human impact, and has a low capacity to absorb and recover from changes. Biological growth-rates in the cold desert environment are slow, and landscapes have evolved over many thousands of years. Much of the scientific value of the McMurdo Dry Valleys derives from the fact that the environment has been relatively undisturbed by human activity. The increasing level of activity and an appreciation of the ease with which the unique environment and scientific values can be disturbed has led to new initiatives to manage better both science and the environment in the region. This heightened awareness culminated in a workshop, sponsored by the NSF and held in Santa Fe, New Mexico in March 1995, to discuss central environmental issues in the dry valleys [*Vincent*, 1996]. The Santa Fe workshop concluded that there is a need for more formal and coordinated approaches to management to ensure long-term sustainability of scientific and environmental values.

This paper aims to summarize important issues and potential problems arising from the multinational activities in the dry valleys, necessarily drawing on the findings of the Santa Fe workshop [*Vincent*, 1996]. The views expressed, however, are of the author and not necessarily those of Santa Fe workshop participants, nor those of the national programs operating in the area.

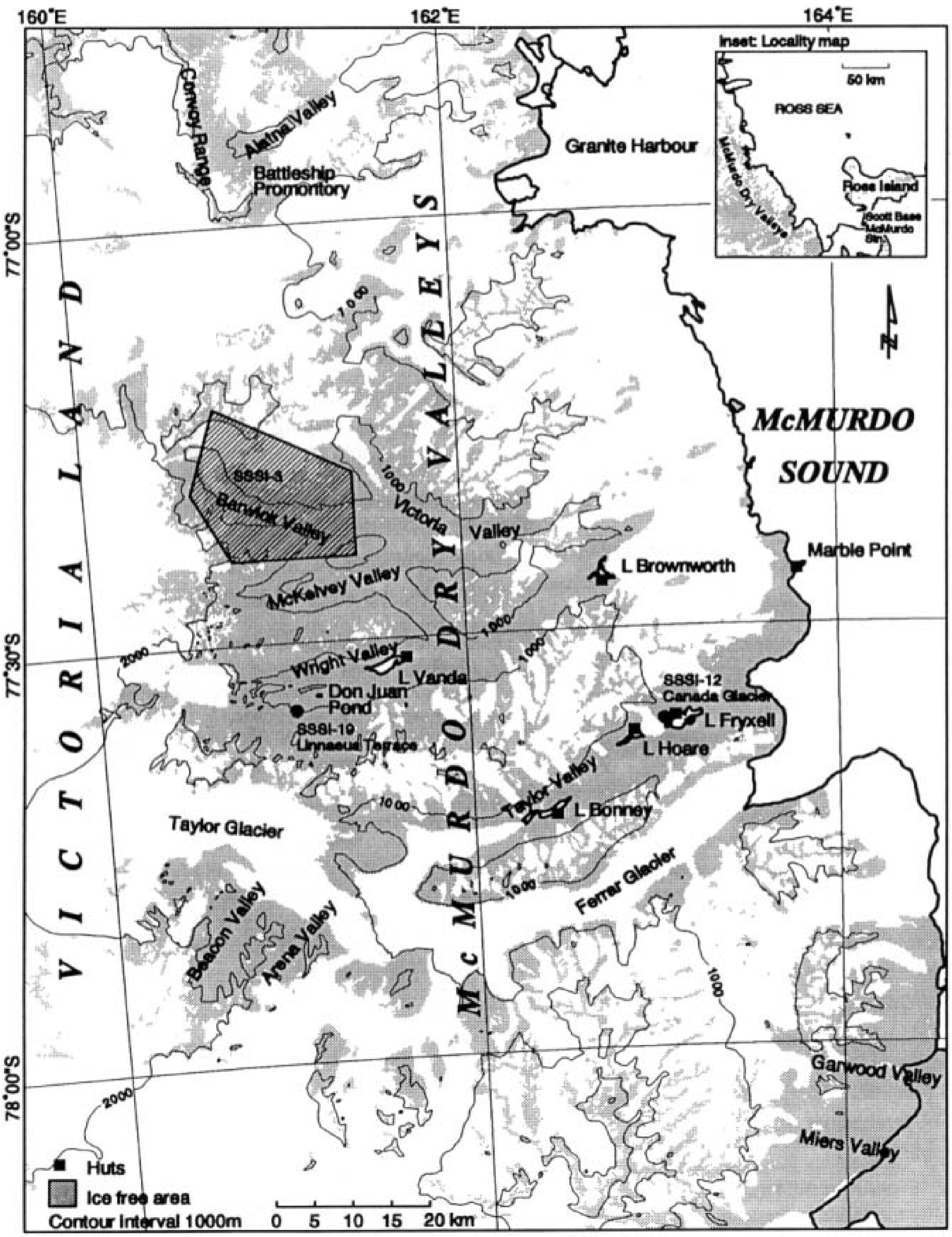
EXISTING MANAGEMENT INSTRUMENTS AND MECHANISMS

In 1991 the Antarctic Treaty Parties agreed the Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol), which rationalized existing rules and provided a new framework for more comprehensive approaches to environmental management in Antarctica. As of April 1997 ratification of the Madrid Protocol was required by two of the 26 states party to its negotiation for it to come into full international legal effect. These states are expected to ratify in the near future and most countries have already begun to implement Madrid Protocol provisions as though the agreement is in force. The Madrid Protocol provides a range of mechanisms for environmental management and those of most relevance to this paper are those on environmental impact assessment and on the protection and management of special areas.

Under the Madrid Protocol, all activities must be assessed for their potential environmental impacts before taking place. If it is concluded at the "Preliminary Stage" of assessment that the impacts will be "less than minor or transitory" then the activity can proceed. Otherwise, an Initial Environmental Evaluation (IEE) must be prepared, which must include detail sufficient to assess whether impacts are likely to have more than a minor or transitory impact. If the impact is expected to be more than minor or transitory, the Madrid Protocol requires that a Comprehensive Environmental Evaluation (CEE) be prepared.

The formal mechanism in the Madrid Protocol providing for strictest control of activities is the Antarctic Specially Protected Area (ASPA), which will replace the existing Sites of Special Scientific Interest (SSSIs) and Specially Protected Areas (SPAs) that are more well-known to Antarctic scientists today. These designations provide for special protection of either sites of long-term special scientific interest or examples of unique or outstanding features and ecosystems in Antarctica. Revision of management plans for existing SSSIs and SPAs so they comply with the provisions in the Madrid Protocol has already been initiated by a number of countries [*Harris*, 1994a]. A second management mechanism is provided in the Madrid Protocol to assist coordination in areas where there is a risk of mutual interference or cumulative environmental impacts or where there is a need to minimize environmental impacts but not necessarily impose such stringent conditions as within an ASPA. This is called an Antarctic Specially Managed Area (ASMA) and replaces the old Multiple-Use Planning Area, which thus far has not been extensively applied. Both the ASPA and ASMA require management plans, but a key difference between them is that the former requires a permit for entry while the latter does not. ASPAs can be contained within ASMAs, but not vice versa.

Figure 1. The McMurdo Dry Valleys region, showing the principal ice-free area, protected areas, and research hut locations.



ACCESS TO AND MOVEMENT WITHIN THE MCMURDO DRY VALLEYS

Access to the region is principally by helicopter from Ross Island, although a small number of parties may travel over sea ice to the Southern Victoria Land coast and then proceed on foot (Figure 1). Some wheeled vehicles were used in the region in the 1960s and 1970s, but this practice has been discontinued. The only land vehicles now in use are small all-terrain vehicles used to assist lake research programs, and these are not used on ice-free ground.

Helicopter traffic in the dry valleys over the summer period is frequent and may consist of several aircraft operating on a daily basis [*Harris and Croteau*, 1996]. There was a 30% increase in the number of helicopter hours flown in the region between 1974 and 1994 (from 636 to 822 hours) [*Vincent*, 1996]. Most flight activity is in the Taylor Valley, although flights are wide-ranging through the region to support the variety of science projects and visits by officials and the media. On-board helicopters operating from cruise ships have made tourist access possible in recent years, but thus far the number of flights has been low. Landing pads have been marked at most permanent field camps, and at two of the three designated protected areas in the dry valleys (at Canada Glacier and Linnaeus Terrace) where landings are restricted to specific sites. The current management plan of the third protected area (Barwick Valley) states that helicopter access into this area should be avoided (Figure 1). Air routes through the dry valleys are otherwise unrestricted and there are no other permanently designated landing sites, although there are a number that are informally marked.

Foot travel within range of the permanent and temporary camps and landing sites is the other main form of access around the dry valleys. In some places, foot prints have been observed to remain in soils for many years, while at others they disappear rapidly in the strong winds. At this time there are no formally designated foot trails in the region, although in a few places traffic has been sufficient to develop effectively permanent tracks over ice-free ground (e.g. the route to a stream weir from the Lake Fryxell Hut to Canada Stream, which is now being proposed as a designated route in the new management plan prepared for the Canada Glacier protected area (Figure 1) [*Harris*, 1994b; *MFAT*, 1997]).

FIELD CAMPS

Seven semipermanent scientific field camps are located in the McMurdo Dry Valleys, five of which are in Taylor Valley where the majority of LTER work is being conducted, and a permanent helicopter refuelling facility is located at Marble Point (Figure 1). The Taylor Valley camps are the most substantial, each consisting of a mess building, several research huts and accommodation / tent space for about 15 workers. Both semipermanent and temporary field camps may be established anywhere within the dry valleys outside of the protected areas subject to prior environmental impact assessment. Tourist groups have generally not yet established camps.

WASTE MANAGEMENT

Waste disposal regulations in the McMurdo Dry Valleys have always been comparatively strict, and general practice has been to remove most solid wastes since regular research began in the region in the 1960s. Some human wastes were incinerated in propane-fuelled combustors at several of the semipermanent camps, but this practice was discontinued in the dry valleys in 1996. In the past, some domestic liquid wastes were discarded at field camps, but this practice has also been discontinued. Where this had occurred at New Zealand's Lake Vanda Station, affected soil had to be removed because rising lake levels threatened to inundate the site and lead to contamination of the pristine lake waters [*NIWA*, 1993]. The old Vanda Station has been decommissioned and a smaller camp established at another site several hundred meters from the lake.

Over time, rules have become more stringent, and the United States for example has had a policy of waste removal at all locations, including the dry valleys, since 1993. The United States and New Zealand have agreed a consistent policy on waste disposal in the dry valleys based on the "Code of Conduct" presented below. The general policy is that all solid and liquid wastes, including all human wastes and water used for any human purpose (including scientific sampling from lakes) are to be removed from the area. This includes human waste generated away from field camps, which must be containerized and returned for disposal. Because all wastes are now transported out of the region, considerable effort is made to minimize the amount generated by field parties.

FUEL AND MATERIALS MANAGEMENT

Fossil fuel is used for three main purposes in the McMurdo Dry Valleys: for aircraft, heating/cooking and powering equipment. A light diesel (JP8) is used in aircraft and for power and heating, while gasoline is used for equipment such as generators, augers, and the all-terrain vehicles used on the lakes. Propane, gasoline ("white gas"), or kerosene may be used for cooking. As helicopters are generally refuelled outside of the dry valleys at nearby Marble Point, the amount of fuel actually transported into and stored in the dry valleys is relatively small and localized at camps. Occasionally drums may be carried aboard aircraft or cached for refuelling in the field.

The most substantial fuel spill event known in the dry valleys occurred when an air drop of JP8 to Vanda Station in 1984 ruptured on landing on the lake ice; the resulting spill was burned and contamination of the lake was thus minimized. Light diesel was used as a drilling fluid in the 1970s Dry Valley Drilling Project (DVDP), and a number of releases were reported, together with other forms of contamination [*Parker et al.,* 1978]. Significant spills are now required to be reported, but, with the exception of the records kept of the DVDP, information on past activities and effects is contained in voluminous field party reports and has yet to be researched and described. Minor spills occur in routine engine or other refuelling operations, and small quantities of fuel are ejected from fuel lines in some helicopters when engines are turned off.

Camp and scientific equipment and building materials are at risk of dispersal in the prevailing winds common in the dry valleys, and foreign materials occasionally escape into the environment. Special measures are required to ensure materials are held secure.

IMPACTS FROM SCIENCE

Any scientific activity results in impact, and the range of possible impacts is diverse. The *SCAR/COMNAP* [1996] workshops on environmental monitoring identified those activities and "outputs" most likely to result in "significant" environmental impacts in Antarctica (Table 1), and this is a good summary of the types of concerns important to planning a science program in the McMurdo Dry Valleys.

In relation to the collection and removal of samples in the course of research, science groups working in the dry valleys have often developed specific codes of practice to avoid detrimental effects. For example, liquid lake water samples are not emptied at the surface, as they once were, to avoid "contamination" of surface ice and underlying liquid water properties. In the case of soil excavations, some scientists replace soil layers in the order that they were removed so that sub-surface sediments are not subsequently dispersed by wind [*Campbell et al.*, this volume]. However, measures have been inconsistently applied and it is not difficult to find evidence of former camp or scientific activity.

The impacts of research activities in the dry valleys, while diverse, may still be considered as relatively localized and of limited scale and duration [*Vincent*, 1996], although as noted above a thorough assessment and inventory of actual impacts has never been undertaken. While it is true that science projects have undoubtedly had their impacts, most of the dry valley region might still be considered close to an undisturbed state. Away from the immediate environs of permanent camps signatures of global pollutants are probably more likely to be detected than local.

MANAGING TOURISM

Tourist visits to the McMurdo Dry Valleys are a recent phenomena and have been facilitated by a single helicopter-capable Russian icebreaker, *Kapitan Khlebnikov*. A total of 715 people have visited on seven tours to Taylor Valley since 1993 (Table 2), each tour lasting, on average, a total of about 6.6 hours. All tourist visits have been to the Taylor Valley, which is also the current region of most intensive scientific use. All visits are supervised by tour staff and by an independent observer from one of the national programs. However concerns were expressed by some scientists when initial landings by tour groups were near research sites. Informal agreement has now been reached between the tour operator and national programs on suitable landing areas in the lower Taylor Valley to avoid possible conflicts of interest. Legally, however, tour operators may visit other sites if they wish, provided these are outside of formally protected areas where permits for entry are required.

As the length of tours is short, with individual passengers having only a few hours on the ground, there is currently little opportunity for tourists to move far beyond the initial point of landing. Tour operators and the national programs take steps prior to visits to educate tourists on the fragile nature of the dry valleys, the importance of the scientific programs, on specific prohibitions (e.g. waste disposal) and provide them with a summary of the adopted "Code of Conduct" presented below. Under these circumstances, waste disposal issues are generally limited to accidental loss of wrappers (e.g. film, food) and perhaps the need by some for urination. The principal impacts for this type of tour are likely to be related to foot traffic, possible disturbance of geological, biological, or scientific features of value, and emissions and spillages from helicopters. Visits are presently targeted at sites where impacts are expected to be minimal.

Table 1. Outputs resulting from human activities in Antarctica and principal physical and chemical indicators of their impact (source: *SCAR/COMNAP*, 1996)

Outputs	Indicators	Possible impacts
Air emissions	• SO_2, NO_x, CO, PAH, heavy metals, fuel consumed • type, quantity, timing, duration	landscape, biological change
Dust	• particulates, albedo, water turbidity • type, quantity, timing, duration	landscape, biological change
Liquid waste (including brine)	• flow rate, suspended solids, BOD pH, fecal coliforms, nutrients (PO_4, NO_3, NO_2, NH_4) TKN • type, quantity, timing, duration	biological change
Solid waste (including dumps and debris)	• leachates, foreign materials • type, quantity, timing, duration	landscape, biological change
Fuel / hazardous materials (including fuel blowdown)	• PAH (air, water, land/snow), albedo, chemicals, radionuclides etc. • type, quantity, timing, duration	landscape, biological change
Noise	• type, quantity, timing, duration	biological change
Electromagnetic radiation	• type (frequency), quantity (strength) timing, duration	biological change
Mechanical actions, Constructions, (excavations, fill, explosions, compaction)	• topography, erosion, deposition, vehicle/foot traffic, albedo • type, quantity, timing, duration	landscape, biological change
Heat	• temperature, thermal regime • timing, duration	biological change
Introductions, Sampling, Extractions, Relocations	• alien biota, geological / biological specimens, snow/ice/water levels • type, quantity, timing, duration	landscape, biological change

1. Biological change covers all changes to individuals, populations and communities. Habitat disruption is covered under both landscape and biological change. Biological indicators are not included in the table. Aesthetic / wilderness disruption and changes to scientific capability are possible impacts that apply to all categories
2. Definitions (*SCAR/COMNAP* ,1996, p.*x*): "outputs" : "any physical change (e.g. movement of sediments by vehicle traffic, noise) or an entity (e.g. emissions, an introduced species) imposed on or released into the environment". The factors measured to assess the level of output are considered "indicators", while the "impact" is the consequence of the change (e.g. a reduction in nematode populations).

Table 2. Tourist visits to the Taylor Valley, McMurdo Dry Valleys, 1993–96.

Tour Date	Passengers	Duration of visit (hours)
Feb 10, 1993	106	8
Feb8, 1994	104	8
Jan 11, 1995	112	8
Feb 3-4, 1995	105	4
Feb22, 1995	96	5
Jan 19, 1996	105	6.5
Feb17, 1996	116	7
Total	744	46.5
Average per visit	106	6.6

Data source: D. Schoeling and E. Waterhouse [*Vincent*, 1996].

PROTECTED AREAS

Existing protected areas in the McMurdo Dry Valleys are summarized in Table 3 and shown in Figure 1. The Barwick Valley (SSSI–3) is the largest of the protected areas in Antarctica and was designated in 1975 on the grounds that it is one of the least disturbed and contaminated areas in the McMurdo Dry Valleys. As such it was considered valuable as a reference against which changes in other regions of the dry valleys being subjected to greater levels of activity could be compared. During a brief visit in December 1993 to assess management issues in the protected area, a number of signs of early scientific activity were observed, including evidence of old camp sites, soil pits, remains of a wooden crate, and a broken food cache partly submerged in Lake Vashka [*Harris*, 1994a]. Much of this material was subsequently removed, although the extent of contamination of Lake Vashka remains unknown. Despite this evidence of localized disturbance, there have been only a small number of visits to the area since it was designated for protection.

Table 3. Existing protected areas in the McMurdo Dry Valleys.

Site	Location	Approx. area (ha)	Main purpose
Sites of Special Scientific Interest			
SSSI 3	Barwick Valley, Victoria Land	30,000	Dry valley ecosystem reference site
SSSI 12	Canada Glacier, Taylor Valley	100	Preserve terrestrial plants and ecosystem
SSSI 19	Linnaeus Terrace, Asgard Range	300	Cryptoendolithic communities
Specially Protected Areas			
None.			

Linnaeus Terrace (SSSI–19) is located in the Asgard Range above the South Fork of the Wright Valley at an elevation of about 1650 m (Figure 1). The site is one of the richest localities for the cryptoendolithic communities in the Beacon Sandstone, was the site of the original detailed Antarctic cryptoendolithic descriptions and is considered a type locality with outstanding scientific values related to this ecosystem. The sandstones exhibit a range of fragile biological and physical weathering forms, and damaged rock surfaces would be slow to recolonize. Impact at Linnaeus Terrace is low, and the science groups working there have generally been meticulous in their efforts to minimize disturbance. However, even here impacts are present in the form of rock surfaces broken by trampling, sites affected by early waste disposal practices when urine was not retrograded for disposal, and through the release of the carbon-14 radioactive isotope as part of research experiments [Friedmann, personal communication, 1994]. The radioisotopic contamination is considered insignificant in terms of impact on the environment, but it has rendered the small area affected (<100x100 m) unsuitable for radiocarbon dating, compromising the scientific value of the locality. This illustrates how significant impact may result even from the most careful of field studies.

Canada Glacier (SSSI–12) is located on the north shore of Lake Fryxell and an adjacent area of land was designated in 1985 to protect some of the richest plant growth (bryophytes and algae) in the Southern Victoria Land dry valleys (Figure 1). Most biological growth occurs in a flush area close to Canada Glacier and extends along the small meltwater stream (Canada Stream) draining into Lake Fryxell. Three moss species have been identified in the area [*Schwarz*, 1990]: *Bryum argenteum*, *Bryum pseudotriquetrum* and *Pottia heimii*. Lichen growth is inconspicuous, but a number of epilithic and chasmoendolithic species may be found [*Schwarz et al.,* 1992]. Over 37 species of freshwater algae and invertebrates from six phyla have been described at the site [*Broady*, 1982; *Schwarz*, 1990]. Weirs have been built on Canada Stream to quantify water flows through the area [*von Guerard et al.,* 1994]. The Canada Stream drainage area has been well-studied and documented, which adds to its scientific value. However, the biological communities are fragile and vulnerable to disturbance by trampling, sampling, pollution, or alien introductions. The site is of limited extent and has been subjected to increasing pressure from scientific and logistic activities. Evidence of human activity in the area includes footprints in the soft sediments and in moss beds, foot trails, abandoned markers, litter blown in from nearby camps, soil pits, cores extracted from moss turfs, and paint applied as markers on rocks. Ironically, sites damaged at known times in the past have been identified and provide one of the few areas in the dry valleys where the long-term effects of disturbance, and recovery rates, can be measured. A research hut facility was present within the area for more than a decade, but this was removed in 1995–1996 and steps were taken to remediate visually obvious impacts at the same time. The new draft management plan for the region encourages scientists to locate their camps outside of the protected area and contains more stringent conditions on the conduct of scientific activities in the area, including sampling, constructions and the use of chemicals and isotopes [*MFAT*, 1997].

MONITORING

A comprehensive analysis and review of the requirements for monitoring of environmental impacts arising from science and operations in Antarctica was recently undertaken through two workshops held by *SCAR/COMNAP* [1996]. The final report concluded that environmental monitoring should be hypothesis-driven and tied to an environmental management strategy. The principal objectives of monitoring were considered to be (1) the protection of the scientific value of Antarctica, (2) to improve environmental management, and (3) to meet legal requirements under the Madrid Protocol and national legislation [*SCAR/COMNAP*, 1996]. More specific goals were as follows:

1. establish the present status of key values or resources;
2. provide early warning of deterioration in key values or resources;
3. identify activities most responsible for deterioration;
4. evaluate current activities with a view to avoiding or mitigating deterioration;
5. verify the effectiveness of predicting impacts through the EIA process.

National programs have conducted specific assessments of impacts and monitored environmental performance of science and tourist groups, but at present there does not exist a formal, internationally coordinated framework and strategy for monitoring of human impacts in the McMurdo Dry Valleys.

MANAGING CUMULATIVE IMPACTS

Cumulative effects can be characterized as impacts on the natural and social environments from single or multiple sources which occur so frequently in time or so densely in space that they cannot be "assimilated", or that combine with effects of other activities in a synergistic manner [Sonntag *et al*., 1987 cited in *Martin*, 1991]. A cumulative impact may be additive or interactive (e.g. synergism, antagonism, biomagnification). The presence of multiple research programs from a number of countries creates a context where cumulative impacts may be particularly hard to address, and may need proactive approaches to management.

INFORMATION MANAGEMENT

Access to a reliable base of information is essential to sound environmental management. Geographical Information Systems (GIS) and Global Positioning Systems (GPS) technologies, with their ability to tie multiple data sets to a common framework spatially and temporally, were viewed at the Santa Fe workshop as essential to establishing an efficient environmental information base. It was concluded a system-wide GIS for the McMurdo Dry Valleys should be established [*Vincent*, 1996].

A project recently funded by NSF promises to expand current McMurdo Dry Valleys GIS capabilities through an investigation of recent environmental change using satellite imagery and aerial photography [Prentice, personal communication, 1996]. The project will incorporate data layers on glaciology, hydrology, geology, and sedimentology into a GIS framework at several spatial scales. When completed, this database will be made accessible to the research community. It is expected that these data will also represent a valuable resource for managers and those conducting environmental impact assessments.

GIS vendors have been quick to see the potential of the Web to enable improved access, integration, and query of spatially referenced data, and several now offer interfaces to the Web from the GIS software. This type of approach is particularly valuable in contexts where there are a number of groups from a range of disciplines and countries that would benefit from a mutually shared base of environmental data, such as we see in the dry valleys.

CODE OF CONDUCT FOR ACTIVITIES IN THE MCMURDO DRY VALLEYS

A draft environmental Code of Conduct for field work was developed at the Santa Fe workshop based on the experience and input of a wide range of scientists and program managers with experience in the dry valleys [*Vincent*, 1996]. Following the workshop, the United States and New Zealand national programs refined and adopted a Code of Conduct for field work in the McMurdo Dry Valleys, which was implemented in the 1996–1997 season (the full New Zealand version is provided in Table 4) [Jatko and Waterhouse, personal communications 1996–1997]. The code formalizes and makes more accessible many of the approaches and procedures developed through experience by the national programs and the scientific groups working in the region. Management plans developed for ASMAs under the Madrid Protocol require the elaboration of a Code of Conduct for activities within the area designated, and the Code developed could easily integrate into a management plan.

DISCUSSION

In relation to procedures for environmental impact assessment of activities in the dry valleys, interpretation of which impacts are "minor" and "transitory" is presently made on a case-by-case basis by scientists and the national programs. How the terms are interpreted is important, because this will affect the type and perhaps quality of environmental assessment undertaken. In a multinational context such as the McMurdo Dry Valleys, a problem could emerge if there were inconsistencies in the rigor to which environmental assessments were prepared by scientists from different programs. Discussion toward consistent definitions is continuing in the context of Antarctic Treaty deliberations over liability for environmental damage. In present practice, programs exchange IEEs and CEEs to try and achieve a broad level of consistency in the application of EIA procedures. However, prior circulation of IEEs among potentially affected parties is not a requirement, although the Protocol does provide for circulation of lists of IEEs after they have been completed. There is no requirement or mechanism for the exchange of Preliminary Stage assessments, although it may be impractical and bureaucratic to exchange all such assessments. In relation to work in the McMurdo Dry Valleys, circulation of all IEEs before activities take place would be valuable and practical. There would also be value in regular exchange of sample "Preliminary Stage" assessments between national programs to help ensure a broad level of consistency.

The spread of impacts could be reduced by requiring scientists, wherever possible, to re-use previously impacted camp sites. However at present there is no accessible record, or register, kept of where field parties have previously camped or worked, and information on such sites is generally gained by word of mouth. With an increase in activity and a more multinational context there is need for a more effective means to access such information. The information currently exists in several forms and could be obtained from the reports filed to national programs by field parties or derived from helicopter flight schedules (which record numbers of people, flight destinations, and amount of equipment transported). This information should be placed in an accessible geographical database, as discussed below.

Many of the semipermanent camps in the dry valleys have been located adjacent to lakes (Fryxell, Hoare, Bonney, Vanda, Brownworth) for practical reasons related to research priorities and local terrain. Helicopter pads are sometimes immediately adjacent to the lake edge, taking advantage of suitable flat ground. The net result is that most of the traffic, food, wastes, and other materials transported into and out of the dry valleys is through these focal points close to the lakes. Dust disturbance, engine emissions, fuel spills, and loss or spill of other materials all occur most intensively and present the greatest environmental risks at these points. Moreover, many lake levels are rising, and several sites may be threatened with inundation within less than a few decades. Scientists and managers should question whether current camp and helicopter pad locations provide for long-term sustainability of the scientific and environmental values of the dry valleys lakes.

The network of protected areas in the McMurdo Dry Valleys has been developed partly in response to direct needs for protection from scientific pressure, in part to set aside a reasonably large area as a reference baseline and also to protect several sites for their outstanding qualities. However, a systematic assessment is needed of whether examples of the key environmental values of the dry valleys are being adequately represented within these areas, and whether there are sites of special significance at risk that are currently excluded. Several additional sites in the McMurdo Dry Valleys have been suggested as meriting special protection [*Keys et al*., 1988]. For example, Don Juan Pond in Wright Valley, was suggested because of its highly unusual hypersaline aquatic ecosystem, and Lake Vanda has also been suggested because of its unique properties, but the proposals have yet to be taken further. The only lakes currently under special protection are those within the Barwick Valley; other lakes in the dry valleys have quite distinct and unusual properties which may also warrant special protection. An outcrop of Beacon Sandstone at Battleship Promontory, near the Convoy Range and Alatna Valley (Figure 1), has been identified by Friedmann [personal communication, 1994] as richly colonized with the most diverse community of cryptoendolithic lichens known in Antarctica and exhibits unusual and fragile weathered landforms. Battleship Promontory is remote and inaccessible, and does not appear to be under immediate threat, but pro-active special protection would provide a safeguard to ensure the outstanding values of this site are maintained.

The permitting and reporting procedures required within protected areas represent important procedural tools for tracking human activities within these areas, thereby allowing more effective identification, assessment, and management of environmental impacts. The Scientific Committee on Antarctic Research (SCAR) has adopted a standard format for reporting visits to protected areas, which was recently endorsed by the Antarctic Treaty (*ATCPs*, 1995]. The format makes specific provision for reporting on, for example, sample quantities and locations, instrumentation or equipment installed or material released, observations of human effects, evaluation of whether the area is being adequately protected, and recommendations on further management measures needed. SCAR hopes that reports will help organize scientific use of the sites and provide the basis for evaluation of conservation practices and the effectiveness of management plans. Scientists should make use of this standard format when reporting their activities within protected areas.

Table 4. Code of Conduct for field work in the McMurdo Dry Valleys (source: *Antarctica New Zealand*).

Environmental Code of Conduct for
Field Work in the McMurdo Dry Valleys

Why are the Dry Valleys considered so important by the scientific community? The Dry Valleys ecosystem contains geological and biological features that date back thousands to millions of years. Many of these ancient features could be easily and irreversibly damaged by inadvertent human actions. Unusual communities of microscopic life forms, low biodiversity, simple food webs with limited trophic competition, severe temperature stress, aridity and nutrient limitations are other characteristics which make the Dry Valleys unique. This ancient desert landscape and its biological communities have very little natural ability to recover from disturbance. Research in such systems must always aim to minimise impacts on land, water and ice to protect them for future generations. This code suggests how you can help to ensure this.

General Conditions:
- Your visit to the valleys should have as little impact as possible. Everything taken into the valleys must be removed and returned to Scott Base. Do not dump any unwanted material on the ground.
- Activities which would result in the dispersal of foreign materials should be avoided (e.g., do not use spray paint to mark rocks) or conducted inside a hut or tent (all cutting, sawing and unpacking).
- Solar and wind power should be used as much as possible to minimise fuel usage.
- The location of any disturbance, spill, camp site, soil pit, or other sampling site should be mapped and recorded in your field report for eventual transfer to a management GIS. Where possible, the GPS coordinates of the site should be recorded.
- Water used for ANY human purpose must be removed or treated in a grey water evaporator.
- All human waste must be collected and removed.
- Do not leave any travel equipment behind (e.g. ice screws, pitons). Avoid building cairns.
- Ground vehicle usage should be restricted to snow and ice surfaces.
- When travelling on foot, stay on established trails whenever possible. Avoid walking on vegetated areas and delicate rock formations.

Field camps: location and set up
- Campsites should be located as far away as practicable from lake shores and stream beds to avoid damage or contamination. Do not camp in dry stream beds.
- Campsites should be re-used to the greatest extent possible. Before entering the Dry Valleys you should attempt to determine the location of previously used campsites in the area you are visiting.
- Ensure that equipment and supplies are properly secured at all times to avoid dispersion by high winds. High velocity katabatic winds can arrive suddenly and with little warning.
- Maximise the use of fixed helicopter pads. Use markers clearly visible from the air to mark pads.

Fuel and chemicals
- Take steps to prevent the accidental release of chemicals such as laboratory reagents and isotopes (stable or radioactive). Chemicals of all kinds should be dispensed over drip trays or other containment. When permitted to use radio-isotopes, precisely follow all instructions provided.
- Ensure spill kits are appropriate to the volume of fuel/chemicals and you are familiar with their use.
- Use fuel cans with spouts when refuelling generators and only refuel generators and vehicles over trays with absorbent spill pads.
- Never change vehicle oil except over a drip tray.

Sampling and experimental sites:
- All sampling equipment should be clean before being brought into the Dry Valleys.
- Do not displace or collect specimens of any kind, including fossils, except for scientific and educational purposes; in SSSIs or SPAs the sample size will be specified in your collecting permit.
- Once you have drilled a sampling hole in lake ice or dug a soil pit, keep it clean and make sure all your sampling equipment is securely tethered.
- Backfill soil pits to prevent wind erosion and dispersal of deeper sediments.
- Avoid leaving markers (e.g. flags) and other equipment for more than one season without marking them clearly with your event number and duration of your project.

Lakes:
- Clean all sampling equipment to avoid cross-contamination between lakes.
- Retain any excess water or sediment for removal to your station.
- Never use explosives on a lake.
- Only use vehicles on lake ice when essential; park the vehicle on permanent ice rather than moat ice during the period of summer melt.
- Ensure that you leave nothing frozen into lake ice which may ablate out and cause contamination.
- Avoid swimming or diving in the lakes. These activities could contaminate the water body and physically disturb the water column, delicate microbial communities and sediments.

Streams:
- Use designated stream crossing points whenever possible.
- Avoid walking in the stream bed at any time; you may disturb the stream biota which represent several decades of slow growth.
- Avoid walking too close to stream sides as this may affect bank stability and flow patterns.

Valley floor and sides:

- Avoid disturbing mummified seals or penguins.
- Avoid sliding down screes or sand dunes; these features have taken many thousands of years to form and may also contain surface deposits of major scientific importance.

High Desert:

- Beware of causing damage to delicate rock formations. Some of the biological communities in them have taken several thousand years to develop.
- Collect only the minimum sample of endolithic community required for scientific analysis.

Glaciers:

- Minimise the use of liquid water (e.g., with hot water drills) which could contaminate the isotopic and chemical record within the glacier ice.
- Avoid the use of chemical-based fluids on the ice.
- If stakes or other markers are placed on a glacier, use the minimum number of stakes required to meet the needs of the research; where possible, label stakes with your event number and project duration.

The lack of an internationally coordinated environmental monitoring framework or strategy to monitor human impacts in the dry valleys needs to be addressed. Scientists working in the McMurdo Dry Valleys should consider how their own research could contribute to the objectives of environmental monitoring as noted above and outlined in detail in the *SCAR/COMNAP* [1996] report. More specifically, an internationally coordinated network of spatially distributed monitoring sites, both near to and distant from the permanent field camps and in relation to known environmental conditions/ environments (terrestrial and marine), should be established in order to determine more precisely the nature, magnitudes, durations, and extents of impacts in the region. It would also be useful to establish a network of control sites in different environment types (e.g. glacial, ice-free valley floor, ice-free high desert, lake, and stream). Where possible, efforts should be made to integrate data from existing research sites. There may also be value in designating one or two long-term control (reference) areas where access is completely prohibited for some period, during which additional new impacts within the area(s) would be limited to those transported by more regional or global processes. To fulfil the role as a reference area effectively it may be necessary first to conduct a thorough baseline assessment.

In terms of cumulative impact, individually minor impacts may be of significance when accumulating over time or interacting synergistically. Cumulative environmental impacts are difficult to address under current models of environmental management in Antarctica, and the single-project based method of environmental impact assessment, in particular, is not designed to address such problems. The high level of coordination and information exchange required in the international context of operations in the McMurdo Dry Valleys represents a significant challenge to assess and minimize cumulative impacts. Because the range of cumulative effects can potentially be very large, and there are limited resources available for monitoring and assessment, there is a need to define appropriate study boundaries and effective indicators of environmental changes. There is also a need for appropriate biophysical characterizations against which change can be measured.

Some of the factors impeding environmental management in the dry valleys relate to the management of information. The Santa Fe workshop recommended a system-wide GIS be established for the region to marshal the environmental data needed for management. To some extent, the core of such a system already exists through efforts by the LTER, the United States Geological Survey, Land Information New Zealand and the International Centre for Antarctic Information and Research, but this needs to be developed further. A full and up-to-date register is needed of the sites of most significant value. Moreover, there is need for an inventory of the past effects of human activities on the environment (e.g. impacts resulting from the Dry Valley Drilling Project) before this information is lost. Scientists should consider it their responsibility to plan data collection and report locations of campsites, sampling, and environmental impacts, so that additional benefit might be gained from their data when it might eventually be incorporated into such a system-wide GIS.

For efforts toward a McMurdo Dry Valleys GIS to be fully effective, it is important that current errors in the geographical reference datum in the region are corrected. A program of field work funded by the United States and New Zealand in 1996–1997 is expected to result in this correction, and the data gathered will be used to apply corrections to existing digital geographical data sets so they all sit on a reliable, GPS-compatible, reference framework. This is important if data being collected in the dry valleys using GPS are to be incorporated meaningfully into an underlying map framework. Once corrected, it is important that all scientists working in the region use the corrected base map so that all observations are made using the same consistent and accurate geographical datum; this would simplify the process of integration of spatially referenced data from disparate sources so often necessary in multidisciplinary science and for impact assessments.

The recent advances in information and communications technology have enabled effective real-time access to remote databases, even from the McMurdo Dry Valleys. Access to GIS over the World Wide Web offers the potential to operationalize an environmental information system that could be shared internationally in support of science and management in the dry valleys. Such a system could enable access to a common information base for management by national programs, both in home countries and at stations in Antarctica, and provide scientists with access to a base of environmental data both in their institutions and in the field. This type of information system would be invaluable in support of a management plan for the region and would assist many forms of science.

CONCLUSION

Science conducted in the dry valleys, as illustrated within this volume, is vital to understanding fundamental questions related to the structure and functioning of environmental processes. Much of the research being conducted is critical to understanding questions related to global change and also the nature of life in an unusual environment at the extremes of existence on Earth. It is important that this science continues and that it is not unduly constrained by environmental regulation. It is equally important that the scientific values of the unique region are safeguarded, and that the region is managed so that its environmental, aesthetic, and wilderness values are sustained for future generations.

The NSF workshop on environmental management in the McMurdo Dry Valleys [*Vincent*, 1996] concluded there is a need for more formal and coordinated approaches to management to sustain the long-term scientific and environmental values in the region. The workshop concluded that current approaches have "failed to deal with longer term degradation processes in the valleys associated with the continuing proliferation of camp and sampling sites" [*Vincent*, 1996; p.18] and that a management plan should be formulated for the region. The workshop recommended this plan incorporate appropriate zones to accommodate different activities and intensities of use. A management plan would provide a clearer basis for operations and make it easier for scientists to plan their activities with information sufficient to minimize and avoid environmental impacts. It would also assist coordination between scientific groups from different disciplines, and facilitate greater international cooperation, thus helping to minimize conflicts of interest between research groups. For the management plan to be effective a reliable and accessible base of environmental information would need to be developed and maintained. Development of the system-wide GIS for the McMurdo Dry Valleys suggested by the Santa Fe workshop would help meet these needs.

The national programs working in the region are taking steps in this direction, and the science community should give these initiatives their full and continued support.

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