PROJECT SUMMARY

Intellectual Merit

Antarctica is a cold, low food environment. Plankton production reaching the benthos varies tremendously with weather and ice conditions. Like other parts of the world, decadal variations in ocean climate are linked to regime shifts in Antarctic ecosystems, at least as indicated by key species. Our ability to document and understand long-term trends in ocean climate and ecology, including the role of human activities on the biosphere, depends on an adequate knowledge of natural interdecadal fluctuations. A major objective of this proposal is to document changes in benthic ecosystems in McMurdo Sound over the last four decades, since the beginning of quantitative studies of population and community organization. We will retrieve, analyze, and archive historical data of benthic assemblages in both hard and soft substrata. Because of the great value of time-series information, we propose to recover and work on several time series projects begun in the mid-1960s and early 1970s. In addition to describing community and population patterns within natural habitats, we will also document the succession of marine invertebrate communities that have settled and survived on a variety of artificial substrates placed on the sea floor from the late 1960s to 1989. The substrates were involved in a wide variety of experiments, ranging from cages excluding predators to racks holding experiments and floating off the sea floor. These harbor several decades of information on patterns of settlement, growth, survival, age and longevity, and overgrowth and other biological interactions. In this effort, we can also recover larval settlement projects begun at the same time. The successional work adds significantly to our understanding of natural communities and the processes that drive benthic ecosystems over decades. Since the original researchers are still available, we have a unique opportunity to relocate and permanently mark (with GPS) historical sampling sites; to resample the best of these; to recover data from as much of the historical work as possible; to provide meta-data to insure that past data are understood and sites can be properly resampled; and to make all data available to the general science community in a permanent database housed at SCAR-MarBIN. Sampling the artificial structures involves the same logistic support as that required to sample the natural sponge spicule and soft-sediment substrates. This is important, because we have a limited opportunity to realize the proposal’s objectives.

Broader Impacts

The proposed work will be closely coordinated with an international macroecology program in the Ross Sea, represented by our collaborator Simon Thrush (Latitudinal Gradient Project). This group will be the first to use the historical data and new database in our joint effort. They may also be the first to revisit our best sites to monitor benthic ecosystems in the future. In addition to reporting results in peer-reviewed publications and providing research support and opportunities for 2 plus graduate students, we will involve undergraduate and high school interns in the project, participate in teacher education programs, collaborate with K-12 outreach and college programs hosting our interactive web page in classrooms that focus on ocean science (all of these we have done successfully in the past), and develop a new, broader public outreach effort with the Birch Aquarium at SIO. Our most important scientific contributions are recovering and compiling historical data, updating these data with new sampling during the project, and placing all data and meta-data in a database that will be open to the international science community in the same spirit as the CALCOFI program at SIO. The longer the database is maintained, the more valuable it becomes. The principal investigators will assemble a coordinated, complete legacy compiling decades of research in the McMurdo region, participating personally to relocate and resample historical stations, and to produce the meta-data and much of the data for the baseline database.

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*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

LTREB: Collaborative Research: Decadal variation in Antarctic marine benthic ecosystems

COLLABORATIVE SUBMISSION STATEMENT

This is a joint proposal from two primary institutions: Moss Landing Marine Laboratories (MLML), and Scripps Institution of Oceanography (SIO). Paul Dayton (SIO) and John Oliver (MLML) are the Principal Investigators. They represent the historical benthic work in McMurdo Sound, and are thus the key to recovering past data, relocating past sampling sites, and resampling selected stations. Dayton will oversee the work on time series in the sponge community and succession on artificial substrates. Oliver will oversee work on the soft bottom time series, sponge spicule infauna, and succession in sedimentary habitats. Stacy Kim (MLML) will coordinate the field groups, ROV operations, and research interactions among all the investigators from taxonomy to database development and quality control. She will also coordinate our effort on database development and management with other US Antarctic programs, particularly around Palmer Station. In addition to the core group, we will work closely with Simon Thrush at National Institute of Water and Atmospheric Research (NIWA) in New Zealand. Thrush and NIWA represent the largest ongoing benthic sampling effort in the Ross Sea. They are keenly interested in the historical database this proposal will develop. He is essential in providing a smooth interface between developing the full database for use in the ongoing and future benthic work in the region. Kathy Conlan (Canadian Museum of Nature), Josep-Maria Gili (Institut de Ciénces del Mar), Miquel Zabala (Universidad de Barcelona) Iosune Uriz (Centre d'Estudis Avançats de Blanes - CEAB), Xavier Turón (CEAB), Daniel Martín (CEAB), and Peter Brueggeman (SIO) will be involved for their taxonomic expertise and knowledge of the natural history of polar benthos. Jonny Stark (Australian Antarctic Division) will coordinate the McMurdo Sound and Ross Sea benthic sampling with the benthic work being done at Casey Station. The entire group will be working with other foreign benthic programs outside the Ross Sea region in the same effort to coordinate database structure and availability so we can share data readily and examine larger geographic patterns, even at the continent scale.

This proposal was submitted twice to Polar Programs. We got six excellents, one very good, and one good rating in the first review, which primarily wanted greater detail on the database organization. We provided this in a second submission, which got poorer reviews. The LTREB program is our best chance to recover the best historical database on the structure of benthic communities from anywhere in Antarctica, a large and important part of the biosphere.

RESULTS OF PRIOR NSF SUPPORT

Paul Dayton: Five NSF OPP grants, 1966-1990. Paul Dayton first went to the Antarctic from August 1963-December 1964 working for Stanford University. The subsequent series of grants spanning 27 years established major paradigms for benthic community ecology in the Antarctic. The work during the 1960s laid the natural history ground work for much subsequent research in the area and produced 9 papers, including definition of the faunal zonation pattern caused by regular anchor ice disturbance at shallow depths. The work during the 1970s included continuation of the sponge ecology plus a new focus on soft bottoms with John Oliver and resulted in 5 reviewed papers (excluding AJUS notes). The key role of seastar predation in controlling the distributions of slow-growing sponges was developed as a central tenant of Antarctic benthic ecology. The work in the 1980s continued the sponge work, developed an oceanographic program with graduate student Jim Barry, and focused on bottom up forcing on both sides of the Sound. The 1980s produced 8 reviewed papers. These linked productivity and circulation patterns, showing their impacts on benthic ecosystems across larger spatial scales of tens to hundreds of kilometers. The initial synthesis of decadal patterns showed a strong ecological response to oceanographic variation, and in this context, the relatively minor stabilizing effect of predatory seastars on population explosions, but subsequent potentially large effects on overall sponge distributions.
John Oliver: Two NSF OPP grants, 1990-1999. Oliver first went to the ice as a graduate student with Dayton from 1974-78 to explore soft-sediment communities and parallels between Antarctica and the deep sea. Dayton and he established a dominant mesoscale paradigm for McMurdo Sound that differences in the availability of plankton production create dramatic differences in benthic communities

on the poorly-fed west compared to the well-fed east sound. They showed that the western side has many deep-sea characteristics that numerous researchers have investigated since then. Oliver was an author on 7 peer-reviewed papers supported from Dayton's grant. He returned in 1983 and 1988 to help OPP analyze station operations that disturbed the nearshore environment. At the invitation of the OPP director, Oliver returned from 1990-1992 with Hunter Lenihan under a Technical grant to establish a benthic monitoring program for the sewage discharge and historical chemical contamination of sediments in Winters Quarter Bay. Their program also compared these anthropogenic impacts to natural disturbances to the benthos from anchor ice and iceberg grounding. The human contamination at McMurdo Station is now one of the best described pollution gradients in the world. This technical grant supported 6 peer-reviewed papers. Their benthic monitoring program is the best model for the continent. From 1993 to 2004, benthic communities were sampled along the pollution gradient as ancillary work in four separate OPP projects directed by colleagues who were former students of Oliver. As a result of this coordinated effort, we have an excellent time series in soft-sediment communities around McMurdo Station and at several far-field reference sites from 1974 to 2004, including a complete year of monthly sampling and more than six years of continuous annual sampling.

INTRODUCTION

Processes acting at decadal time scales have a dominant impact on marine ecosystems from local coastal communities (Dayton et al. 1999), to boundary currents (Roemmich and McGowan 1995, McGowan et al. 1998, Francis et al. 1998), to the central ocean gyres (Polovina et al. 1994). The Pacific Decadal Oscillation (Francis et al. 1998, McGowan et al. 1998, Mantua and Hare 2002) and the Atlantic Oscillation (Hurrell 1995, Pearse and Frid 1999, Weijerman 2005) involve weather changes that influence winds and water circulation with profound regime shifts in marine ecosystems over large regions of the ocean. The best understood regime shift is the 1976-77 change in the Pacific Decadal Oscillation. This understanding rests solely on the fact that there are good time series data for both the physical and biological conditions in the California Current (Mantua et al. 1997). The value of documenting natural fluctuations in marine ecosystems on large spatial scales and over long time periods was proved in California by the California Cooperative Fisheries Investigations (CalCOFI) that provided these data (McGowan 1990). The ecological changes were observed primarily for plankton communities and commercial fisheries, but also for marine birds and mammals (Francis et al. 1998) and kelps (Tegner et al. 1996). The Antarctic Oscillation involves changes in weather and sea ice that also are linked to potential regime shifts in marine ecosystems, at least as indicated by the abundance of penguins, Weddell seals, and a common sponge (Dayton 1989, Ainley et al. 2005). The discovery that krill lifespans were double expected (Ross and Quentin 1986) also changed perceptions about productivity and stability in the Antarctic plankton ecosystem. In fact, all the regime shifts are described on the basis of key species (Francis et al. 1998, Chavez et al. 2003). There are very few studies that show how an entire community responds, which is often done best in the benthos (Dayton and Tegner 1984, Tegner et al. 1996, Tunberg and Nelson 1998, Oliver et al. in prep.). With a few regional exceptions, the first quantitative baseline observations of marine benthic communities began in the 1960s and 1970s, and the first groups of researchers to obtain these time series are retired or nearing retirement.

There is a growing emergence of the need for ecosystem-based management. Ecologists are struggling to better understand large-scale and longer-term natural processes to interpret anthropogenic-driven changes. An important but rarely attempted research objective is to differentiate natural long-term changes such as regime shifts from those induced by cumulative anthropogenic changes that may drive ecosystems into much more stable phase shifts (Pauly et al. 1998, Scheffer et al. 2001). At a local scale, these changes may involve simple positive or negative feedbacks such that the local scale processes build on each other to produce the important large-scale shifts (Dayton et al. 1999). Regime shifts or any large ecosystem phase shift can be a result of the interactions of many ecological processes, including chance "founder events" of species with important roles becoming established and changing the system dynamics (Dayton et al. 1999).

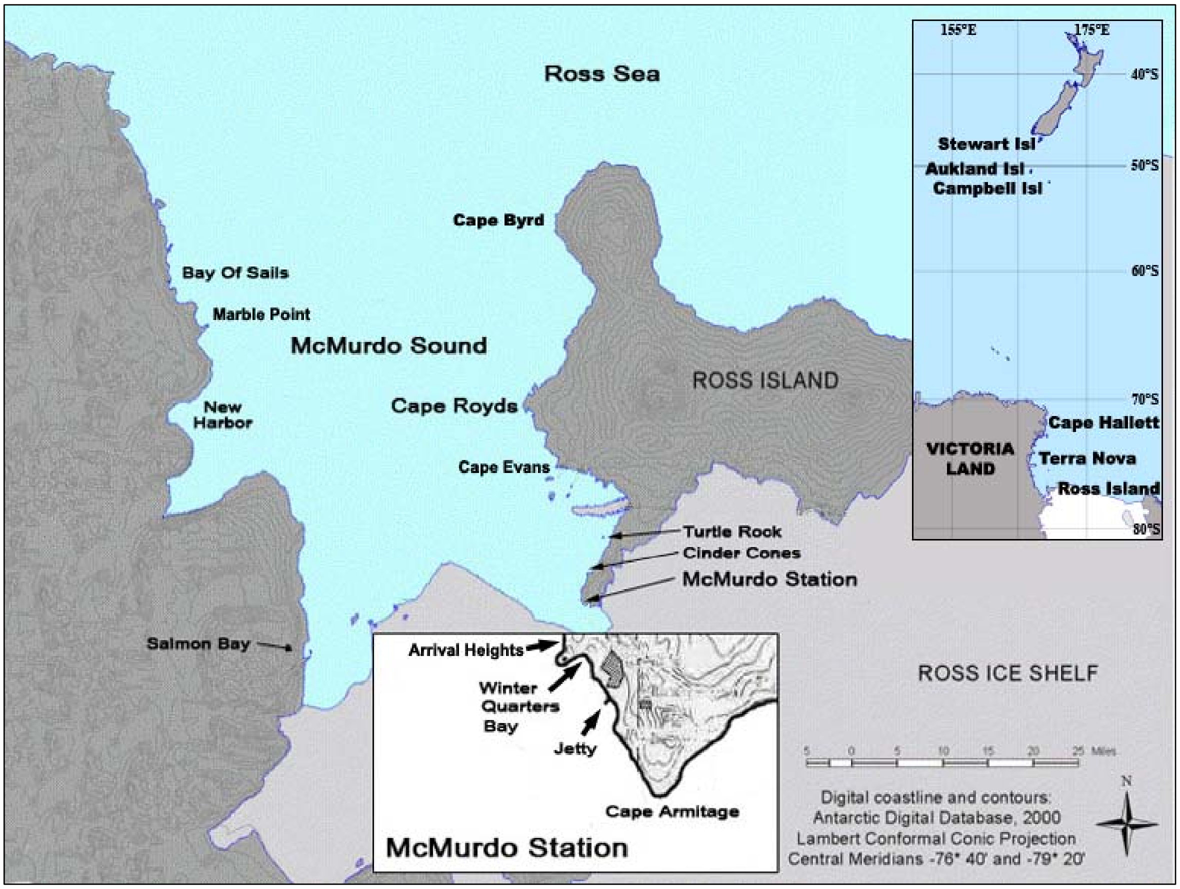


Figure 1. Map of McMurdo Sound, Antarctica, with inset of McMurdo Station, showing locations of previous experiments and place names referred to in the text.

Sea ice patterns produce spatial and temporal gradients in bottom disturbance that control large-scale ecosystem patterns in the Ross Sea benthos (Dayton and Oliver 1977, Thrush et al. 2006, Norkko et al. 2007). Icebergs commonly gouge the sea floor at depths greater than 150 m at Cape Byrd (Figure 1), limiting the development of the dense infaunal community to deeper water (Lowry 1976). The same community occurs in 20 m in the southeastern McMurdo Sound, which is protected from iceberg disturbance by a more permanent cover of sea ice (Oliver and Slattery 1985). Iceberg disturbance produces similar community gradients along the western side of the sound (Dayton and Oliver 1977, Thrush et al. 2006). On both sides of the sound, anchor ice disturbance produces distinct animal zonation above 30 m, but zonal boundaries are different for infaunal communities compared to the larger sessile epifauna (Dayton et al. 1969, 1970, Bockus 1999). There is also a dramatic difference in planktonic and benthic production between the eutrophic eastern and oligotrophic western sound with significant impacts to the structure of benthic invertebrate communties (Dayton and Oliver 1977, Dayton et al. 1986). So, there are strong large-scale environmental gradients in iceberg and anchor ice disturbance that fluctuate in time with potentially different impacts to infaunal and epifaunal communities. There are also related gradients in planktonic production with significant impacts on benthic ecosystems (Dayton and Oliver 1977, Dayton et al. 1986, Sweeney et al. 2000, Dunton 2001). These strong environmental gradients will help in relating ecological patterns to environmental drivers, including those acting on decadal scales.

The importance of polar regions to climate change and decades of intensive ecological research around McMurdo Station make this a prime site for continuous, long-term sampling efforts. The only marine LTER site is at Palmer Station on the Antarctic Peninsula, where there is little temporal data on benthic communities. McMurdo Station has been the site of the earliest and longest sampled benthic community anywhere in Antarctica. The primary goal of the proposed project is to recover as much of this time series as possible and make it available to future generations.

BACKGROUND

McMurdo Sound is the most southern marine station in Antarctica (Figure 1). It is protected from wind and waves by a long season of sea ice cover, and occurs at the least exposed end of an iceberg disturbance gradient (Thrush et al. 2006). The only significant physical disturbance to the sea floor is from the growth and uplift of anchor ice, which is limited to a narrow zone in shallow water (Dayton et al. 1969, 1970, Bockus 1999). Since most of the adjacent land is frozen, there is little stream runoff and very little input of sediments. The annual plankton bloom is primarily advected into the eastern sound, and is highly predictable, usually arriving in the first week of December. It lasts only a month or so (Barry and Dayton 1988, Barry 1988). Even anthropogenic disturbances are small scale, localized, and well known (Dayton and Robilliard 1971, Lenihan et al. 1990, Conlan et al. 2004). Therefore, the benthic habitat of the south McMurdo Sound is one of the least disturbed in the world (Dayton et al. 1974, Dayton and Oliver 1977). Since McMurdo Station is the major logistic center for NSF Polar Programs, the adjacent sea floor has been intensively studied since the 1960's. However, the only extensive long-term sampling has been done in the sponge spicule community along Cape Armitage (Dayton et al. 1974, Dayton 1989), and in the soft bottom habitat in front of the station (Lenihan et al. 1990, Conlan et al. 2004). This work has been discontinuous and dependent on short-term grant support.

With the combination of high underwater visibility and low disturbance, McMurdo is uniquely positioned as a prime location for long-term ecological research on decadal patterns and regime shifts. As a result of low sediment inputs and the single, short pulse of production, water clarity in the sound is extremely high almost all year. This makes the nearshore benthos easy to observe and sample with scuba gear and now with remote equipment (e.g. ROVs). The ice cover that minimizes wave and swell action creates a regime of low physical disturbance that permits establishment and maintenance of experimental structures that persist for decades, and potentially longer.

There is a long and proud history of collecting work in Antarctica, starting with Thomas Vere Hodgson on Robert Falcon Scott's first expedition in 1901, through John Dearborn in the first International Geophysical Year in 1957-58 (e.g., Bullivant and Dearborn 1967). Quantitative benthic observations of the sponge communities began in the late 1960's around McMurdo Station (Dayton et al. 1969, 1970, Dayton 1989, 1990). Dayton's work from 1967 to 1989 involved the placement of a variety of experimental structures on the sea floor, including cages, settling plates, racks, hanging arrays, and tables (Table 1). Many of these artificial substrates are still on the sea floor and have been colonized by benthic invertebrates (Figure 2). The artificial structures harbor a unique, untapped record of the patterns that can reflect ecological successional dynamics. In 1974, the sponge community investigations were extended into soft-sediments (Dayton and Oliver 1977, Oliver and Slattery 1985, Slattery and Oliver 1986, Keist 1993, Lenihan and Oliver 1995). This work later focused on documentation and experimental evaluation of human impacts near the station (Lenihan et al. 1990, 1995, 2003, Conlan et al. 2000, 2003, 2004).

PROJECT OBJECTIVES

Our main objective is to establish a single benthic community database that consolidates the many transects, experiments, and other baseline samples and observations established around McMurdo starting in the mid-1960s. This database recovery and development allows us to explore decadal fluctuations in Antarctic benthic ecosystems from the 1960s to the present. The logistical costs of recovering the historical data and using it to explore decadal ecosystem patterns also permit us to document patterns of ecological succession on artificial substrates deployed in Antarctica since the late 1960s; and to sample historical experiments evaluating hypotheses about settlement and survivorship of larvae in Antarctic spicule and soft-sediment habitats. Some of the sponge community sampling and much of the infaunal samplng has segments of over 6 years of continuous annual sampling. But much more important is the whole time series, which covers almost 40 years of data, and has no other plans for recovery and survival.

We will recover three basic types of benthic community data: photographics of animals and habitats from natural bottom areas, photographs of animal communities on artifical substrates, and core samples of benthic infauna. We have worked on natural sponge-spicule habitats and artificial settlement surfaces at McMurdo since 1967, though not continuously. Permanent transects were begun in 1974 and were established around Cape Armitage and New Harbor (Figure 1). We also established various artificial surfaces that allow a measure of larval recruitment in the mid-1960s, the mid-1970s, and the mid-1980s (Table 1). Thus, we have some measure of community, population, and larval settlement patterns at decadal scales, with a conspicuous gap during the last two decades in the sponge community, but not the soft-sediments (Table 2).

Table 1. Condensed summary of known experimental substrates in McMurdo Sound. Locations include stations at multiple depths. Items in bold have been relocated with GPS coordinates. # = number of replicates; these are minimums based on conservative interpretations of field notes. Substrate types are compressed into three classifications for compact presentation but statistical analysis will compare individual types. M = metal substrates (cages, racks, vehicles, table, casing); P = plastic substrates (settling plates, tubes, floats, tuffies, domes, buckets, trays, stakes, plants, mannequin, box); O = other substrates (gangplank, fuel hose, natural sponges).

Year Deployed	1958	1960	1961	1967	1974	1975	1976	1984	1988	1989	1992
Location (depth in m)											
Cape Armitage (14-56)		**1M**	**16**/50**M** **1P**	**2**/4**M** **3**/8**P**	12P	1M **4**/6**P**		**2P**	5P	1P	
Cape Evans (15-39)					6P						
Cape Royds					1M 12P						
Cinder Cones (18-41)					**6P**			**12P**			
Heard Island							1M				
Hut Point (18-41)	**2OM**			**11M**	**5M** 1P	1P		1M 1P			
Jetty (21-39)					4M 6P	1M 2P 1O	2M		1P		
New Harbor (30-42)					**19**/32**M** **33**/40**P**	6P	1M	1P			
Outfall (0-24)		**1M**									**1M**
Salmon Bay (20)										1M	
Turtle Rock (14-39)					**7**/10**P**	4P					
Winter Quarters Bay (18-24)		**1M**			2M 4P						

1. Establish the First Quantitative Database for the McMurdo Benthos

A composite database is a springboard for new work, future hypothesis testing, and model building. Our primary goal is to save as much of the old baseline data and metadata as possible, while those who collected the data are still able to contribute directly. The recovery of historical data and development of the first baseline for McMurdo depend on getting metadata and sampling locations from Dayton and Oliver. Most of the photographs and data are extant, but these data need to be associated with the precise localities. Modern GPS positioning capabilities will allow the sites to be integrated into future investigations. We have GPS locations for 23 stations, but at this point the remaining 85 stations must be located from old notes, photographs, and memories. Only a few of the transects run in 1966-67 (built into Dayton et al. 1974) were made permanent, because we were simply sampling rather than attempting baselines, but a few were well established. So, the primary field work will be to relocate stations with long-term data sets, obtain the best GPS position for each site, and then resample each site.

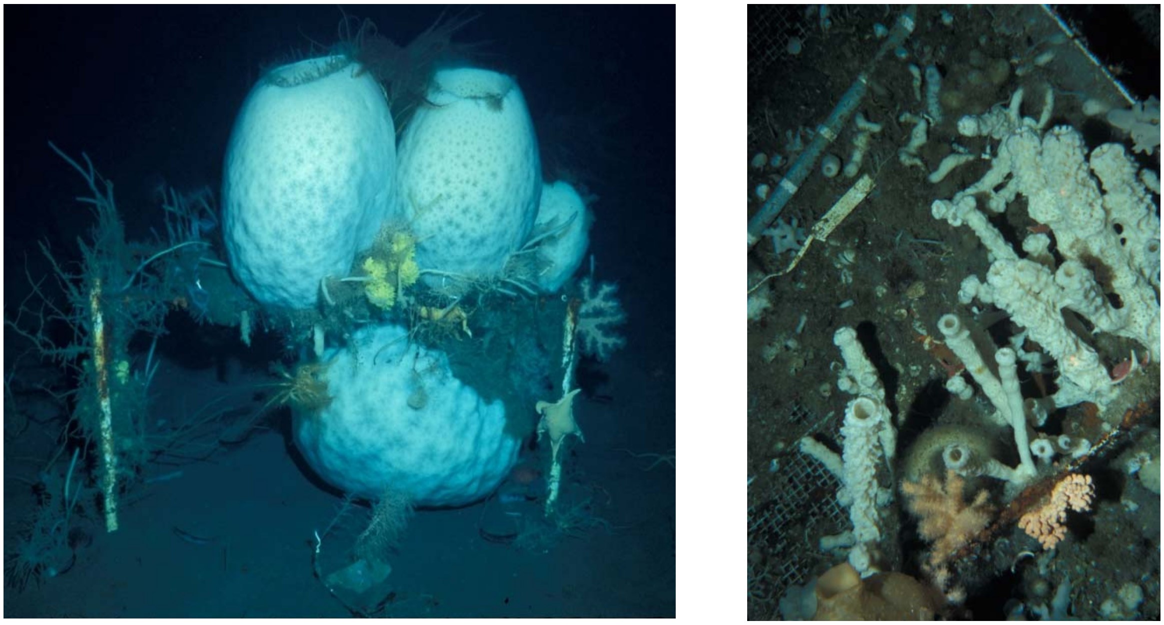


Figure 2. An example of *Anoxycalyx (Scolymastra) joubini* growing on substrate emplaced by Dayton at 30 m depth in McMurdo Sound. Overall organism height is approximately 50 cm. B. One of Dayton's experimental cages still on the seafloor at Cape Armitage in 2004. Sponges, soft corals, tunicates and bryozoans have grown on the cage, but mesh is still visible in the lower left corner.

Table 2. Collection information for quantitative samples of macrofaunal invertebrate communities collected in soft-sediments. Additional quantitative samples were collected by Italian investigators around Terra Nova and in recent years by a multi-national team exploring latitudinal patterns throughout McMurdo Sound and particularly along the Victoria Land coast (Thrush et al. 2006, Norkko et al. 2007). There are also limited collections of meiofauna (mostly Foramnifera) from various investigators.

Location	Depth	Project Years	Investigators
Cape Byrd	35-45 m	1970-1971	Lowry
Cape Hallett	104-250m	1972	Lowry
Campbell Island	14-16m	1971	Lowry
Auckland Island	11-15m	1973	Lowry
Stewart Island	42-43m	1972	Lowry
Cape Royds	10-20m	1974-1978	Oliver, Dayton
Cape Evans	20-30m	1974-78, 2002-04	Oliver, Dayton, Kim, Conlan
Turtle Rock	20m	1974-78, 88-92, 2002-04	Oliver, Dayton, Lenihan, Kim, Conlan
Cinder Cones	6-20m	1974-78, 88-92, 2002-04	Oliver, Dayton, Lenihan, Kim, Conlan
Winter Quarters Bay	20-30m	1974-78, 88-98, 2002-04	Oliver, Dayton, Lenihan, Kim, Kvitek, Conlan
McMurdo Station	10-20m	1988-98, 2002-04	Oliver, Lenihan, Kim, Conlan, Kvitek
Jetty	10-30m	1974-78, 83, 88-98, 2002-04	Oliver, Dayton, Lenihan, Kim, Conlan, Kvitek
Cape Armitage	6-40m	1974-78, 88-98, 2002-04	Oliver, Dayton, Lenihan, Kim, Conlan, Kvitek
Salmon Bay	20-30m	1974-78, 2002-04	Oliver, Dayton, Kim, Conlan
New Harbor	20-30m	1974-78, 88-98, 2002-04	Oliver, Dayton, Lenihan, Kim, Conlan
Marble Point	20m	1988-92, 2002-04	Oliver, Lenihan, Kim, Conlan
Bay of Sails	20-30m	1988-92	Oliver, Lenihan, Kim
West Ross Ice Shelf	20m	1974-78	Oliver, Dayton
Ross Sea			Barry

In the two years prior to the field work, historical pictures will be evaluated for inclusion in the database. They will be linked to a station that can be marked with GPS in the third year, and resampled. They will be scanned into a digital format, and population and community patterns will be estimated and these data placed in the database. The new images will be digital. The selection of historical sites and their successful relocation cannot be done without the authors working with the data and especially establishing a GPS location for each station in the field. In addition to phototransects and many photoquadrats, artificial substrates will be selected when the time of deployment is known, time series photographs are available, and the substrates can be relocated by the authors to mark permanently with GPS.

To populate the quantitative database, we will compile and archive as much of the historical data as possible on the spatial and temporal variations in the structure of the benthic communities. We and our coworkers and students obtained the bulk of the community data for McMurdo Station area, New Harbor, and many other areas around McMurdo Sound, and the raw data remains in our custody. For the sponge spicule community, much of the historical data has yet to be obtained from past photographs of natural bottom areas (natural reference areas next to experimental setups, bottoms associated with distinct natural features, and fixed-line transects). Many of these areas have been photographed over time, and will be photographed again during the proposed study. There are at least 100 transects and experiments established in the 1960s and an equal number established in the early 1970s. These early stations were monitored as possible through the 1970s and 1980s and serendipitously from photographs taken by others through the last 25 years. Consolidating these old records is a major effort, but most transects and experiments are extant and this objective is imminently feasible. Relocating and rephotographing the artificial substrates requires little additional work, but adds extremely important natural history from recruitment and growth to loingevity.

In the sedimentary habitats, core samples of standard areas have been collected since 1974 in many locations around McMurdo Station and the west side of the sound, especially New Harbor. They have all been processed (sorted and the animals identified to the lowest possible taxon), so the primary need is to update the taxonomy from data produced before 1988. Data collected after 1988 are already taxonomically current. We will place all these community data into the database and make it accessible to future researchers. During the proposed study, we will revisit sites where there are historical data but no recent sampling, and resample these. As in the past, the infaunal sampling includes collecting cores from the sponge spicule mat to document patterns in the macrofaunal communities there as well (in addition to the epifauna or megafauna sampled in photographs).

This effort to relocate the historical transects and other early baseline sites with GPS, to convert the historical photographs of natural bottoms and experimental substrates into data, and to generate a comprehensive, taxonomically consistent database, will conserve and continue the rational scientific thread of decades of research effort. The database will be created using Microsoft Access, following a hierarchical organization. Tables will incorporate levels from metadata (Data Source) down to individual specimens for growth data (Figure 3). The database can be queried to extract any subset of interest and can be exported to Excel or a statistical package for further analysis. Image data will be referenced in the database and the images themselves digitally archived in a file system. We are exploring options that incorporate the image storage within the database (e.g. Oracle Database 10g) but at this point are more confident in an external file system that is referenced in the database. The full database will be permanently housed within the Scientific Committee on Antarctic Research Marine Biodiversity Information Network (SCAR-MarBin, please see Danis letter of support). SCAR-MarBIN is the regional node for the Ocean Biogeographic Information System (OBIS), which in turn is the information component of the Census of Marine Life (COML) and GBIF (Global Biodiversity Information Facility), and is a companion project to the Census of Antarctic Marine Life (CAML). The metadata will also be entered in the Antarctic National Directory/Global Change Master Directory, with further links to the New Zealand Latitudinal Gradient Project and SCARs Evolution and Biodiversity in the Antarctic: the Response of Life to Change program. We will perform indirect gradient analysis on the newly created database, and other statistical analyses to address specific hypotheses (see below) and to search for patterns that are less obvious but may be ecologically significant.

We will also fill in the baseline where there are ecologically compelling reasons to expand the existing spatial and temporal database. We will use a remotely operated vehicle (ROV) to extend observations into depths near 200 m to set important ecological boundaries to the main historical study sites, which were to depths of 60 m before diving limits were set at <40 m; and to locate and photographically sample unique benthic habitats and communities below scuba diving depths. For example, we know there is a unique forest of giant volcano sponges below 60 m around the south end of Cape Armitage. Using the ROV, we will establish a quantitative baseline for this community for future workers to monitor and explore. Once again, establishing deep boundaries to the long-term study sites and locating these unique areas depends on the experience of the older researchers. They can be easily accomplished with the same logistical requirements for the rest of the study.

This project is also an opportunity to assemble the key past researchers with a group of younger investigators who are likely to be the first to use the baseline. With this collaborative effort, the extensive data legacy will be fully and seamlessly integrated into this and future studies. Since we do not have an LTER site in McMurdo Sound, the next 10 years of resampling sites in the database cannot be precisely predicted. But without the database, there will be no time series for future investigators to use. Every year the database lives, it becomes more valuable. As long as we continue to explore Antarctic ecosystems, future investigators will add another ten years to the time series to explore important variations in the benthos. This will be the most complete benthic time series available for Antarctica, and McMurdo Station will likely continue to be the most active research facility here for many more decades.

2. Decadal Variations in Benthic Ecosystems

Sponges are major components of Antarctic benthic ecosystems (McClintock et al. 2005). Decadal fluctuations were defined by Dayton (1989) with regard to a population explosion of the sponge *Homaxinella balfourensis* in the anchor ice-disturbed zone described in 1969. The sponges were eliminated by heavy anchor ice formation in the 1980s. This phenomenon was related to oceanographic shifts that brought deep, super-cooled water into the McMurdo Station area in the 1960s and 1980s (Barry 1988). While sponges have defensive chemicals that may mediate predation pressures (Amsler et al. 2001), one possible consequence of the explosion of sponges was very heavy recruitment of asteroid predators. It was speculated that these predators might shift the patterns of sponge distribution and abundance recorded in the 1960s and published by Dayton et al. (1974). Antarctic echinoderms often break Thorson’s Rule (1946) and produce planktonic larvae (Pearse et al. 1991) that may survive extended time in the plankton (Marsh et al. 1999, Shilling and Manahan 1994). It is even possible that appropriate conditions for settlement and metamorphosis could lead to mass settlement events. This leads to the testable hypothesis that there are now differences in both the abundance of the predators and their prey from those described in the 1960 era research. This hypothesis will be evaluated by revisiting transects at McMurdo Station, Cape Armitage, and Arrival Heights. The changes posited by Dayton (1989) will be applied to the density patterns reported in 1974 (Dayton et al. 1974) and compared to more recent observations.

Remarkable interdecadal patterns also were observed both at Arrival Heights and especially in New Harbor (Figure 1) with the sponges *Anoxycalyx (Scolymastra) joubini* and *Dendrilla antarctica* and possibly others. These are sponges that were carefully measured and photographed in experiments and experimental controls in 1967-1989. With a few exceptions, no settlement or growth was observed in any of the areas studied. The exceptions were approximately five *A. joubini* that had settled on the Hut Point Gangplank (a large structure that fell off an oil tanker that was tied up over 1957-58 that drifted out to sea during the IGY) and a Weasel, a small tracked vehicle that fell through the ice off Hut Point about 1960. Two other *A. joubini* were observed in 1988 and 89 at New Harbor on a large floating array that had been in place with no fouling since 1974. In each case the *A. joubini* were about 25 cm long by 1989. By 2004, these sponges, which had otherwise never been observed to settle or grow, completely covered the Gangplank at Hut Point as well as many of the structures in New Harbor. Many individuals, measured in scaled photographs, were over 40 cm in diameter (Figure 2). In addition to *A. joubini*, there were also large colonies of *D. antarctica* on New Harbor structures. The sizes of known tagged individuals and individuals with constrained settlement dates (on deployed substrates) will be quantified and growth curves estimated. Our preliminary observations have already negated the null hypothesis of no interdecadal variation in recruitment and growth. In addition, these observations offer improved understanding of oceanographic as well as successional dynamics.

The quantitative data from soft-sediment communities permit exploration of decadal patterns beginning in 1970, when Lowry (1976) sampled at Capes Byrd and Hallett and at several northern islands forming a latitudinal gradient that can be compared to the ongoing latitudinal studies of Thrush and colleagues (Table 2). *Spiophanes tcherniai* is a foundation species of the dense infaunal community along the eastern McMurdo Sound, simply because it forms so much of the dense tube mat. Variations in its abundance are likely to have significant impacts on the rest of the infaunal community (Oliver and Slattery 1985). *Spiophanes tcherniai* is a suspension and surface-deposit feeder, and likely to thrive during periods of higher plankton production (Oliver et al. in prep.). It has almost disappeared from sites where it was once a numerical and biomass dominant (Oliver and Slattery 1985, Conlan et al. 2004). This and other variations have not been documented with the existing data, and may prove to be related to shifts in oceanographic climate (e.g., the Antarctic Oscillation), which has been correlated with population changes in penguins and seals (Ainley et al. 2005), and the sponge, *Homaxinella balfourensis* (Dayton 1989). The grounding of giant icebergs like B-15 and 16 appears to decrease regional temperature, prevent ice breakout, and lower the advection of primary production into McMurdo Sound (Arrigo and Van Dijken 2003, Seibel and Dierssen 2003, Hunt et al. 2003). This might also decrease the abundance of *S. tcherniai* and grossly modify sediment communities in the same manner as decadal regime shifts. We have access to all the useful historical soft-sediment data from the region, and will resample key locations at Cape Armitage, Jetty, Winter Quarters Bay, Cinder Cones, and New Harbor for comparisons to expose decadal patterns in sedimentary habitats.

On the west side of McMurdo Sound, oligotrophic conditions predominate. The sea ice breaks out only every few years, and the thickness of the multiyear ice limits light and *in situ* production, except in the narrow moats of meltwater that sometimes form at meter depths along the shore (Stockton 1984, Dayton et al. 1986). Advected production from open water in the Ross Sea to the southwestern sound is minimal (Figure 1). The regional ocean circulation moves plankton and larva-rich waters southward along the east side of the sound, then under the permanent Ross Ice Shelf, before turning and moving northwards on the west side of the sound (Figure 1). Before the water reaches the west sound, it is filtered by the communities on the east sound and had time for particles to settle under the Ross Ice Shelf. The benthic communities of the west sound are thus bathed by a depauperate plankton, and the cover and biomass of the benthos is also low (Dayton and Oliver 1977). The two sides of the Sound appeared to be out of phase for at least two decades. Dayton (1989) reported that experimental substrates in New Harbor (west sound) had virtually no settlement beside scattered serpulid polychaetes through the 1970s, but by the late 1980s there was heavy settlement of hydroids, bryozoans and several sponges. This is interesting because during the 1970s when *Homaxinella balfourensis* was taking over the bottom between 10 and 30 m at McMurdo Station (east sound), virtually nothing settled on plates on the other side of McMurdo Sound at New Harbor, but during the cold, heavy anchor ice years in the 1980s at McMurdo Station there was a strong settlement of many species at New Harbor. These are also examples of the importance of episodic founder effects with long-term ecosystem consequences. Resampling the New Harbor transects for comparison with east sound sites will enable examination of differences in community trajectories under oligotrophic and eutrophic conditions, and may pertain to changes in the east sound that result from ice-mediated decreases in productivity.

We already know that there are significant decadal variations in the McMurdo benthos, and a major goal of this project is to document these patterns with all of the historical data and updated sampling. This permits us to test several broad ecosystem hypotheses:

<u>Hypothesis 1-A</u>: Decadal variations in benthic community patterns are related to oceanographic climate changes, in particular the Antarctic Oscillation: In addition to the Antarctic Oscillation (AAO), there is a Semi-Annual Oscillation (SAO) and a Southern Ocean Oscillation (SOA), as well as more than half a

decade of regional oceanographic change caused by the grounding of giant icebergs at the mouth of McMurdo Sound. The discontinuous nature of the historical benthic data may not permit statistical correlations with these oceanographic indices and patterns, but they will permit ecologically important comparisons that may single out one major process, like the AAO. Although fishing impacts to the regional benthos are unlikely, they may be significant for pelagic ecosystems in the Southern Ocean (Pauly et al. 1998).

Hypothesis 1-B: Decadal variations will favor certain functional groups that will have a profound impact on other population: We mentioned the increase in asteroid predators apparently caused by their improved recruitment in the dense beds of *Homaxinella balfourensis*, and their potential negative impact on other sponges. Lower numbers of *Spiophanes tcherniai* in soft-sediments may permit larger populations of animals that are limited by a dense tube mat, or a decline in others that depend on the structure.

Hypothesis 1-C: There are significant differences in decadal variations in benthic communities on the oligotrophic west sound compared to the eutrophic east sound: Benthic communities along the west and east sides of McMurdo Sound differ tremendously probably because of differences in plankton production (Dayton and Oliver 1977, Dayton et al. 1986). The dense infaunal communities (Oliver and Slattery 1985) and the unique sponge spicule habitats (Dayton et al. 1970, 1974) are found primarily on the food-rich east side. These eutrophic and oligotrophic communities may respond differently to variations in oceanographic climate.

Statistical analyses will include using Primer, software designed for marine environmental studies (Clarke 1993, Clarke and Ainsworth 1993, Clarke and Warwick 1994, 1998, 1999, 2001, Clarke et al. 2006). Abundance data, transformed as necessary, will be used to construct a Bray Curtis similarity matrix, and cluster analysis used to create a hierarchical dendrogram of dissimilarity between years and sites. Bray Curtis similarity is the “gold standard” of similarity coefficients and is appropriate in all but a few specific cases. Groupings that are significant will be determined using the ANOSIM procedure (the multivariate analogue to ANOVA) for the a priori hypothesis/predictions. To determine which species are responsible for differences between groups, and which typify groups, we will employ the SIMPER routine, which is an exploratory analysis and will be used to further examine whether the functional ecology of species typical of different groups support or refute the predictions. In case relationships are not as simple as hypothesized, ordination (non-metric multidimensional scaling - MDS), complementary to the cluster analysis, will be performed. MDS results in 2 dimensional “maps” of sample similarity, and for gradual continuums of change, displays patterns more clearly than a dendrogram, especially if stress values, which measure accuracy of the 2-dimensional representation of multidimensional data, are <0.1. If community patterns are gradient rather than stepwise, BVSTEP will be used (instead of SIMPER) to distinguish typical and discriminatory species for comparisons with functional group predictions. Finally, oceanographic indices (AAO, SAO, SOA, iceberg presence) will be superimposed as bubble plots on the MDS; some of these variables are likely collinear, thus a full BIO-ENV analysis is unnecessary to determine their relationship with ordination gradients.

3. Patterns of Succession and Recruitment

While the topic has had a checkered career in the literature, the process of succession is one of the oldest and perhaps the most important processes organizing ecological communities (Margalef 1963, 1968, Connell and Slatyer 1977). In addition to understanding the perturbations, the study of succession classically involves understanding the processes that drive propagule dispersal, settlement, survivorship, growth, and especially species interactions. Succession occurs on many spatial and temporal scales and undoubtedly during regime shifts in ocean ecosystems. Since succession often involves a predictable temporal pattern of community change, the process has been central to many manipulative field experiments, where the pattern is interfered with to test hypotheses about community organization. In polar environments, there is limited knowledge of the basic patterns and rates of succession, and therefore of how the process differs from other latitudes and influences the organization of polar ecosystems. Our limited Antarctic knowledge comes from a few studies of iceberg disturbance (Lenihan and Oliver 1995, Gutt et al. 1996, Peck et al. 1999, Gutt and Piepenburg 2003, Teixidó et al. 2004), and the impacts of

human activities (Chivilev and Ivanov 1997, Conlan et al. 2004). These studies mainly concern sedimentary habitats, and usually involve short periods of observation, months to 1-2 years (except see Lenihan and Oliver 1995 and Conlan et al. 2004). In contrast, there is rather little mechanistic information on succession in polar hard bottom communities or in the unique Antarctic sponge spicule community. These ecosystems usually are composed of large and very long-lived invertebrate species.
With a series of artificial substrates that have been emplaced for up to 40 years, we have a singular opportunity to document the ecological succession of marine animals colonizing new bottoms over many decades, elucidating patterns of recruitment and growth for both common and rare Antarctic species. Considering the difficulties in measuring age and growth rates in this habitat, these settlement surfaces offer at least three important insights: 1) We have evidence of what growth is possible in the time elapsed between photographs and other sampling. 2) Spatial patterns derived from dominance and overgrowth relationships are more easily understood on the experimental surfaces. 3) We begin to understand how long different species can live. The longevity of benthic invertebrates is extremely poorly known for many groups.

Historical experimental studies included the sponge spicule system and the soft sediments on both sides of McMurdo Sound (Dayton and Oliver 1977, Oliver and Slattery 1985, Lenihan and Oliver 1995, Lenihan et al. 1995). Most of these studies were not designed to evaluate succession or long-term changes in ecosystems, but there are so many observations and they cover so many years that there is great potential for collating the results to detect large-scale changes over time. For example, at Cape Armitage we have at least 85 substrates that were deployed in 1960, 1961, 1967, 1974, 1984, 1988, and 1989. We will first examine the data using Primer, which requires no prior assumptions of data distribution and is not affected by unequal samples sizes. Cluster analysis and MDS (as above) can be used to visualize patterns (using all community data) that may be driven by the factors year, depth, and substrate. SIMPER or BVSTEP will again be used to identify species driving the observed patterns. Following our initial analysis, if the data meet assumptions we will utilize a three-way ANOVA to test the influence of the factors year, depth and substrate on variables species richness and abundance (using key species identified above) using a general linear model. If our power is too low for valid hypothesis testing, we will simplify the model to year only. To maximize data use, we will combine depths and substrates when appropriate. Because of the gaps between past projects, the interpretations of past observations are limited, but data-mining efforts will likely detect patterns in large-scale changes in both time and space. Settlement and survival on the artificial surfaces, which have been photographically monitored since they were placed, permit us to document large-scale and long-term patterns of benthic succession and to test a number of broad ecological hypotheses that can each be broken down into numerous specific hypotheses:
<u>Hypothesis 2-A</u>: Succession varies with habitat, geographic location, and time in McMurdo Sound: We have placed artificial structures at different water depths, over different types of bottoms (sponge spicule to soft-sediment), and along a latitudinal gradient on the east side of the sound. Below the zone of frequent anchor ice disturbance, habitat and then the geographic gradient are likely to be most important (see previous discussion for east-west decadal differences in settlement). While we lack the resolution to evaluate some successional changes, we will be able to outline a broad brush picture that will provide focus for future research on patterns and differences that are presently unknown.

Figure 2 gives an indication of the potential for documenting patterns of succession on historical experimental substrates that have been on the McMurdo Sound seafloor since 1967. There are over 265 separate artificial substrates at a dozen locations, including cages, settling plates and tubes, racks, and floats, as well as incidental substrates such as machinery and equipment. Our unpublished observations of settlement on cleared natural and artificial substrates near McMurdo suggest that substrate type is not as strong a driver as location, depth or habitat type; nevertheless, many differences within and between artificial and natural substrates have been detailed in the literature and so we will constrain our comparisons by substrate type and orientation. We will photograph the surviving structures in the field, and then collect a selected group of them for more detailed observation, sampling, and other analyses in the laboratory. We will leave another selected group in the field for future sampling to reveal additional growth patterns, potential biological interactions, and longevity of particular species.

Hypothesis 2-B: Succession is different along the food-poor west and food-rich east of McMurdo Sound: Again, our field observations indicate that differences between the east and west side of the sound are the most profound, probably because the general environmental conditions are the most different in this contrast. There is a strong gradient in productivity, in particular, in this food limited polar region. In addition to settlement on artificial structures, over the years on both sides of the sound, we have documented the colonization of infaunal animals into azoic sediments placed on the seafloor and in experimental boxes on and above the bottom and also into large gouges made by grounding ice bergs (Lenihan and Oliver 1995, Lenihan et al. 1995, Kim et al. in prep.). Experiments, already relocated at New Harbor but awaiting rediscovery at Jetty and elsewhere, will be sampled to extend the observations of succession in soft bottoms.

Many 1 m^2 cages have covered bottom areas for over 30 years, mostly in the sponge community but also at New Harbor on the western side of the sound. The cages are now completely covered with animal growth. When the cages are removed (see section on Field and Laboratory Methods), there should be little or nothing living on the underlying bottom, and probably very little infauna as well. Therefore, we will expose replicate natural, nearly defaunated substrates to colonization at different water depths and locations. This is an unprecedented opportunity to follow the colonization of both macrofauna (infauna) and epifauna (megafauna), which can be compared to the known successional patterns in soft sediment, to those we document on the historical experimental substrates, and to succession on new artificial substrates placed on and just above the sea floor during the proposed study. These comparisons are likely to reveal important ecological information on community organization including the role of recruitment, growth, competition, predation, and symbioses. Moreover, while patterns of infaunal succession have been documented in sedimentary habitats around McMurdo Sound (Lenihan and Oliver 1995, Lenihan et al. 1995, Conlan et al. 2004, Kim et al. in prep.), nothing is known about succession of the infauna or macrofauna living within the sponge spicule mat. It is extremely difficult to defaunate natural substrates to produce this experimental opportunity, and perhaps unwise. So this is a highly fortuitous outcome of cage retrieval.

In addition to artificial structures that were designed for other experimental purposes (e.g., predator exclusion cages, cage controls, and racks and tables for containing short-term experiments), structures were designed to evaluate the effect of vertical position and microhabitat on larval settlement. Plates attached to posts were established in horizontal, 45 degree, and vertical positions. In addition, pipes, tuffy scrubbers, and other microhabitats were made available both on the posts as well as on floating arrays suspended as much as 30 meters above the bottom. Settling plate experiments were begun in 1974 and sporadically continued through 1989. They were established at Cape Armitage, Hut Point, Cinder Cones, Turtle Rock, Cape Evans and New Harbor (Figure 1). We know that a number of these are still in place because colleagues have photographed them for us over the years. These settling experiments allow us to test several hypotheses relating to recruitment and survival of many species that were observed to settle over the decades. In some cases the settling surfaces were studied but not in enough detail to publish. But we know, for example, that there are marked differences between surfaces lying on the bottom and those suspended above the bottom. There were settlement patterns in Bryozoa and a few other species that related to aspect of the plate, and there may have been some microhabitat differences.

Like the cages and other artificial substrates, the settling structures have been periodically photographed since they were deployed, with the biggest gap in monitoring being the 1990's. We will photograph the surviving structures, and collect selected structures for more detailed observations, sampling, and analysis in the laboratory. We will select another group of these settlement plates to leave on the sea floor for sampling in the future. As for the succession data, we will use ANOVA or a non-parametric equivalent to test hypotheses. The model will be heirarchical, with orientation and height above bottom nested within substrate as factors.

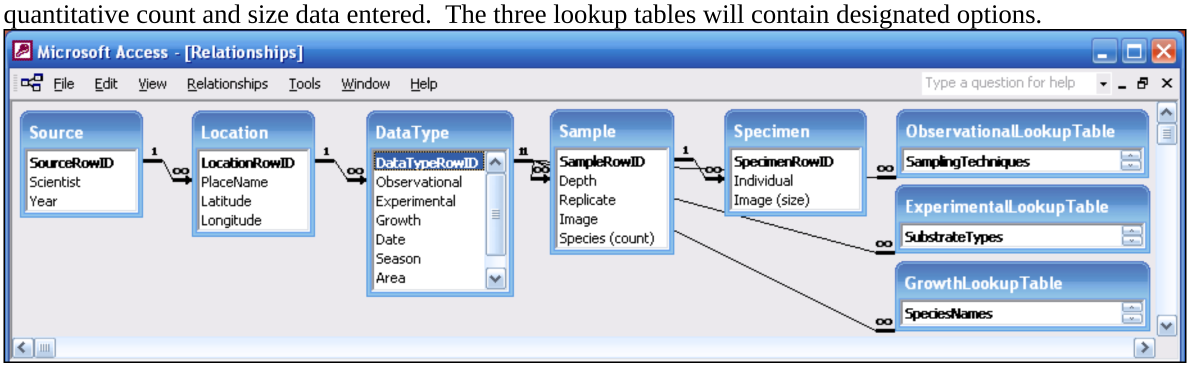
We can test a number of hypotheses about recruitment by sampling these recruitment structures.

Hypothesis 2-C: Various types of predators (or filters as per Thorson 1947) consume or interfere with propagules, influencing recruitment success: The most obvious pattern in all of the settlement experiments was a striking lack of recruitment on the plates on the bottom while there was often rather pronounced settlement on substrata held above the bottom (usually 0.5 to 1 m). This pattern was general in all the habitats we studied, but the apparent predator-filter was much stronger in the sponge spicule community. Potential reasons for the differences are effective substrata-associated predators on the settling propagules, or differences in larval supply with height above bottom. The massive decade-long population explosion of *Homaxinella balfourensis* was restricted to the disturbed 15-30 m depth but was not common on the spicule mat immediately below the *H. balfourensis* zone. This clear trend supports the hypothesis of effective predation in the sponge spicule mat.

Hypothesis 2-D: Recruitment patterns will show consistent trends with substrate type, local habitat conditions, and geographic location: The settlement structures included different substrates (cage mesh, solid plates, tuffy scrubbers), and different substrate orientations (tops and bottoms of plates, plate angle, distance above the sea floor). They were also located in different local habitats, along the anchor ice gradient, and on spicule and soft sediments; and over a broad geographic area, Cape Evans to Cape Armitage on the east sound and New Harbor on the west side. This provides an opportunity to document differences in settlement, survivorship, overgrowth patterns, individual and colony growth, and age/longevity under these different environmental conditions.

There are additional hypothesis that can be tested by sampling the settlement plate experiments and the other artificial surfaces, but perhaps the most important contribution will be to document these long-term patterns of settlement and succession, to see what hypotheses they support or refute, and to see what ideas they suggest for future testing.

Figure 3. Outline of the planned database structure in Access. The five tables will contain the listed fields, with quantitative count and size data entered. The three lookup tables will contain designated options.



FIELD AND LABORATORY METHODS

We will locate permanent transects, other historical sampling sites, and experimental structures (and other structures) with scuba divers in depths <40 m and with an ROV at the edge of scuba depths and deeper (to around 200 m). At shallow depths, divers will take scaled photographs of structures and natural bottom sites and help bring experimental substrates to the surface, mainly by attaching tow ropes pulled from the sea ice. Divers will also collect core samples from the natural sediments and sponge mat, and from areas under cages that should be largely defaunated. At depths greater than 40 m, we will use SCINI (Submersible Constructed for under Ice Navigation and Imaging), a modular, torpedo-shaped ROV with excellent navigational and imaging capabilities. SCINI is designed, built, and operated by Bob Zook, an engineer working with the MLML Benthic Lab. It is deployable through a 15 cm ice-hole that can be drilled with a stock drill bit and hand-held power device available at McMurdo Station, and so will allow us to search and sample very large areas of bottom with minimal logistical support and cost. The depth range of SCINI will allow us to access experiments, structures, and areas now beyond scuba depths.

In addition to scaled photographic sampling of the fauna living on the natural bottoms and on the artificial structures, selected experimental structures will be lifted to the ice surface, placed in mobile aquaria, and returned to the laboratory for additional analyses. Lab work will include photographic sampling of all surfaces, direct counts and cover measurements, direct size and weight measurements of individuals and their morphology, live observations in laboratory aquaria, and preservation for future laboratory work (including molecular studies). Exactly which and how many experimental substrates will be recovered will depend on what is relocated, and will be balanced between replication sufficient for robust statistical analysis for the current proposed work and future needs. We will also sample for small nestling macrofauna, which will provide important ecological information to compare with the macrofauna within the spicule mat and the infauna of adjacent sedimentary habitats. The laboratory also has large holding aquaria for keeping the structures for more extended periods of observation/sampling.

Historical photographs will be scanned into a digital form, and all new images will be taken with a digital camera - so a complete temporal record of each sampling area will be stored in the computer database at SCAR-MarBIN. From these photographs, we will identify species of benthic invertebrates, the numbers of individuals per species, and/or percent cover of each species for those that are large enough to identify. We can also measure individual or colony size when desirable and possible. At key sites, we will piece together many single photographs to make a photographic mosaic of a much larger bottom area (up to 50x50 m or greater), producing a significantly larger sample area that can be resampled in the future (e.g., Kim et al. 2005). Many large species, like the giant volcano sponges, can only be adequately sampled at these larger spatial scales. We can also obtain a single image of a larger experimental region, distinct habitat feature (like a cliff face or cluster of boulders), or a large population or community patch. Since our cameras are equipped with laser scaling systems, all images from the smallest to a larger mosaic can be linked to a known bottom area to facilitate quantitative sampling and future resampling. With the navigational system of the ROV tied into GPS, we can georeference imagery to relocate exact sites and even specific animals in the future.

PROJECT SIGNIFICANCE

Intellectual Merit

The most important scientific contributions are the recovery of historical data on the structure of benthic ecosystems in McMurdo Sound; updating these data with new sampling during the project; and creating a permanent database that will be open to pubic access in the future. No other polar environment has a benthic time series that is this long and includes broad spatial coverage of habitats and larger-scale geography. The database permits us to describe four decades of variations in the Antarctic benthos, and to relate these to changes in oceanographic climate like the Antarctic Oscillation, which has only been possible thus far for penguins and seals (Ainley et al. 2005), and the sponge *Homaxinella balfourensis* (Dayton 1989). The great value of the CalCOFI program as opposed to many other time series is the fact that the data are completely open and available to the entire science community. The ideal in this proposal is to make the data and meta-data available for future workers in the same spirit as CalCOFI, by placing the metadata within the SCAR Antarctic Master Directory, which will also provide a direct link to the permanent full database housed at SCAR-MarBIN. The observations of succession on artificial substrates are only possible because of the long-term experimental work at McMurdo Station. Like the time series for the natural communities, they span four decades with this proposal. There is nothing like this successional record available from any other polar environment, enriched by observations of colonization patterns into soft sediments and with this proposal into the sponge spicule mat. The succession and recruitment work on artificial substrates is simple to accomplish in the field, and depends on the same very expensive logistics that gets our group to McMurdo Station for any data recovery.

Next to developing the database and then mining it for temporal patterns, the most significant impact of the proposed project is our direct link to the multinational ongoing benthic investigations in the McMurdo Sound region. A primary part of our collaboration is with the ongoing international macroecology program with New Zealand and Italy along the west side of the Ross Sea. This is an ecosystem-based program that already relies on our past work for background hypotheses and mechanistic understanding. They are finding fascinating exceptions to some of our conclusions, so it will be very valuable to coordinate and work with this program. In recent years, Simon Thrush and his coworkers from New Zealand, Italy, Australia, and the US have added to the benthic data discussed in this proposal, while documenting latitudinal changes in the benthos primarily in the Ross Sea along the Victoria Land Coast, but also in coastal areas of McMurdo Sound (Thrush et al. 2006, Norkko et al.

2007). We will closely coordinate the proposed work with their latitudinal investigations, including data collection and storage, which is one reason Thrush is a primary collaborator the proposed project. The baseline data generated from this proposal will provide an important contextual link to their macroecology program, which does not yet have the long-term component in sampling and has not been as spatially intensive, but instead geographically extensive - reaching to Cape Hallett. Their hope is to initiate seasonal and other temporal sampling in McMurdo Sound as an anchor for the latitudinal sampling, so the historical information we can provide will be extremely useful. They are likely to continue monitoring our sampling sites for which there are the best historical data, and are thus the best candidates for the future 10 years of sampling. The transition from the historical work and up-dated sampling in this proposal will be seamless with the ongoing and future work of the macroecology program. There are additional historical data that we hope to include in the database (e.g., Lowry, Sam Bowser, Jim Barry, and Rob Dunbar) if the individual scientists are willing to contribute them. Future opportunities for even larger scale comparisons and analyses are emerging; a database from the Peninsular region (Admiralty Bay Benthos Biodiversity Database – ABBED), which has been sampled periodically and less intensively since the 1970s, is being developed by SCAR with Polish and Brazilian contributions.

Broader Impacts

The proposed work will promote teaching, training, and learning for graduate students, undergraduates, K-12 and the general public. The project will entrain the interests and foster skills of graduate students who will be participating in laboratory analyses and have the opportunity for part-time support and to compete for field participation. We also expect that a total of 10-15 graduate students will participate in class and lab work that substantially draws from this project. Undergraduate and high school research interns will be involved in sample processing and analyses as part of ongoing mentoring programs with the California State University and University of California systems, Monterey Academy of Oceanographic Science (http://www.mpusd.k12.ca.us/MontereyHigh/Academies.htm), and Monterey Bay Aquarium Young Women in Science programs (http://www.mbayaq.org/lc/kids_place/kidseq_soc.asp). An informal web page that has been a highly successful connection between our previous Antarctic research and K-12 classes will be upgraded to a professional product (http://aspire.mlml.calstate.edu). We have been involved in three NSF-funded education and outreach programs: PolarTREC – Teachers and Researchers Exploring and Collaborating (http://www.polartrec.com/), ARMADA Project - Research and Mentoring Experiences for Teachers (http://www.armadaproject.org/), and TEA - Teachers Experiencing Antarctica and the Arctic (http://tea.armadaproject.org/). We provided a letter of support to the current proposal for Polar ARMADA, and are eager to participate again by hosting an educator or journalist. We will continue our normal outreach activities of public speaking and involvement in other educational programs, which include spending several weeks a year working on local K-12 programs with teachers, giving classroom lectures, and participating in other student programs. In addition, we plan an even broader public outreach effort with the Birch Aquarium at the Scripps Institution of Oceaography (SIO). This includes collaborating with large format film producer and Director of America's Ocean Challenge, Soames Summerhays, to film the adventure of science in action under the ice and the discoveries at the core of this proposal's hypotheses. The film acquisition will also include Remotely Operated Vehicle (ROV) footage with which Summerhays Films can produce an underwater audiovisual module concerning the natural long-term and large-scale fluctuations in polar benthos and how they relate to our understanding of polar and global climate change and human impacts to climate. The audiovisual module is targeted for use in the Birch Aquarium at SIOs new exhibit on climate change and for broader distribution to Informal Science Centers nationwide. The underwater environment in McMurdo Sound is one of the most photogenic in the world, having some of the clearest waters, unique underwater ice structures, and a colorful and exotic marine fauna. The biomass and diversity of benthic life contrasts remarkably with the almost lifeless, extensive frozen masses and unvegetated ice-free patches of land above the water. While there have been outstanding still photographs of the underwater richness, the potential for video and film images and story telling is tremendous, as well as timely and significant.

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