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INTRODUCTION

We propose the establishment of a Long Term Ecological Research (LTER) site for the Taylor Valley in the McMurdo Dry Valleys of southern Victoria Land, Antarctica (Fig. 1). Although known for its massive ice coverage, Antarctica also has ice-free regions. The term "dry valleys" derives from the deeply-incised, relatively ice-free valleys located near the coast. The McMurdo Dry Valleys are the largest of these ice-free areas (~ 4800 km2) and are located on the western coast of the Ross Sea (77o00'S, 162o52'E) approximately 100 km west of the USA scientific base, McMurdo Station (Fig. 1). The McMurdo Dry Valleys are among the most extreme deserts in the world; far colder and drier than any of the established LTER sites (Fig. 2). The perennially ice-covered lakes, ephemeral streams, and extensive areas of soil within the valleys are subject to low temperatures, very limited precipitation and salt accumulation.

Figure 2. Approximate mean annual temperature (annual precipitation (cm) for LTER sites: a. Taylor Valley, b. Jornada, c. Toolik Lake, d. Sevilleta, e. Bonanza Creek, f. CPER, g. Cedar Creek, h. North Temp Lakes, i. Konza, j. Kellog, k. Niwot Ridge, l. Barrier Islands, m. Harvard Forest, n. North Inlet, o. Hubbard Brook, p. Coweeta, q. Luquillo Forest (400 m), r. HJ Andrews, s. Luquillo Forest (750 m).

The biological systems in the McMurdo Dry Valleys are relatively simple. For example, there are no vascular plants or vertebrates and very few insects (Table 1). Trophic interactions and biogeochemical nutrient cycles are largely limited to microbial populations and micro-invertebrates. Species diversity and abundance are low as would be predicted for such extreme environments. Despite this simplicity, complex interactions among species and between the biological and physico-chemical environment exists in the lakes, streams and soils. Furthermore, interactions between various components of the ecosystems enhance the overall productivity of the dry valley landscapes (Table 2).

Table 1. Presence of some major groups of organisms in McMurdo Dry Valley ecosystems.

Group	Lakes	Streams	Soils
Heterotrophs:			
Bacteria	+	+	+
Fungi	+	+	+
Protozoa	+	+	+
Rotifers	+	+	+
Tardigrades	+	+	+
Nematodes	+	?	+
Acari	-	-	*
Crustaceans	-	-	-
Insects	-	-	*
Mollusca	-	-	-
Oligochaeta	-	-	-
Vertebrates	-	-	-
Autotrophs:			
Bacteria**	+	?	?
Cyanobacteria	+	+	+
Algae	+	+	+
Lichens	-	-	+
Bryophytes	-	-	+
Trachaeophyta	-	-	-

*only associated with mosses

** photosynthetic and nitrifying bacteria

Physical factors largely control biological processes in the dry valleys (Campbell and Claridge 1987). Stream ecosystems are controlled by the quantity and timing of glacial meltwater during the austral summer (October through February). Discharge from these streams and thickness of perennial ice cover are the primary factors regulating the lake environment. Soil communities are controlled by moisture availability, salt concentrations, and allochthonous carbon inputs. The most productive sites (aquatic) are those that are buffered from the most severe, short-term climatic fluctuations. Aeolian transport of organic carbon from these productive sites may form the base of the food chain on the most exposed sites (terrestrial soils). In turn, nutrients are carried by water and wind from glaciers and soils to the streams and lakes.

Table 2. Material transport between McMurdo Dry Valley ecosystems.

Recipient Ecosystem:	Donor Ecosystem: Lakes	Streams	Soils
Lakes	-	water, sediments, solutes	sediments, solutes
Streams	organic matter (?)	-	sediments, solutes
Soils	organic matter	organic matter	-

All ecosystems are shaped to varying degrees by climate and material transport, but nowhere is this more apparent than in the McMurdo Dry Valleys. The obvious effects of an extreme environment coupled with the general simplicity of ecosystem structure makes the McMurdo Dry Valleys an ideal location to study these basic relationships. We present two central hypotheses that embody this central theme.

HYPOTHESES

Our central hypotheses focus on the effects of physical constraints and material transport on Taylor Valley ecosystems. Although a number of specific corollaries are suggested by these hypotheses, we have chosen those that can be most practically addressed given the limited data presently available for these ecosystems and the considerable constraints imposed on research conducted in the McMurdo Dry Valleys (see p. 5).

Hypothesis 1. The structure and function of the Taylor Valley ecosystems are primarily controlled by physical constraints.

There is considerable day-to-day variability in temperature and irradiance of dry valley ecosystems during the austral spring, summer, and fall, which directly and indirectly affects biological activity. Low species diversity and simple trophic structure result in few biotic interactions and there are no vascular plants to provide a variety of microsites. Hence, microenvironments are primarily defined by physical factors. During mid-summer, temperatures hover near 0oC so that small temperature changes can be expected to have large effects on ecosystems via rapid phase changes between liquid water and ice. Changes in irradiance affect local energy budgets and primary production.

Corollary 1. The light regime controls the productivity in lake ecosystems.

Lake ecosystems are buffered against short-term temperature fluctuations, but are sensitive to changes in irradiance. This is because less than three percent of incident irradiance normally penetrates the perennial ice cover (3.5 - 4.0 m thick).

Corollary 2. Wind ablation and hydrologic regime control biomass and productivity of stream ecosystems.

Streams are intermittent, dry or frozen in winter and driven by glacial melt during the summer. Physical processes such as wind ablation when streams are dry and flood scouring control biomass in streams; whereas liquid water is essential for the inducement and maintenance of primary production.

Corollary 3. Moisture availability controls the productivity of soil ecosystems.

Precipitation in the dry valleys is virtually limited to winter snowfall (<10 cm water equivalent). Therefore, soils are extremely dry with moisture availability determined primarily by the erratic distribution of windblown snow.

Hypothesis 2: The structure and function of the Taylor Valley ecosystems are modified by material transport.

Biological activities of dry valley ecosystems are higher than expected, given the extreme climatic conditions. This may result from the transport of materials between ecosystems (Table 2). Glacial melt is the primary source of water to aquatic systems, carrying dissolved solutes and sediments from the glaciers and soils. In addition, high winds (up to 160 km hr-1) disperse sediments and organic materials throughout the valleys that variously affect recipient ecosystems.

Corollary 1. Productivity of lake ecosystems is modified by sediment inputs.

Sediments and nutrients are among the materials received by the lakes and provide substrate and nutrition for planktonic and benthic communities. Differences in deposition rates and chemical composition of sediments may affect colonization and productivity.

Corollary 2. Productivity of stream ecosystems is modified by the nutrient content of the water.

During the austral summer temperatures hover near 0oC and small changes in energy balance can produce large changes in glacial melt controlling stream volume. In turn, fluctuations in stream flow control the amount of nutrients available to stream communities.

Corollary 3. Productivity of soil ecosystems is modified by allochthonous inputs of organic carbon.

Cyanobacteria are some of the most common primary producers in the McMurdo Dry Valleys. Yet, there is little evidence to link the distributions of cyanobacteria and higher organisms (rotifers, tardigrades and nematodes). Aeolian transport of organic carbon may enhance productivity of soil systems.

PERSONNEL

We have assembled an interdisciplinary team of scientists to address these hypotheses. The majority have extensive field experience in the Antarctic and have made substantial contributions to our current understanding of the McMurdo Dry Valley ecosystems. The personnel consists of: Drs. Robert A. Wharton, Jr. (PI, limnology), Diana W. Freckman (soil ecology), W. Berry Lyons (geochemistry), Diane M. McKnight (hydrology), Daryl L. Moorhead (systems ecology), John C. Priscu (microbial ecology), and Cathy M. Tate (stream ecology).

CONSTRAINTS ON FIELD STUDIES

There are significant constraints on conducting field research in the Dry Valleys of Antarctica, which must be considered before a study can be developed. These limitations are imposed by: 1) climate, 2) logistics, 3) safety and 4) environmental impact. Constraints imposed by climate are most obvious; it's cold (-35o to ~0oC) and frequently windy during the austral summer (October-February). Weather is unpredictable and researchers can be stranded in the field for several days. In winter, extremely low temperatures and high winds make travel to and research in the McMurdo Dry Valleys impractical.

Logistical considerations begin with the long flight from the USA to New Zealand. A subsequent flight on a cargo plane ends on the sea ice at McMurdo Station. Delays can occur at anytime due to weather conditions. Once at McMurdo, a helicopter must be scheduled to fly approximately 100 km to Taylor Valley (weather permitting). Field conditions are primitive with facilities consisting primarily of tents and plywood shacks. No ground vehicles are available, so all supplies, equipment, samples, etc. must be carried to and from study sites.

Safety is a primary concern in field operations and creates some peculiar inconveniences. The potential for accidents always exists, for example, working in cold conditions on rocky terrain near glaciers and SCUBA diving below the ice in lakes have inherent risks. Taylor Valley is harsh, rugged and isolated, so that it is difficult to ensure timely aid to the injured. For these reasons, acceptable safety limits for field operations are dictated by the NSF Division of Polar Programs (Safety in Antarctica, NSF 1991).

The environmental impacts of field studies on the dry valleys is of increasing concern. The McMurdo Dry Valley LTER will be operating under a rigorous set of environmental impact constraints imposed by the National Science Foundation (Final Supplemental Environmental Impact Statement for the U.S. Antarctic Program, NSF 1991).

The collective experience of the authors totals 22 summers of conducting research in the McMurdo Dry Valleys. In our opinion, the field studies outlined in this proposal are within the guidelines for acceptable safety and environmental impact. These studies will meet the logistical and environmental criteria established for field parties in the Dry Valleys as well as satisfying the scientific requirements of an LTER site.

BACKGROUND

The McMurdo Dry Valley LTER will concentrate studies within the Taylor Valley (Fig. 3) during the first six years. This site was selected because: 1) Taylor Valley has been the site of several non-integrated ecological studies since the 1960's and is presently a focal point for terrestrial and limnetic research by the United States and New Zealand, 2) it is generally representative of all Antarctic ice-free areas, 3) it is within a reasonable distance from McMurdo Station (forty minutes by helicopter, weather permitting), and 4) it is large enough to contain three relatively large lakes, numerous streams and a variety of terrestrial ecosystems. Our efforts will focus on the integration of the biological processes within, and material transport between, the lakes, streams and terrestrial ecosystems comprising the Taylor Valley landscape.

Site Description

The McMurdo Dry Valleys were formed by the advances and retreats of glaciers through the coastal ranges of the Transantarctic Mountains, which rise several thousand meters above sea level and act as barriers to the flow of ice from the Polar Plateau. Glacial and periglacial features are a major component of the landscape. Taylor Valley, the site of our LTER, is approximately 33 km long by 12 km wide and contains three major lakes, Bonney, Hoare and Fryxell, fed by 15 glaciers (Fig. 4). The valley bottoms are predominantly glacial till and the higher slopes consist of granites, dolerites, sandstones and occasional volcanics. Rock outcrops are typically highly-weathered by the fohn winds. Outlet, piedmont and alpine glaciers drain from the Polar Plateau and cirques onto the valley floors. The dry valleys have been predominantly ice-free for the past 4 million years. The lakes in the Taylor Valley are the remnants of a much larger lake, Glacial Lake Washburn, that existed 10,000 - 24,000 years ago (Lawrence and Hendy 1989; Denton et al. 1989).

The McMurdo Dry Valley region was originally explored by members of Robert F. Scott's expeditions during the early 1900's (Scott 1905; Huxley 1913). For half a century after their discovery, the climate, geology, and biology of the dry valleys remained unknown (Parker et al. 1982A). It was not until the International Geophysical Year (1957-58) and the establishment of United States and New Zealand scientific stations on Ross Island that studies in the dry valleys resumed. Taylor Valley was discovered by Scott's expedition in 1901 and is one of ten valleys in this region.

The climate of the Taylor Valley is extreme. The annual precipitation is received as snow and averages < 10 cm yr-1 (Keys 1980). The low precipitation, low surface albedo, and dry fohn winds descending from the Polar Plateau result in extremely arid conditions (Clow et al. 1988). Mean annual temperature is ~ -20oC, average wind speeds are 5.0 m sec-1, mean relative humidities are < 50%, and solar flux (available energy) is < 100 W m-2 (Clow et al. 1988). This region of Antarctica has four months each of continuous sunlight followed by twilight and darkness.

Lakes

Compared to the terrestrial and stream ecosystems, the lakes in Taylor Valley have been well studied (Vincent 1988; Table 3). Their continual existence as ice-liquid water equilibria is the result of two climatic conditions: 1) mean summer temperatures are low enough that the winter accumulation of ice does not melt completely in the summer, and 2) meltwater from local glaciers resupply ablation losses from the lake surface (Wilson 1982; Clow et al. 1988). Water level is established by the balance between summer melting and annual ablation (Chinn 1985; Clow et al. 1988). The thickness of the ice cover is determined by the energy balance of the lake (McKay et al. 1985). The turnover times for solutes, dissolved atmospheric gases, water volume, and ice in these lakes are < 3000, 45, 50, and 10 years, respectively (Green et al. 1988, Wharton et al. 1989). Thus, the lake environment responds to changes on a 10-1000 year timescale.

Table 3. Physical and chemical features of Lakes Fryxell, Hoare, and Bonney. Ranges indicate values observed during the austral summer from the ice-water interface to the sediment-water interface (Parker et al. 1982a; Green et al. 1988).

	Fryxell	Hoare	Bonney
Surface Area (m2)	7.0 x 106	2.9 x 106	3.2 x 108
Volume (L)	4.3 x 1010	2.6 x 1010	6.0 x 1011
Ice Thickne(m)	4.5	3.5	4.0
Max. Depth (m)	18.5	34	40
Depth of oxycline (m)	9.5	28	20
PAR1 (mE m-2 sec-1)	19.5 - 0	10.4 - 0	91.0 - 2.6

% PAR	1.5 - 0	0.8- 0	7.0 - 0
Water Temperature (oC)	0 - +1.0	0 - +4.0	-2.0 - +7.0
Conductivity (mmhos cm^{-2})	500 - 8,600	400 - 800	500 - 156,000
pH	8.4 - 7.0	8.9 - 7.3	8.4 - 5.3
Diss O_2 (mg L^{-1})	41.9 - 0	52.1 - 0	45.8 - 0
AIC[2] (mM L^{-1})	6.67 - 60.17	0.67 - 6.50	0.8 - 61.2
NH_4^+ (mM L^{-1})	0.1 -> 7.1	0 -> 7.1	0 - 300
NO_3^- + NO_2^- (mM L^{-1})	0 - 0.3	0 - 3.5	4.5 - 178.2
PO_4^{-3} (mM L^{-1})	0.04 - 11.24	0.02 - 0.12	0.04 - 0.37

1 PAR = photosynthetically active radiation (400-700 nm wavelengths)
2 AIC = available inorganic carbon

Physico-Chemical

Despite the close geographical proximity of the three Taylor Valley lakes, marked differences occur in their temperature-depth profiles. Lake Hoare's water column is near 0oC. Lake Fryxell's water column temperature ranges from 0oC to +4.0oC, while the east lobe of Lake Bonney goes from 0oC immediately below the ice cover to +7.0oC at 15 m, then drops to about -3.0oC at 40 m.

Ice cover affects the quantity and spectral distribution of radiation reaching the underlying water (Ragotzkie and Likens 1964; Lizotte and Priscu 1992; Wharton et al. 1992a). From an ecological perspective, the penetration of photosynthetically active radiation (PAR; 400-700 nm wavelengths) depends on the general albedo and sediment cover, attenuation coefficient, thickness, and scattering properties of the ice. In Lake Hoare, spectral downwelling measurements showed that the full wavelength PAR beneath the ice was < 3 % of maximum incident surface PAR (Palmisano and Simmons 1987). Also, there are significant seasonal variations in the optical properties of ice (Goldman et al. 1967; Wharton et al. 1989, 1992a; Lizotte and Priscu 1992).

A unique feature of these lakes is the occurrence of supersaturated O_2 and N_2 in the upper portions of the water column, ranging from slightly over 400% and 160%, respectively. There are two primary sources of O_2: 1) gases carried into the lake by the meltstreams are forced into the water column when the water freezes onto the bottom of the ice cover, and 2) photosynthesis and loss of reduced carbon in the sediments (Wharton et al. 1986, 1987; Craig et al. 1992).

Although there are similarities between these three closed-basin lakes, each has a distinct water chemistry (Table 3). The three lakes represent a continuum of trophic status (Parker et al. 1982a) from ultra-oligotrophic (Lake Hoare) to eutrophic (Lake Fryxell). Lake Bonney, which is situated between Hoare and Fryxell in trophic status, has hypersaline bottom waters (i.e., salinity ~ 35%). Lake Fryxell has an intermediate salinity level and Lake Hoare is relatively fresh. Numerous other ions (e.g. Cl^-, Na^+, Mg^{+2}) show clearly different vertical patterns (Parker et al. 1982a; Green et al. 1988) and macronutrient chemistry varies between lakes (Gardner et al. 1984; Green et al. 1988). This chemical variation is thought to be due to both variations in stream chemistry input and in-situ lake processes (Green et al. 1988). In Lake Fryxell, an $N/P < 10$ at all depths suggests nitrogen is the limiting factor for microbial activity. Experiments utilizing 15N verified that microbial populations immediately beneath the ice were N-deficient (Priscu et al. 1989). In Lake Hoare, nitrogen is apparently deficient to 9 m ($N/P < 4.0$), however, N/P increased to 51 at 27 m (anoxic boundary) and then dropped to about 2 (Green et al. 1988). In Lake Bonney, shallow water microbial populations were also N-limited whereas those near the bottom of the trophogenic zone were not (Priscu, unpublished data).

Biological

The lakes have abundant planktonic and benthic microbial populations (Vincent 1987, 1988). The main phototrophs are cyanobacteria, phytoflagellates, non-flagellated chlorophytes, and in Lake Fryxell, purple sulfur bacteria. The phytoplankton and other microbial populations are typically stratified with depth, reflecting the hydrologic stability of the water columns (Parker et al. 1981, 1982a; Vincent 1981; Priscu et al. 1987,1989). Flagellates such as Cryptomonas and Chroomonas (Cryptophyceae), Ochcromonas (Chrysophyceae), Chlamydomonas , and Pyramimonas (Chlorophyceae) frequently form virtually unialgal layers (Vincent 1988). The lakes also contain heterotrophic bacteria, fungi, protozoans, rotifers, tardigrades and nematodes (Vincent 1988).

Microbial mats are abundant throughout much of the benthic regions of these lakes and are composed primarily of cyanobacteria (e.g. Phormidium, Oscillatoria, and Lyngbya), pennate diatoms, and eubacteria (Wharton et al. 1983). Many of these mats precipitate calcite, iron, and sulfur, and trap and bind sediments, forming alternating laminae of organic and inorganic material ("modern stromatolites"; see e.g., Parker et al. 1981; Wharton et al. 1982; Love et al. 1983). While there are differences in the relative abundances of the species which comprise microbial mats, the most interesting features are differences in mat morphologies within _ and between lakes. Species distribution and microbial mat morphologies may be dependent upon particular environmental conditions (Wharton et al. 1983; Simmons et al. 1992), as affected by local climatic variations and the nature of perennial ice cover (Wharton et al. 1992a).

Biological properties, such as phytoplankton abundance and depth distribution, chlorophyll a concentration, and primary production differ greatly between the Taylor Valley lakes (Simmons et al. 1992). For example, maximum chlorophyll a levels exceed 20 mg L-1 near the bottom of the trophogenic zone (~ 9.5 m) in Lake Fryxell, whereas the primary chlorophyll maximum (~ 2 mg L-1) occurs just beneath the ice of Lake Bonney with secondary maxima in the middle and near the bottom of the trophogenic zone (Priscu et al. 1987; Priscu, unpublished data). Maxima in primary productivity generally coincides with these biomass peaks. Such differences presumably reflect the physico-chemical properties of each lake since light penetration of the surface ice is similar (Vincent 1981; Priscu et al. 1987; Priscu 1989).

Material Transport

Gases, solutes and solids move through the ice in both directions. Microbial mats break free from the lake bottom, rise to the surface, are frozen into the bottom of the ice and eventually reach the ice surface by sublimation (Parker et al. 1982a). Gas and solutes are trapped as the ice forms at the ice-water interface and move upward in the same fashion (Craig et al. 1992). Cracks in the ice allow both gas exchange between water and atmosphere, and the downward transport of wind-blown sediment (Nedell et al. 1987; Wharton et al. 1989). At Lake Hoare, discrete piles of sediment occur on the lake bottom beneath cracks in the ice (Squyres et al. 1991). Surface ice melts around the periphery of the lake forming moats that allow deposition of wind-blown material and gas exchange.

Streams

Glacial meltwater streams flow intermittently during the austral summer when the area experiences continuous daylight. Stream flow often increases rapidly (within hours) during warm periods and may decrease as rapidly during temperature drops (Vincent 1987). The streambeds are composed of cobbles and fine sediments to varying degrees, and microbial mats and mosses are present in streams that do not have a high sediment load (Howard-Williams and Vincent 1985). In these streams, the sources of solutes and suspended material are deposition from the glaciers, dissolution of salts, ion exchange from the streambed materials, and leaching of microbial mats and mosses (Green and Canfield 1984; Green et al. 1988).

Streams of the dry valleys lack terrestrial inputs from higher plants and are missing higher trophic levels (i.e., macroinvertebrates and fishes) in contrast to streams draining other LTER sites (Table 4). Thus, dry valley streams represent an end member in the continuum of LTER sites especially for dissolved organic carbon (McKnight et al. in press).

Table 4. Comparison of physico-chemical and biological characteristics of the McMurdo Dry Valley streams to those at other LTER sites. Data for LTER sites from Meyer et al. "Sites for stream research in the LTER Network" (unpublished).

				Site1						
Characteristic	AND	ARC	BON	COW	HUB	KON	NIW	NTL	SEV	MDV6
Physical										
Temp oC	8	9	2.3	13	6	9.9		-2-22		0-5
Flow2	P	I	P	P	P	I	P	P	E	I

Chemical[3]										
pH	7.2	7.2		6.7	4.9	7-8.2	6.9	7.1		
alkalinity[4]	3m	200m	36m	<10m		5.2q	2-10m	<1q		
NH4 (mg l-1)	8	3.6		2-4	30	ND	1-80	22		ND-2
NO3 (mg l-1)	50	ND		2-18	1700	4-27	750	6		2-18
Total N (mg l-1)	75	300				77-148				
SRP (mg l-1)	8	ND-5		1-2	3	1	20	4		0.2-6.5
Total P (mg l-1)	25	9	3.6							
DOC (mg l-1)	0.8	6		0.9	2	1.3	.6-1.1	5-8		1-3
Biological[5]										
Algae	+	+	+	+	+	+	+	+		+
Bacteria	+	+	+	+	+	+				+
Fungi	+		+	+	+					+
Meiofauna	+			+		+				+
Macroinvert.	+	+	+	+	+	+	+	+	+	-
Fish	+	+	+	+	+	+	+	+		-
Detrital										
Wood	+	-	-	+	+	-	-	+	-	-
Leaves	+		+	+	+	+	+	+	+	-
Peat		+								-
Grass						+	+	+		-

1 AND: Andrews; ARC: Kuparic River (Arctic); BON: Bonanza Creek (Taiga); COW: Coweeta; HUB: Hubbard Brook; KON: Konza Prarie; NIW: Niwot/Green Lakes Valley; NTL: North Temperate Lakes; SEV: Sevilleta: MDV: McMurdo Dry Valleys, Antarctica.
2 P = perennial, I = intermittant, E = emphemeral
3 ND = none detected
4 m = mm, m = mg l-1, q = meq l-1
5 + = present, - = absent, blank = not measured
6 Information for Lake Fryxell streams from (Downes et al. 1986; Howard-Williams and Vincent 1989; Vincent and Howard-Williams 1989)

Physico-Chemical

Stream flow is closely coupled with air temperature and solar radiation. The hydrograph is relatively predictable as to the period of flow (i.e., late November to early February) but highly variable in the annual quantity of discharge and in the day-to-day peak and minimal flows (Vincent 1987). Stream flow is predicted to respond nonlinearly to small temperature shifts either above or below the 0oC threshold. Slight cooling will result in a large decrease in water yield, whereas, slight warming will add substantially to total discharge and the extent of stream habitat. These factors can have a major impact on nutrient levels and biological processes.

Nutrient concentrations in stream water vary both temporally and spatially (Vincent 1987). Nutrient concentrations vary seasonally (i.e., highest NO3 and PO4 when glacial melt begins and decreases during summer) and daily (e.g., NO3 concentrations vary inversely with discharge). In one of the meltstreams feeding Lake Fryxell, concentrations of nitrate and urea decreased and dissolved organic nitrogen and carbon increased downstream of the glacier (Downes et al. 1986; Howard-Williams et al. 1989). Similar patterns have been observed in other algal dominated temperate streams (e.g., Konza Prairie LTER site; Tate 1990)

Biological

Microbial mats typically occur in areas that are water saturated for some period during the austral summer and in certain streams biomass can be abundant (>15 mg Chl a cm-2; Howard-Williams and Vincent 1989). The mats are composed primarily of filamentous cyanobacteria with species of Phormidium and Nostoc being common. Bacteria, yeasts, protozoans, rotifers, and nematodes are also found within the microbial mats (Vincent 1987). The estimated age range of the mats is 50-100 years. Biomass accumulation occurs from November to January. Howard-Williams et al. (1989) have shown that photosynthesis occurs within hours after the mats first become wetted by the initial streamflow, and that the overall photosynthetic rates are low. However, the low assimilation numbers may be a result of the persistence of photosynthetically inactive chlorophyll a associated with senescing cells of chlorophyll a decomposition products (Vincent and Howard-Williams 1989). In the Fryxell stream communities both, the amount of measured chlorophyll a and standing stock carbon are extremely high relative to the amount of carbon fixed (> 1mg chla (mg C fixed h-1)-1, >500 mg biomass-C (mg C fixed h-1)-1, suggesting the persistence of large quantities of biologically-derived material that is not associated with metabolically active cells. It is possible that undecomposed inactive cells or detritus have produced overestimates of chlorophyll a, and therefore underestimates of assimilation(Vincent and Howard-Williams 1989). Mosses occur in moist areas farther away from the main stream channel. During winter these organisms are left in a freeze-dried state and continuous darkness.

Material Transport

The main linkage between the terrestrial and aquatic systems in the McMurdo Dry Valleys is hydrologic transport of solutes and suspended material by streams. Canfield and Green (1985) noted high concentrations of nitrate and phosphate in the Onyx River during the initial flow period of 1980 and speculated that the ice of the Lower Wright Glacier is the source of high nitrate. However, the NO3- concentration in the surrounding glacial ice is low (Lyons et al. 1990) thereby suggesting some yet unknown pre-concentration mechanism of nitrogen in the glacier-stream systems. These patterns could be due to transport processes occurring in the hyporheic zone of these streams. The extent of the hyporheic zone in the streambed and banks is constrained by the depth of the permafrost. Canfield and Green (1985) further showed that phosphate levels are very low in the glacial ice, and that soils are likely the primary source of phosphate. Readily soluble nitrate and carbonate salts from the ephemeral stream beds and banks may be generally depleted in the hyporheic zone and only incursions of streams into new areas significantly increase input of solutes from the terrestrial to the aquatic systems.

Algal abundance in temperate streams is controlled by a variety of biotic and abiotic processes, with macroinvertebrate grazing and flood scouring being important examples. Dry Valley streams are subject to different removal processes due to the nature of the microbial community and physical environment. Biotic processes causing removal of mat materials include grazing by protozoans and micrometazoans, autotrophic respiration, and possible drift from mats. Physical removal processes include wind ablation when streams are dry and flood scouring. The relative importance of, for example, wind ablation versus in situ grazing is important because the fate of the materials may represent loss from the stream and input to other ecosystems in contrast to trophic transfer within the stream ecosystem.

Given the apparent lack of light and nutrient limitation for the mat communities (Howard-Williams and Vincent 1989), removal processes may be regulating biomass accumulations. Since microbial mats are likely to be significant in removal of nutrients and other ions from solution and in transformations of nitrogen. Understanding controls on mat abundance will be necessary in understanding the dynamics of other elements and amounts of important nutrients reaching the lake and soil ecosystems. In addition to providing key information about quantitatively important ecosystem-level processes, research on mat dynamics offers the opportunity to examine herbivory by "non-traditional" grazers (Excerpts from Antarctic Dry Valley Workshop, Cary Arboretum, October 1991, in prep.).

Soils

Antarctic soils are among the coldest, oldest and driest on earth. However, the underlying geology of the McMurdo Dry Valley region is comparatively simple. Parent materials often extend over vast areas and are not modified by vegetation. Geomorphological features include: moraines, kames, alluvial fans, deltas, outwash plains, gravel and moving sand dunes, screes, solifluction deposits and permafrost. Landforms are typical of warm deserts, with soil features experiencing vesicular or salt floc structure and horizons containing soluble salts.

Physico-Chemical

McMurdo Dry Valley soils are poorly developed, coarse textured and have low biological activity (Ugolini 1970; Campbell and Claridge 1987). According to Campbell and Claridge (1987) Antarctic soils can be classified as aridisols. Since precipitation is very low, the soils are not leached and weathering products accumulate in the soil profile (Pastor and Bockheim 1980; Bockheim et al. 1990). Antarctic soils are similar to other desert regions (Campbell and Claridge 1968) and are primarily oxidized desertic saline or alkaline sands and loams with pH values > 7 (Cameron et al. 1970; Campbell and Claridge 1987).

These soils also have unique chemical attributes related to the absence of higher plants (Wrenn and Beckman 1981; Campbell and Claridge 1987; Vincent 1988). Organic C and N levels are lower than other desert soils due to the lack of vegetation (Cameron et al. 1970). For example, organic C and nitrogen contents in the "richest" soils of Victoria Valley ranged from 0.02%-0.04% C and 0.002-0.004% N (Cameron and Conrow 1969). Even in moss communities, there appears to be little or no accumulation of humus (Campbell and Claridge 1987). In contrast with temperate soils, nitrate exceeds organic N concentrations by as much two orders of magnitude (Vincent 1988), although data indicate an atmospheric rather than marine source of nitrate (Wada, Shibata and Torri 1981). Age is another important factor in determining chemical properties of dry valley soils. Older soils with the best developed profiles have excessive salt accumulation (Ugolini 1970; Bockheim 1990). Furthermore, the steep physical and chemical gradients and local heterogeneity of dry valley soils at the nano-, micro-, and macro- scale are distinctly different from more temperate soils where free flow of water blends such gradients (Wynn-Williams 1990).

Soil temperatures (0-20 cm) in the McMurdo Dry Valleys are consistently above freezing during December and January. Because of high surface roughness there is a layer of relatively calm air immediately above the ground so that surface temperatures are often considerably higher than ambient. Thus, soil temperatures may be favorable for chemical and biological reactions, even in areas where standard meteorological data indicate extremely severe conditions (Vincent 1988). However, soil temperatures may be favorable and no liquid water available. The desiccation gradient can be so steep that even the reservoir of ice in the permafrost cannot furnish adequate liquid water for the microbial growth necessary to stabilize the soil surface (Cameron and Devaney 1970; Wynn-Williams 1989).

Biological

Studies of biota in the McMurdo Dry Valleys has generally been limited to geographic distribution, or noting the relationship of the taxa to soil physical or chemical factors. The number of microorganisms in dry valley soils varies widely from 0 to 107 g-1 soil (Cameron and Conrow 1969; Cameron et al. 1970; Cameron 1972, 1974; Friedmann 1978, 1982), but it is not uncommon to find soils even in relatively sheltered areas without traces of life. This has contributed to the incorrect dogma of the "sterile dry valleys" (Campbell and Claridge 1987). In fact, species abundance and diversity are constrained by availability of water and soil salinity. Although isolated patches of "complex" ecosystems exist, with food chains including mosses/algae, protozoa, rotifers, nematodes, tardigrades, yeasts, filamentous fungi, bacteria and an occasional mite or collembolan, these are a very small fraction of the dry valleys soils and are generally limited to moist areas near glaciers (Freckman and Virginia 1990).

The abundance and diversity of organisms from dry valley soils is, at present, related to "environmental favorability" (Cameron et al. 1970). For example, non-pigmented aerobic heterotrophs dominate the most stressful habitats. As soil conditions become more moderate (increased soil moisture, lower salinity) other groups including actinomycetes, algae, sulfate reducers, and nitrogen fixers are present (Cameron and Conrow 1969; Cameron et al. 1970; Vincent 1988). In drier soils, algae and cyanobacteria are restricted to areas that are moistened during at least part of the year (Wynn-Williams 1990). Soil nematodes (aquatic roundworms) occurred in more than 65% of dry valley soils sampled and were more abundant in dry soils than rotifers and tardigrades (Freckman and Virginia 1992) . The latter were restricted to moist soils near meltstreams. The spatial distribution of nematodes in the dry valleys was more patchy than in hot desert soils; but, where nematodes occurred, the densities (up to 4000 kg- 1 dry soil) were comparable to those of warm deserts. The relationship between nematodes and soil properties in the valleys is complex. Soil moisture, total N, organic C, PO4, and salinity did not significantly correlate with nematode abundance, although soils without nematodes did have high salinities. The diversity (three genera) and trophic structure of the nematode community in dry valley soils was less complex than in warm deserts (Freckman et al. 1987). In the dry valleys, nematodes only occupy two or three functional levels, e.g., bacterial-feeding (Scottnema lindsayae, Plectus sp.) and omnivore/predator (Eudorylaimus sp.).

Although not strictly soil habitats, certain rocks contain cryptoendolithic communities. Cryptoendolithic rocks also occur in warm deserts. These are the most studied terrestrial microfloral communities in the dry valleys (Friedmann 1982). The extent of their distribution has not been mapped, but is generally limited to high altitude sandstone rocks. These organisms (lichens, bacteria) establish a few millimeters below an apparently sterile rock surface. Melting snow is the source of moisture, and increased temperatures within the rock during the summer allow the community to grow. The internal rock temperature and moisture was monitored via satelite demonstrating the level of field monitoring that may be used in dry valley studies (McKay and Friedmann 1985). Friedmann, La Rock & Brunson (1980) have shown that the soils near these rocks contain high levels of organic nitrogen (1.97-6.06 g m-2), no chlorophyll a, and higher levels of ATP than in the rocks (19.4-46.3 mg ATP m-2 vs 0.76- 18.4 mg m-2 in the rocks).

Material Transport

Wind is an important feature of the McMurdo Dry Valley ecosystems and particles as large as small pebbles may be transported (Campbell and Claridge 1987). The organic content of the soil is probably replenished by propagules of bacteria, fungi (Wynn-Williams 1990), yeasts (Vishniac and Hempfling 1979), cryptobiotic nematodes (Orr and Newton 1971; Freckman 1978; Freckman and Womersley 1983), and pieces of algal mats (Parker et al. 1982b; Wharton et al. 1985). Fungal spore deposition rate (11hr-1 m-2) was estimated to provide sufficient energy to support the observed maximum doubling rate for yeast cells at 10oC in dry valley soils (Vishniac and Hempfling 1979). The wind deposition of such carbon sources could be sufficient for soil community development at microscales. This suggests that the soil communities are primarily dependent on primary production of aquatic habitats.

Landscape

McMurdo Dry Valley landscapes are a mosaic of ice-covered lakes, ephemeral streams, arid soils, permafrost and surrounding glaciers. Materials are transported between sites by wind and water_defining functional relationships between these landscape units (Table 5). Water flows primarily from glaciers to streams to lakes (except in cases where glaciers are in direct contact with the lakes, e.g. Taylor Glacier/Lake Bonney and Canada Glacier/Lake Hoare), while wind disperses particulate matter throughout the valley. The transport of these materials appears to enhance the overall productivity of the dry valleys. Were it not for the melting of surrounding glaciers, there would be no streams or lakes in these valleys, the lakes would eventually freeze and sublimate. Furthermore, glacial meltwater and leaching from soils adjacent to streams provide solutes to both streams and lakes, enhancing production. Winds deposit sediments on and remove organic mats from the surface of lake ice. The productivity of soils appears to exceed site-specific photosynthetic capacity and may be due to allochthonous inputs of wind-borne organic carbon.

Transported materials can be divided into two categories, inorganic (solutes, water) and organic (bound carbon and nutrients). Transport media are abiotic (primarily wind and water) and the direction of transport is determined by topography and wind direction. Lakes receive materials from streams, glaciers and soils, through the actions of wind and water. It has been speculated that groundwater inflow may also be important to the solute budgets of the lakes (Wharton et al. 1989; Lyons and Mayewski 1992). Streams receive the majority of water from glacier melt and both sediments and solutes from glacial water and soils. Particulate organic matter input to streams is probably small compared to stream productivity. Soils receive water from snow melt, with spatial abundance determined by drifting patterns (wind-dependent) and, possibly, subsurface lateral flow. Some mineral inputs may be of significance to soils and organic materials appear to be provided by streams and lakes (including the erosion of buried glacial Lake Washburn sediments).

Table 5. Primary sources of materials received by various ecosystem types.