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Heard Island Wilderness Reserve: reports on natural science and cultural heritage research

Compiled by P.M. Selkirk

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CONTENTS

Heard Island Wilderness Reserve: reports on natural science and cultural heritage research

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Preface

The Heard Island Wilderness Reserve comprises the islands and ocean of the Territory of Heard Island and McDonald Islands at approximately 53° 05´S 73°30´E. The islands have been included in the World Heritage List and the Reserve is managed by Australian Antarctic Division for the Australian Government according to the Heard Island Wilderness Reserve Management Plan of 1995.

Heard and McDonald Islands form one of the seven groups of sub-Antarctic islands that flank the Antarctic Convergence (Antarctic Polar Front) in the Southern Ocean: Marion and Prince Edward Islands, Iles Crozet, Macquarie Island and Islas Diego Ramirez to the north of the Convergence; Iles Kerguelen on the Convergence; South Georgia and Heard and McDonald Islands to its south. In common with the other sub-Antarctic islands, Heard Island and McDonald Islands are small, remote, oceanic, and are breeding grounds for multitudes of marine-feeding birds and mammals. The islands are volcanically active, and of enormous interest geologically.

The sub-Antarctic islands and their surrounding ocean are in a region of the world in which significant environmental change has been observed during the last 50 years. Documentation of past and present natural science phenomena in this region is of considerable interest and of particular value to the prediction of likely consequences of future climate change.

During the second half of the 19th century, visitors to and settlers on Heard Island made their living from harvesting marine-feeding birds and mammals that were temporarily ashore. During the 20th century a number of scientific parties have visited for various lengths of time. The evidence of their visits left by both sealers and scientists forms part of the island's cultural heritage.

Reports on research on a range of inter-related aspects of natural science and on cultural heritage of Heard Island are summarised in the abstracts collected in this volume. Fuller presentation and discussion of this research, and of plans for future research will occur at the Heard Island Workshop, Australian Antarctic Division, 29 June-1 July 1998. Publication of full-length scientific articles on these topics is anticipated in the Papers and Proceedings of the Royal Society of Tasmania during 1999.

Thanks are due to Cathy Bruce for assistance in preparation of this volume, to Tony Molyneux and Debbie Brown for assistance in organising the Workshop, and the Australian Antarctic Division for providing accommodation and facilities for the Workshop.

1. Plant ecology on Heard Island: a new vegetation scheme and predictions for climate change

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Significantly ice covered and with a very small flora (11 vascular species and approximately 60 bryophyte taxa), Heard Island is the sub-Antarctic island within the Kerguelen Province on which the effects of the last glacial maximum are persisting the longest.

Combining three ecological approaches, which focus on vegetation structure, plant species characteristics and species richness, a new vegetation scheme has been formulated along with a general framework of environmental conditions. The vegetation scheme is a based on two elements, a nomenclature format and an identification of principal directions in variation in vegetation on the island shown in Figure 1. Five major vegetation types have been recognised: feldmark vegetation on shallow stable ground; feldmark vegetation on labile ground; *Azorella* cushion vegetation; closed vegetation in wet sheltered areas; coastal and other vegetation in nutrient enriched areas. Many variations on these five types can also be found on the island and vegetation on the island can be viewed as inter-gradings or continuums. Bryophytes are notable components of many of the vegetation types both in terms of biomass and species richness.

A major feature of much of the vegetation, and particularly in the dominant *Azorella* cushion vegetation is the importance of tolerator taxa such as *Azorella selago* and the moss *Dicranoweisia* spp. In contrast to their behaviour on other volcanic sub-Antarctic islands such as Marion Island, and in the absence of more competitive taxa such as *Agrostis magellanica* and *Blechnum penna marina*, tolerator taxa have been able to develop to the extent that they are the major components of vegetation structure and biomass and exhibit wide ecological amplitude on Heard Island. This most likely reflects the colder climate on Heard Island, including a significant winter snow cover compared with other sub-Antarctic islands. With current climate change the situation may, however, rapidly change. Under a warmer climate regime, in association with new lands forming with rapid deglaciation, more aggressive taxa may be able to establish on the island. In addition, it is predicted that with warming conditions, increases in metabolic respiration in *Azorella* cushions will decrease overall growth rates reducing any competitive ability of this species severely. The result being the significant reduction in the extent of *Azorella* cushion vegetation and the contraction of the distribution of *Azorella* to high altitude localities, as can be found on other sub-Anatrctic islands today.

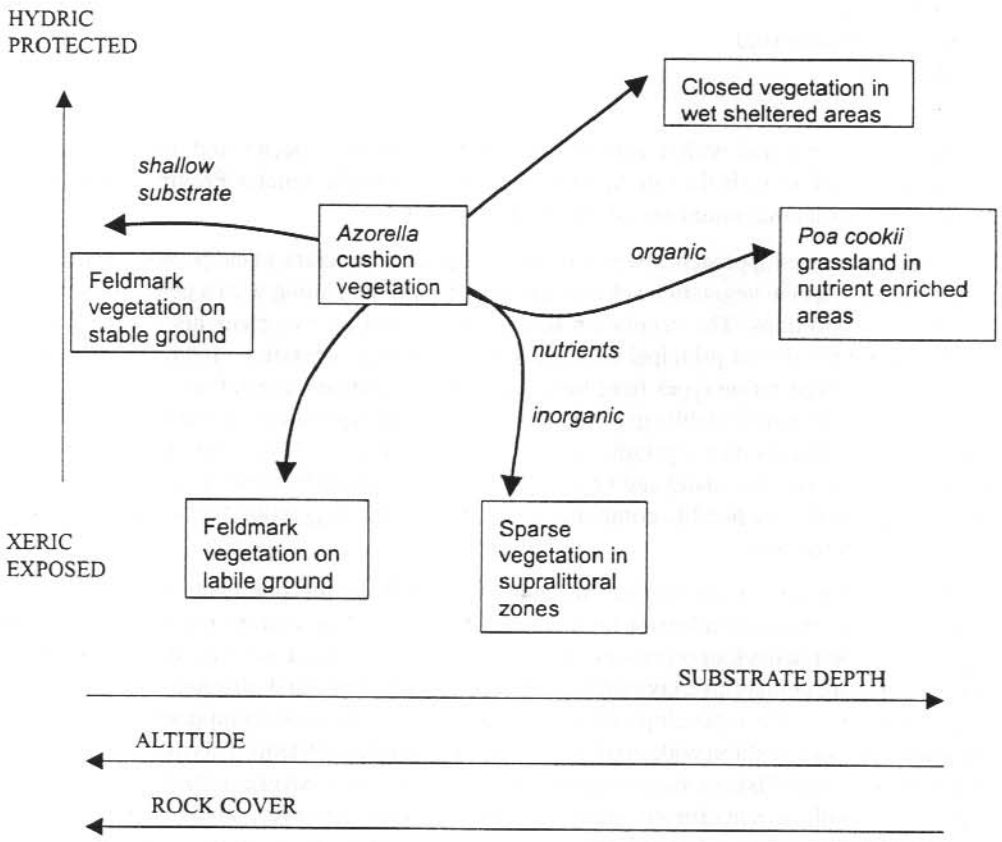

Figure 1. Directions in variation in Heard Island vegetation

2. Changes in Heard Island glaciers, king penguins and fur seals between 1947 and 1971

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Heard Island was continuously occupied by parties of the Australian National Antarctic Research Expeditions (ANARE) from 1947 to 1955 (and a U.S. wintering party in 1969), and was visited by summer expeditions of 1-6 weeks in 1963, 1965, 1969 and 1971. All except the 1965 expedition were based at Atlas Cove, and work elsewhere was done by unsupported field parties of two or three men travelling on foot, which repeatedly visited most parts of the island and on three occasions made complete overland circuits. These expeditions established the main features of the island's topography, geology, glaciology, and biology, and documented the first decades, described below, of the current glacier fluctuations and recolonization by king penguins and fur seals.

Glaciers

Available records show no apparent change from 1874 to 1929 but general minor recession by 1955. By 1963 there was obvious major recession of almost all glaciers. However, the next eight years brought a mixed pattern of retreat and readvance. Retreat continued in the Brown, Jacka, and Schmidt glaciers, whereas strong readvance occurred in the Baudissin, Little Challenger, Vahsel and Winston glaciers. These fluctuations followed increases and subsequent reductions in regional air temperature, and suggested that the Heard Island glaciers were sensitive indicators of climate change in the Southern Ocean.

King penguins

King penguins (*Aptenodytes patagonica*) were abundant at Heard Island in 1858 and a breeding colony was still present in 1929, but only three chicks were seen in the seven years from 1947 to 1955. In 1963 it was discovered that regular breeding had recommenced, and over the next 8 years the population rapidly increased, doubling in size every two years at some colonies. At Spit Bay and Vahsel moraine there were 21 eggs and chicks in 1963, and 103 in 1969 – a fivefold increase. Direct and indirect evidence strongly suggested (and subsequent work at Kerguelen and Iles Crozet has confirmed) that few chicks had survived to fledging and that the population increase was largely due to immigration.

Fur seals

Fur seals were present at Heard Island in the 1850s but were soon exterminated by sealing. Between 1947 and 1955 they were frequent summer visitors, but the largest concentration seen was 50 seals (at Red Island) and no evidence of breeding was found. In 1963 a total of 439 Antarctic fur seals (*Arctocephalus gazella*), mostly non-breeding males, were counted at Red Island, Saddle Point, Fairchild Beach, Skua Beach, and Spit Bay, and two suckling pups were photographed. By 1969, the populations at these sites had increased sixfold to 2,662 seals, and in 1969 and 1971 groups of several cows and suckling pups were seen. The first known landing on McDonald Island, in 1971, revealed only seven harems with a total of 68 cows and 46 black pups – clearly too few to have colonised Heard

Island. The sighting at Red Island in 1971 of an anomalous pale-coated fur seal, of a kind hitherto seen only at South Georgia, has raised the possibility that the huge and crowded colonies at South Georgia may be the source of *A. gazella* at Heard and McDonald Islands, and perhaps at other islands of the South Indian Ocean.

3. Geological, geochemical, and Th-Sr-Pb-Nd isotopic constraints on the character of Heard and McDonald Island volcanism

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McDonald (MI) and Heard Islands (HI) lie on the Kerguelen Plateau (at 72° 35´E - 73°45´E and 53°2´S - 53°15´S) *ca.* 4000 km SW of Australia and represent the site of contemporary volcanism caused by the long lived Kerguelen-Heard mantle plume (Storey *et al.,* 1988; Barling *et al.*, 1994). Accounts of the geology of HI and the MIs have been published by Lambeth (1952), Stephenson (1964, 1972) and Clarke *et al.*, (1983), Quilty *et al.*, (1983), Barling *et al.*, (1994) and Collerson *et al.*, (1998). The oldest rocks on HI are units of mid-Eocene to mid-Oligocene pelagic limestone and chert intruded by gabbro and diabase sills. They are unconformably overlain by Late-Miocene to Early-Pliocene volcanoclastic and clastic deposits, basalt flows, and basaltic and trachytic intrusions of the Drygalski Formation. These units provide a cryptic record of the sedimentation, igneous activity and uplift on the Kerguelen Plateau prior to onset of recent volcanic activity on HI.

Volcanism on HI commenced at 1.2 Ma and continues at Mawson Peak on Big Ben to the present day. Big Ben volcano is composed of Holocene to Recent lava flows with subordinate hyaloclastite deposits. Lavas comprise two groups; one of basanitic composition with between 42.6 to 44 % SiO_2, the other, alkali basalt and trachybasalt with 47 to 61 % SiO_2 (Barling *et al.*, 1994). Parasitic cinder cones also occur at a number of localities. Another group of compositionally variable basanitic to trachytic volcanoes (47.6 to 61% SiO_2; Barling *et al.*, 1994) occurs on Laurens Peninsula, e.g., at Anzac Peak (715 m), Mt. Dixon (706 m) and Mt. Olsen (636 m). Lava flows from cinder cones at Red Island on the northern side of the peninsula and Macey Cone at the western end of the Peninsula are devoid of vegetation and thus are also interpreted to be geologically very young.

The McDonald Islands, 44 km west of HI, are composed of extensively eroded laminated tuffs, kaersutite phyric phonolite domes and pelagic limestone. In view of their extremely eroded character, and K-Ar age dates of *ca* 36±3 ka and 79±3 ka (Clarke *et al.*, 1983), MI volcano was believed to be extinct. Reconnaissance field, geochemical and isotopic data for phonolitic pumices show that MI is an active intraplate volcano and is Australia's second active volcano (Collerson *et al.*, 1998 a and b). The geochemically highly evolved character of the MI pumices together with TIMS Th isotopic data: $(^{230}Th)/(^{232}Th) = 0.846 - 0.889$ and $(^{238}U)/(^{232}Th) = 0.846 - 0.852$, suggest the recently erupted magma resided in a strongly fractionated magma chamber for a long time (>30 ka) prior to eruption (Collerson *et al.*, 1998a). Isotopic compositions of the pumices are different from other potential young volcanic sources in the southern hemisphere, e.g. South Sandwich Islands, Marion Island, Iles Crozet and the Ross Sea Igneous Province.

Strongly leached MI pumice residues define a 835±11 Ma (2s) Pb-Pb isochron. This late Precambrian age indicates the presence of Gondwana sub-continental lithospheric mantle beneath the Kerguelen

Plateau. The same conclusion has also been reached using Os isotopic data for xenoliths from Kerguelen (Hassler *et al.*, 1998). Kerguelen-Heard EM-1 ocean island basalt-type magmatism thus clearly reflects involvement of plume and ancient lithospheric mantle-derived components. The new ICPMS trace element and Sr, Nd, Pb and Th isotopic data show the existence of four geochemically discrete contemporaneous magmatic systems beneath HI (Collerson *et al.*, 1998 a and b). In (^{230}Th)/(^{232}Th) versus (^{238}U)/(^{232}Th) space, Big Ben lavas have the least radiogenic compositions yet reported in ocean island basalt magmas. Magmagenesis of HI-MI lavas involved a deep-sourced mantle plume (represented by Laurens Peninsula) and old continental lithospheric mantle with high Th/U (Big Ben). These new data clearly require further critical questioning of the model for HI magmatism proposed by Barling *et al.*, (1994).

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Predator-prey-fisheries interactions in the region of the Kerguelen Plateau

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This paper examines the development of models on predator-prey-fisheries interactions on the Kerguelen Plateau, particularly in relation to Heard and McDonald Islands. A summary of the Workshop on Predator-Prey-Fisheries Interactions at Heard Island and McDonald Islands and at Macquarie Island held at the Australian Antarctic Division in April/May 1997 will be given along with a discussion of how such models may be used to develop notions of critical ecological reference conditions in the predator-prey system in this region.

Species of commercial interest in the region are *Dissostichus eleginoides* (Patagonian toothfish) and *Champsocephalus gunnari* (mackerel icefish). The role of these species in the food web was the central consideration in the development of the models. The fishery for icefish on the Kerguelen Plateau interacts directly with the foraging activities of macaroni penguins, king penguins, Antarctic fur seals and elephant seals, which all include quantities of icefish in their diet. Elephant seals are the only land-based predator likely to feed substantially on toothfish; toothed whales also feed on toothfish. Indirectly, the fisheries for icefish and toothfish may affect a wider range of higher predators. Icefish feed on zooplankton, euphausiids and mesopelagic fishes. The fishery for icefish may also release euphausiids to squid, macaroni penguins, other birds, and baleen whales, the primary euphausiid feeders on the Kerguelen Plateau and its vicinity. Toothfish feed predominantly on squid and meso and bathy-pelagic fish. Some of these organisms are themselves predators; others feed primarily on plankton. The toothfish fisheries may therefore affect the distribution and abundance of prey of elephant seals, fur seals, king penguins, macaroni penguins, and large flying birds in the vicinity of the Kerguelen Plateau both in positive and negative directions.

Seven main units in a "minimally realistic model" were identified:

(1) seals and penguins

(2) toothed whales

(3) pelagic middle-order consumers (fish and squid)

(4) commercial fish species

(5) zooplankton

(6) production

(7) the Fishery

The outcomes from modeling these interactions are dependent on the status of populations, seasonal patterns of foraging and distribution of prey, availability of prey, foraging selectivity, predator population dynamics, level of model detail, alternative interpretations of available data and fishing activities.

Given the uncertainties and gaps in knowledge, three important questions were identified by the Workshop:

- How much production and prey is imported into and exported from the area?
- What is the effect of fishing on the biomass of toothfish, particularly for the age classes of fish that are of the sizes eaten by elephant seals?
- Which interactions among middle-order predators are likely to be most important in terms of the indirect effects of the fishery on seals and penguins?

The Workshop agreed that the most immediate modeling priority is to develop "strategic" models at the level of complexity of the "minimally realistic model". These models would be used to identify which aspects of the model are most sensitive to input data or theoretical construction, thereby identifying the critical research questions. In addition, the models form the foundation for exploring the ecological implications of different fishing strategies.

5. Heard Islanders, 1858

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The "elephanting" period at Heard Island, from 1855 to 1882, was a significant time when the first human interaction with an otherwise 'natural' environment took place. However, this importance is not reflected in current research. The poster illustrates some of the personalities at Heard Island in 1858. Despite today's unpopular image for last century's "sealers", not all the individuals in the industry were miscreants or criminals (Downes 1996). Without a better understanding of the sealers' life, reaching beyond the simplistic notion that all they did was "kill seals", we cannot know the real history of Heard Island. Nor can we understand the human interaction with a fragile environment, or plan an effective conservation strategy for the future. The few remaining sealers' relics at Heard Island – hut sites, casks, tools, clothing and graves, are our closest link with a past generation of "Heard Islanders". The material is valuable not only because it may provide ecological data. Even more importantly, the relics are a cultural communication between generations, the basis for an empathy which helps understanding between people of a different time and culture. The relics are located on a shore-line which is subject to great topographical change over periods as short as one decade. Valuable material is being lost year by year. Why do we let this happen? Ultimately, this has happened because, as a community in a 'busy' technological age, we have little sympathy for the past and less inclination to consider its complex significance for the future. Perhaps too, these relics remind us that "we were not the first at Heard Island" – other people, (of whom we do not quite approve), once lived and worked in "our wilderness".

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6. Heard Island regional oceanography

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Heard Island is Australia's most distant territory, and its remote location in the Southern Ocean, halfway between Perth and Cape Town has made oceanographic study difficult and surveys infrequent. Despite this remoteness, there is considerable interest in its fish populations and in the characteristics of the surrounding ocean. Systematic surveys of fish populations have been undertaken for a number of years in a large area within the 200 nautical mile (365 km) EEZ that surrounds Heard and MacDonald Islands. Together with the Kerguelen Islands, 550 km to the north, these islands sit on the shallower (200-500m) northern half of the Kerguelen Plateau, which extends south at greater depths (1000-1500 m) nearly to Antarctica. The most biologically productive area is the 200-500m undulating plateau that lies mostly to the north and east of Heard Island. A series of shallow (200m) banks have been the focus of repeated surveys by Williams and Green from the Australian Antarctic Division. In conjunction with the biological studies, three comprehensive physical oceanographic surveys were carried out, all on the RV *Aurora Australis* as part of the ANARE program. The first was in 1990, christened HIMS (Heard Island Marine Science), the second in 1992, called FISHOG (FISHeries and oceanOGraphy), and the third in 1993, called THIRST. Three current meters were also moored in 1990, 50 km east of Heard Island, which yielded 9 months of continuous records. Analysis and interpretation of these records and the oceanographic data are included in this paper.

7. Interactions between fur seals and marine resources in the Antarctic Polar Frontal Zone over the Kerguelen Plateau

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A three year French-Australian collaborative study investigating the importance of the Antarctic Polar Frontal Zone (APFZ) to marine predators (fur seals, king penguins and Patagonian tooth-fish) and their prey (principally myctophid fish and squid) over the Kerguelen Plateau commenced during the 1997-98 summer. The study will be conducted over three consecutive seasons at Iles Kerguelen (1997-98 to 1999-2000). In the final year a similar study on fur seals will be conducted simultaneously at Heard Island. This presentation will summarise the results of the first seasons' work at Iles Kerguelen, the work planned for Heard Island, and make recommendations for planning and logistics for this and other predator-prey investigations planned for Heard Island in the 1999-2000 season.

During February and March 1998, shore-based studies were conducted on the Corbet Peninsula, Iles Kerguelen on Antarctic fur seals and king penguins. These studies were undertaken to determine the three-dimensional distribution of foraging effort, and utilised satellite transmitters and time-depth recorders. Diet was also investigated using faecal and stomach contents. Sea-based studies were undertaken by researchers utilising '*La Curiuse*', a 45m oceanographic vessel stationed at Iles Kerguelen. The foraging locations of satellite tracked fur seals and king penguins were followed using the ARGOS system, and these positions were used to plan systematic trawl surveys of prey species. Trawl surveys were conducted over a 45 day period, consisting of 5 day campaigns alternating between the fur seal foraging zone, king penguin foraging zone, and the laboratory at Port-Aux-Francais (Iles Kerguelen). In the fur seal foraging zone, '*La Curiuse*' conducted four west-east transects, with five trawl stations along their length. Trawls were conducted at night (when fur seals feed) through the scattering layer, usually between 0-80m. Similar trawl surveys were conducted through the king penguin foraging area. French fisheries observers working on legal fishing vessels operating in the same region surveyed by '*La Curiuse*', determined the diet of the commercially caught Patagonian tooth-fish (via stomach content analysis), which is also an important predator of mesopelagic fish and squid. Research planned for fur seals over the 1999-2000 season at Heard Island will seek to compliment the simultaneous study being undertaken at Iles Kerguelen. As the APFZ lies between these two islands, this simultaneous study aims to highlight the importance of this productive zone to high order predators, and aims to quantify the foraging efficiency, and mass-transfer efficiency (milk delivered from mother to pup) of lactating fur seals breeding at sites north and south of the APFZ. Efforts will also be made to determine the status of the fur seal population by accurately censusing pup production. The last comprehensive census was conducted in 1987-88.

The recent predator-prey-fisheries workshop (Australian Antarctic Division 1997) identified many gaps in our knowledge of the trophic relationships between mesopelagic prey and their major

predators, and highlighted the need for further integrated predator-prey studies. The predator-prey studies being undertaken in French waters over the Kerguelen Plateau demonstrate how successful such programs can be, and provide an excellent framework for similar studies in Australian waters over the Kerguelen Plateau. Further, the Australian Antarctic Division should attempt to integrate their studies as much as possible with those being undertaken in French waters. The possibility of Australian and French researchers sharing resources, particularly ship time, should also be considered.

8. Sea surface temperatures at Heard Island

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Sea temperature was measured at Spit Bay weekly from April 1992 to March 1993. Water was collected in a plastic bucket from the sea off the beach cobbles in front of camp. The temperature was recorded at the same period of the day (morning) to avoid any confounding effect of diurnal temperature variation. A standard meteorological thermometer (Dobbie -20° C to + 60° C) was stood in the water until the temperature steadied. Temperature was then recorded to the nearest 0.1° C. To determine whether the shore temperature reflected that offshore, the temperature taken from the shore at Spit Bay on 8 March 1993 was compared with those taken on the MV *Icebird* on 11 and 12 March 1993 whilst it was anchored off Spit Bay. Temperatures recorded from the ship ranged between 3.2° C and 3.4° C; similar to the 3.4° C recorded from shore The temperatures at Spit Bay were graphed against those recorded in Atlas Cove in 1949 (Figure 1).

Sea temperature at Spit Bay dropped from about 3° C in April to late June and then fluctuated around 1° C throughout the winter (reaching a low of 0.4° C on 19 October) before rising from late November. These are similar temperatures to those given for Antarctic surface waters at the Antarctic Convergence in summer and winter respectively (Deacon 1933). Average minimum air temperatures were about the same at Atlas Cove in 1949 and Spit Bay in 1992 (Green 1993), this temperature is the one most likely to affect the water temperature. Ealey and Chittleborough (1956) found at Atlas Cove that island air temperatures lowered the water temperature, with the effect being greatest closer to shore. The site used in 1949, by Ealey and Chittleborough (1956), was about 400m offshore (station II) over nine metres of water in the comparative calm of Atlas Cove, whereas the present data came from within the wave zone so that cold air was more likely to mix with the water, thus cooling it. Atlas Cove too is affected less by glacial outflows whereas outflows from the Stephenson Glacier would have cooled the waters near Spit Camp, with Stephenson Lagoon freezing to a depth of about 50 cm throughout winter. Despite this, the waters at Spit Bay in 1992 were higher than at Atlas Cove in 1949. Surface water temperatures recorded in Atlas Cove fell to below zero in 1949 and sea ice was recorded in mid July and early August (Ealey and Chittleborough 1956). The photograph in Ealey and Chittleborough (1956) shows that the ice was not just a skim on the water but quite robust pancake ice. These factors together would indicate that although the two sites are not strictly comparable, the higher sea temperature recorded in 1992 at Spit Bay compared with 1949 at Atlas Cove, was not an artefact of the site but was indicative of a general warming of the surface waters around Heard Island. Temperatures recorded at Atlas Cove in 1949 did not differ much from the 0.9° C to 1.2° C taken in Corinthian Bay in 1929 (Howard and Sverdrup 1940). These data suggest that sea temperature rises around Heard Island are a recent phenomenon. This view is supported by the accelerated erosion of coastal features since the early 1950s.

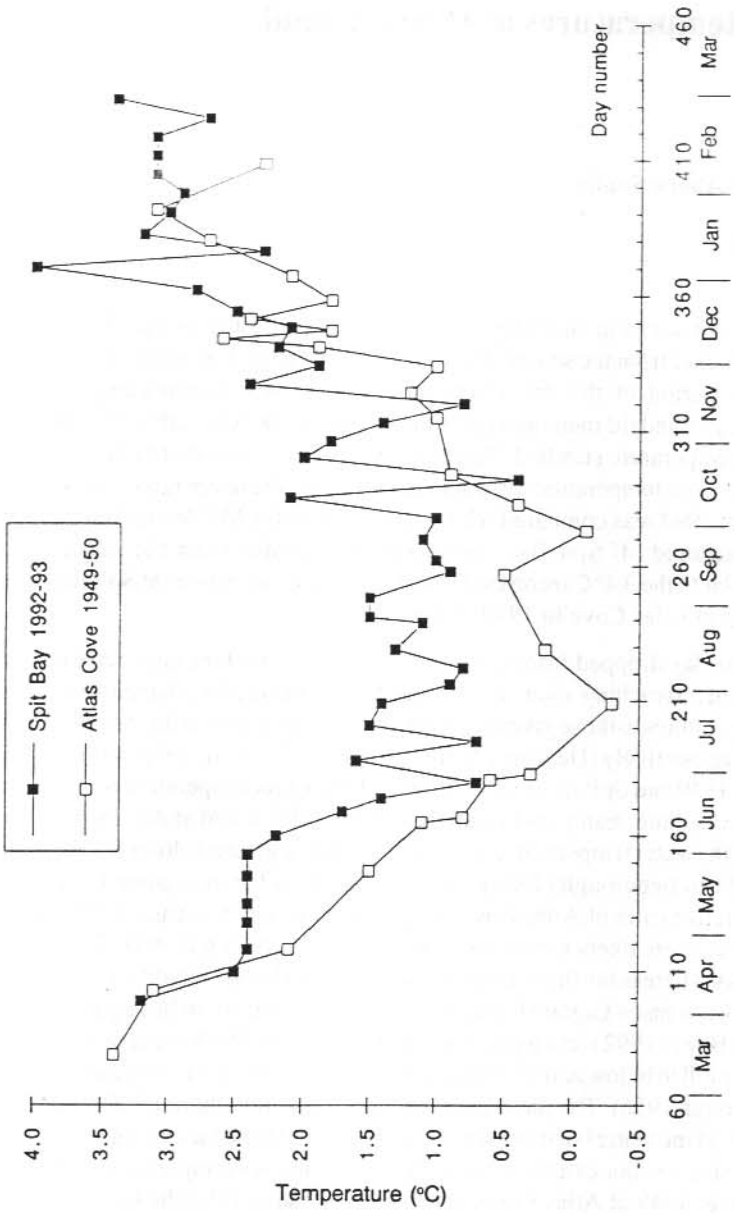

Figure 1. Sea temperature at Spit Bay 1992-93 and at Atlas Cove 1949.

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9. Coastal Landform changes at Heard Island

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The satellite image map with coverage of Compton Glacier for 9 September 1988 shows clearly the retreat of the Compton Glacier. This was a large ice front on the December 1985 edition of the Natmap Heard Island 1:50 000 map and the changes to 1987-88 were mapped by Kirkwood (1989a). The latest estimate of the location of the ice front is shown in Figure 2 of Green (1993). Photographs taken during the erection of the Black Hole (refuge hut) at Spit Bay in 1951 show the Stephenson Glacier jutting out to sea and providing a breakwater, protecting the shore from the strong south-easterly water movement along the coast. The retreat of this glacier is probably the main cause of the accelerated erosion east of Stephenson Lagoon. During 1992, waves came up over the tussocks to within two metres of Spit Bay Camp and the vigorous action of the waves removed boulders placed in front of the Black Hole with one concrete boulder being found 60 metres away.

There has been a general loss of sandy beaches on the north-east coast at Skua Beach and Spit Bay. The frontage at the tryworks at Skua Beach was gradually eaten away in a number of storms in 1992 so that the trypots, inland in 1987, were slowly undermined with the outermost falling onto the beach in December 1992 and disappearing in early 1993. Kirkwood (1989b) reported the tryworks at Spit Bay to be about 30 metres inland in 1987-88, Green (1990) reported "extensive beach erosion" at the tryworks which were about ten metres inland, but by 1993 this had reduced to three metres.

The freshwater Stephenson Lagoon became tidal in 1992. This was the result of storms that deepened and straightened the outlet through the terminal moraine. Water samples taken from Stephenson Lagoon in March 1993 measured 17.9 parts of salt per thousand at 22°C compared to 26.7 parts per thousand for seawater collected off Spit Bay, indicating a considerable mixing with the sea. The tidal nature of Stephenson Lagoon might now lead to the more rapid retreat of Stephenson Glacier. The land on the eastern side of Stephenson Glacier is very low lying (and may in fact be below sea level beneath the ice). Unless there is sufficient material deposited there, it is possible that in a very short time, the waterways between Stephenson Lagoon and Glacial Stream may become connected. This would lead to the creation of a channel between two Heard Islands.

Elephant Spit was complete from early in the year to September 1992. The end of Elephant Spit became an island again, connected to the spit by shallows as late as February 1993 when a crossing could be made to Spit Island. Changes in the orientation of Elephant Spit are evident from comparisons with early sealers' maps. Observations from Long Ridge in 1992 suggested that the Spit had curved further to the north since 1990.

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10. Diving behavior of Antarctic fur seals (*Arctocephalus gazella* Peters) around Heard Island

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The diving behaviour of Antarctic fur seals around Heard Island is characterised by different modes of foraging in different seasons and by different sexes. Differences in foraging ecology between the Heard Island region and other areas where the species has been studied are not reflected in intra-sex differences in diving behaviour. Females foraged to the north-east of the island at night and at shallow depths on schooling fish, resulting in a similar diving pattern to krill-feeding seals elsewhere. However, males generally fed on benthic and bentho-pelagic fish on the shelf around Heard Island or foraged to the south of Heard Island in deep water on the deep scattering layer at depths greater than 200 m with some travelling to Antarctic waters in winter to feed at shallow depths, presumably on krill.

11. An overview of the invertebrate fauna of Heard Island: biodiversity, distribution and ecology

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The first terrestrial invertebrates were collected on Heard Island in the 19th century and since then there have been numerous further collections and one comprehensive survey, that of Brown in 1974. As a result the arthropod fauna of the island is fairly well known and all species so far recorded were listed in the Heard Island Management Plan published in 1995. The fauna consists of ten collembolan, five coleopteran, one thysanopteran, three dipteran, nineteen lice, two siphonopteran, one lepidopteran, thirty four acarine, one spider, and seven crustacean species. There are also one snail, two earthworm, four enchytraeid, five tardigrade and twenty two rotifer species recorded. A further seven tardigrade species have been described since 1995. This gives a total of 124 species for the island. The nematodes and protozoa, however, are not well known so the complete list of terrestrial invertebrates is likely to be more than 150. The fauna has low numbers of pterygote insects and relatively high numbers of mites and springtails, which is characteristic of cold, moist localities. In this respect the fauna, although about a third the size, is similar in composition to that of Macquarie Island, except that weevils are absent on Macquarie.

Studies on the invertebrate fauna made in the summer of 1987-88 and for twelve months from 1992-93 concentrated on obtaining information on densities, distributions of individual species and in detecting annual patterns of activity. The results have not been published and will be reported here. Collections were made in summer by extracting animals from soil cores, litter samples and from pitfall traps from five vegetation types, *Poa* tussock grassland, Meadow, Fellmark, *Pringlea* and *Azorella* vegetation types at Atlas Cove. Densities obtained from soil cores indicated that there are large differences between vegetation types. Highest numbers were found in the *Pringlea,* lowest in the Fellmark and intermediate numbers in the other three vegetation types. The most abundant group collected was the Acari, followed by the Collembola and then by Diptera larvae. Other taxa were in low abundance. Surface active fauna showed different patterns as pitfalls set in *Poa* trapped the largest number of individuals and those in Meadow the fewest, with the other vegetation types being intermediate. The numerically dominant group in pitfalls were adult Diptera followed by Acari, Araneae and Coleoptera.

The influence of the severe environment on species morphology and life history was evident in the Diptera. The most abundant fly, *Anatalanta aptera,* with catches of over 50 individuals per trap day in summer from *Poa* and *Pringlea,* showed a higher level of asymmetry in collections from Meadow, *Azorella* and Fellfield vegetation where it was at its ecological limit, than from *Poa* and *Pringlea.* Females of *A. aptera* were most active early in the season in December while males remained active throughout the summer. Teneral individuals were detected only in January, while on Crozet, where the climate is less rigorous, this species breeds throughout the year.

Eight species of Collembola were collected in soil cores in summer 1987-88, all of which showed preferences for different habitats. Although *Poa* had consistently the highest numbers of Collembola in samples, only two species showed a strong preference for *Pringlea*, one other species was totally

restricted to *Azorella* vegetation, another had a preference for *Poa* and the other four showed a preference for meadow and/or *Azorella*.

Pitfall trap collections made at Spit Bay at monthly intervals for a year in 1992-93 in the same vegetation types indicated that part of the fauna at least is active throughout the year under snow. Traps caught few Collembola except for exceedingly high numbers of *Archisotoma*, a marine littoral species, in *Poa* in winter, presumably a result of storm activities.

Information on Acarina and Curculionidae will also be documented.

12. Marine geoscience research in the Kerguelen Plateau/ Heard Island area

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The Kerguelen Plateau is a NNW-trending ridge 2100km long and located between 45°S, 65°E and 63°S, 83°E. It is about 500 km across and rises 3 to 4 km above the surrounding ocean floor. Kerguelen, Heard and McDonald Islands are peaks on the northern half of the plateau. Water depths on the southern half are as shallow as 700 m but are mostly between 1500 m and 2500 m. In this paper the available geophysical and sediment core data are summarised.

Geophysical surveys have been carried out on the Kerguelen Plateau by the Australian Geological Survey (AGSO) and French institutions have conducted seismic reflection and sampling programs using the Marion Dufresne (Ramsay *et al.*, 1986). Multi-channel seismic data have been collected by the Russian Research Institute for the Geology and Mineral Resources of the World Ocean and a recent series of cruises of the *Rig Seismic* has also been completed mapping the EEZ around Heard and McDonald Islands as part of AGSO's Law of the Sea program (Symonds *et al.*, 1998).

Piston cores were collected from the region during Eltanin cruises, mostly in deep basins next to the plateau, by the *Robert Conrad*, and by the *Marion Dufresne* (Schlich, Wise *et al.*, 1989). ODP leg 119 (Barron, Larson *et al.*, 1989) and leg 120 (Schlich, Wise *et al.*, 1989) drilled 11 holes on the Plateau. Short gravity cores were collected on the Plateau in 1993 and 1995 (O'Brien *et al.*, 1995) using the *Aurora Australis*.

Based on the interpretation of these data sets, a broad geological framework for the setting of Heard Island may be developed. The Plateau is not a fragment of continental crust, but rather it is derived from extensive oceanic volcanism starting from around 120 million years ago (Ma). Eocene volcanogenic sediments on Heard Island give a minimum age for the island (Quilty *et al.*, 1983). Munschy *et al.*, (1989) proposed a three-phase evolutionary history of the Plateau: (1) pre-rift tectonic period from 72 to 42 Ma; (2) breakup between the Plateau and the Broken Ridge, accompanied by a non-deposition period; and (3) post-rift sedimentation that evolved in the Plio-Pleistocene due to climate changes (Howard and Prell 1992). Thick sediment drift deposits adjacent to the base of the slope have been clearly imaged in recent seismic surveys and may contain useful palaeo-environmental records for the region (Phil Symonds, pers. comm. 1998).

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13. The importance of 'historic sites' on Heard Island for protection of scientific resources and environmental management of a world heritage site

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Heard Island has recently been designated as a World Heritage site, largely because of its unique environmental qualities as the only island in the sub-Antarctic without alien plant and animal species. The island also has unique and interesting historic sites relating to both sealing and later scientific activities, which were also cited in the World Heritage nomination documentation. Evidence of human impacts on Heard Island includes sites with generally acknowledged historic value (especially sealing sites, documented by Lazer and McGowan in 1987) and those such as Atlas Cove which are comparatively recent, extremely unattractive in appearance, hazardous to wildlife, and with debatable historic value.

Lazer and McGowan documented the sealing sites on Heard Island, identifying many sites around the island with particular concentrations in the Spit Bay area. A few artefacts of particular interest were returned to Australia, including a unique blubber press that is now in the Queen Victoria Museum in Launceston. Downes has compiled extensive information on sealing era log books and has also investigated dimensions and other data on seal oil barrels. Additional bibliographic information on archaeological and historical studies relating to southern Indian Ocean sites including Heard Island is provided by Cooper and Avery (1986), Graham (1989) and Le Mouël (1994).

Atlas Cove was the first ANARE (Australian National Antarctic Research Expedition) Station and was established in 1947, essentially as a trial for later establishment of stations on the Antarctic continent. Important scientific research was conducted there including pioneering cosmic ray studies. The design of the buildings at Atlas Cove is also historically significant, reflecting a number of attempts to select materials and design features suitable for the cold climate and severe winds. These buildings have now severely deteriorated and fragments are being blown about an area that is a significant breeding area for seabirds and much-frequented by penguins and seals. While the authors (a materials conservator and an archaeologist respectively) would argue that Atlas Cove is historically significant to Australia's Antarctic history, this does not necessarily imply that all elements of the site must be preserved on site.

The ANARE station at Atlas Cove has received less study although photographic documentation by Blunt (during a mountaineering expedition in the early 1980s) and by Hughes in 1992 provide some evidence of the rate of deterioration of structures at this site. Tourism at the island has been sporadic but proposed visits raise issues: a draft tourist questionnaire can be adapted from ongoing research at Mawson's Huts to determine management issues relating to historic sites on Heard Island.

Less information is available on preservaiton of historic sites in sub-Antarctic conditions. Measurements of corrosion rates at Heard Island, Macquarie Island and South Georgia by Hughes, King and O'Brien show corrosion to be a serious problem with conventional corrosion treatments being ineffective. A bibliography of relevant conservation research has been compiled by Hughes and awaits publication. At Heard Island during a brief visit in 1992, Hughes identified high rates of deterioration of timber structures by wind damage, repeated wetting/drying, some defibring and erosion by windborne particles. Some sites on Heard Island are affected by being covered by vegetation (not necessarily deleteriously) and by wildlife (from guano, rubbing and wallowing by seals). Oil Barrel Point at Spit Bay is affected by coastal erosion but is also useful in measuring the rate of erosion of the beach.

The authors will briefly discuss how this existing archaeological and materials conservation data can be used in the study of human impacts on Heard Island and its relevance to environmental management and other scientific projects on the island.

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14. Reconnaissance of the geomorphology of Heard Island and McDonald Island

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The geomorphology of Heard and McDonald Islands (HIMI) is primarily the product of close interaction between vulcanism, glaciation, and vigorous marine processes. The volcanic landforms include the Big Ben strato-volcano (2745 m), scoria cones, domes, lava flows, open vertical volcanic conduits and low gradient lava tubes in which small scale lava flow features are well preserved. Volcanic activity is ongoing from the summit of Big Ben and from Samarang Hill on McDonald Island.

Early but unproven glacial sediments may exist within the Late Miocene-Early Pliocene Drygalskii Formation which forms a 300 m high plateau along the northern coast of Heard Island. Growth of the present glaciers on Big Ben has been partly a response to progressive growth of the volcano. Classical landforms of glacial erosion are not well developed on this very young mountain. Amphitheatres in the surface of some glaciers may reflect a subglacial equivalent of the amphitheatre-headed valleys that develop on fluvially dissected volcanoes. A major debris avalanche hollow on the southern flank of Big Ben has favoured vigorous and erosionally effective ice flow. Depositional glacial landforms include active glacier surface moraines, supraglacially and probably subglacially-formed moraines, and ice front moraines. The latter include lateral moraines, small push moraines and extensive hummocky moraines.

Shallowing of the sea floor 2-4 km off the south coast presumably reflects some combination of bedrock topography, debris avalanche sediment, and glacigenic sediment. Vigorous longshore drift and an abundant sediment supply have allowed rapid progradation of the coast, produced Elephant Spit at the downdrift end of the island, and formed bars from reworked glacigenic sediment that now impound proglacial estuarine lagoons. Some lagoons have enlarged rapidly over recent decades, Compton Lagoon growing from just under 2 km^2 to nearly 4 km^2 between 1980 and Stephenson Lagoon also rapidly becoming much more extensive by progressive wasting of stagnant ice, forward of the active glacier snout.

Rapid historical fluctuations in the sensitive glaciers of HIMI have long been recognised as offering insight into short term climatic fluctuations. Studies of the glacial and coastal sequences offer the possibility of constructing a well dated record of climate change. These studies include radiometric dating of volcanic clasts, and investigation of the relative degree of post-depositional modification to which glacial landforms and sediments have been subjected. The construction of a record also requires determining the history of volcanic activity so that its effects can be discriminated from those of climatic forcing. Research into the geomorphology, surficial sediments and contemporary geomorphological processes is also important to environmental management on land and to management of the adjacent marine environment.

15. Management of the Heard Island lava tube caves

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A rare opportunity exists at Heard Island to preserve a system of lava tube caves, and the values within them, in an essentially pristine condition.

Lava tubes form where the forward flow of molten rock is maintained within a lava flow after the surface has cooled sufficiently to congeal. Caves may remain if the tubes subsequently drain. The lava tubes of Azorella Peninsula on Heard Island are small by world standards but are believed to be the only large bedrock caves known in Antarctic or sub-Antarctic latitudes. A number of significant and, in some cases, fragile attributes are already known from the Heard Island lava tubes, or have the potential to become known. These are associated with the geomorphology, soils, hydrology, cave atmosphere and climate, flora, fauna, microbiology, vertebrate palaeontology and archaeology.

Caves and the phenomena within them may be considered significant for their intrinsic values; for their importance to ongoing natural processes, including ecological processes; or for their instrumental/ economic worth such as their utility for scientific research. Cave managers face the challenge of safeguarding diverse, poorly appreciated and often very sensitive natural and/or cultural values. Difficulties are compounded where there is little detailed information on the resources to be managed, and the site is remote from any management presence.

Non-destructive entry to caves is often impossible. Entry to the Heard Island lava tubes for recreation, tourism or science has the potential to entail serious hazards for the cave environment and possibly also for cave users. Even when great care is taken, research in caves can have environmental impacts at least as profound as those caused by casual visitors, as our experience in maintaining a long term environmental monitoring program in a Tasmanian karst cave has emphasised. One fundamental dilemma at Heard Island is that in seeking to obtain sufficient information to formulate informed strategies to ameliorate user impacts, irreparable damage will probably be caused in the lava tubes. Because of this sensitivity, research programs that might allow a more adequate data base for management purposes may be incompatible with adherence to the vision expressed in the management plan for the Heard Island Wilderness Reserve – that it be retained as a rare, truly pristine area.

Given the acknowledged international significance of Heard Island as a wilderness, and the management issues within the caves, we believe that a policy of safeguarding these lava caves to the maximum possible extent, underpinned by a philosophy that is founded upon a respect for intrinsic values, should be the starting point for their management. The most effective way to achieve this would be their designation as a Restricted Area under the terms of the HIMI Management Plan. If the opportunity exists for any small part of this planet to be left in a pristine condition, then the lava caves of remote Heard Island must be close to the ultimate place, if human curiosity, scientific ambition, economic pressure or politics will allow it to be achieved anywhere.

16. Diatom associations on sub-Antarctic islands as sentinels of climate change

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Diatoms are unicellular algae having silica cell walls with an elaborate and varied patterning that is the basis of their taxonomy. Since silica resists dissolution, diatom fossils preserve well in lake sediments and can provide a record of former communities.

On Macquarie Island, the sediments of former lakes are often readily accessible due to gully erosion. Examination of diatom fossils in lake sediments dating from the terminal Pleistocene to the present has shown a number of distinct associations, certain of which appear to have no links to the present flora of the island. The terminal Pleistocene was a period of relatively cooler temperatures, and these associations may be dependant on cooler conditions than prevail at present on Macquarie Island.

Sub-Antarctic islands provide the only terrestrial records of past climates for a major zone of the earth's surface. Records on islands such as Macquarie Island and Heard Island, which lie close to the Antarctic Convergence, may be especially sensitive to climate change. Only limited use has so far been made of the diatom records on sub-Antarctic islands. The only known survey of diatoms on Heard Island was restricted to marine species and the Heard Island freshwater diatom flora has apparently never been examined.

The climate of Macquarie Island in the terminal Pleistocene/early Holocene may have resembled the present Heard Island climate. This would be indicated if diatom associations, which are restricted to this period on Macquarie Island, now form part of the present Heard Island flora.

17. On their own: towards an analysis of sealers' sites on Heard Island

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This paper examines differences between and the distribution of the suite of sites associated with the nineteenth and early twentieth century sealing industry on Heard Island. This analysis is based on the fieldwork undertaken in 1986-87 by my colleague Estelle Lazer and myself, which followed on from the site records made by Harry Burton in 1985. We recorded over 20 sites on beaches around the southern and northern ends of Heard Island. In this paper I argue that a number of formal differences can be identified in the remains found at the southern and northern ends of the island.

All the southern sites show such formal similarities that they are almost certainly from the same or related operations, and probably date from the last sealing expedition in the 1880s. Here there seems to have been a distinct separation between living and work areas. Elevated stone work platforms were constructed at a number of locations on the southern beaches on which the industrial activities took place. The living huts were located up on the moraines, often in the lee of large boulders. The stone working platforms appear to be a form of sealing architecture unique to Heard Island.

On the northern side, the functional differences are less clear cut, with living and working areas virtually adjacent.

There are a variety of hut styles, and evidence for the use of a variety of materials, including: large stone-based wooden huts at Sealers Beach, a stone and turf-protected tent on a stone mount at Long Beach, and wood-lined stone huts on the northern beaches. There are also some occupied caves. The small six-sided Admiralty Hut built by sealers in the 1920s for the British Admiralty is very different from the larger and earlier stone-based huts.

Finally, I discuss a number of specific interpretation frameworks for archaeological research at Heard. All are fundamentally related to the theme of isolation and include: technology and industrial processes; social separation and isolation and other social issues; economic history; and that recurring theme in archaeology – the colonisation of the world.

18. Setting the scene: Heard Island as part of the Kerguelen Plateau

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Heard Island was recently inscribed on the World Heritage List because of its unique geological features. In addition to its geological value, Heard Island appears unique in that there is no evidence of introduced species, certainly among the larger animals and plants.

It lies in the central southern Indian Ocean at 53°05´S; 73°30´E and has an unenviable reputation for wind and cloud. Like so many other sub-Antarctic islands, the temperature range is very limited and close to that of the surrounding sea. Heard Island's temperature range at sea level is about -2 to + 8°C, and the temperature falls off with altitude but the data are very few. Good weather is rare and a cause for rejoicing! Because of its location south of the Antarctic Polar Frontal Zone, icebergs are seen occasionally from the island. The island commonly is regarded as more Antarctic than sub-Antarctic.

The island is part of the Australian Territory of Heard Island and the McDonald Islands and Australia has defined a 200 nautical mile Exclusive Economic Zone (EEZ) around the territory. This was developed in consultation with the French because Isles Kerguelen are only 376 n. miles away and thus the boundary is almost straight between the islands. There also is a large legal continental shelf because of the bathymetric and sediment characteristics of Kerguelen Plateau.

The history of the island is very complex for what seems at first to be a simple oceanic island. It sits as an exposed part of Kerguelen Plateau, the world's largest submarine plateau, which has a history at least 115 million years long, commencing as a series of horizontal lava flows formed above sea level as India departed from Gondwana and allowed the Indian Ocean to form at about 125-130 million years (Early Cretaceous). After an interval above sea level, Kerguelen Plateau sank and initiated a long history as a site for deposition for carbonate sediments. The basement of Heard Island, visible best around the southern margin of Laurens Peninsula, consists of some of the weakly indurated limestones about 35-50 million years old, formed as part of the depositional process. These were folded or faulted during an unknown interval. The surface has been eroded plane and formed the base for the deposition about 6-10 million years ago of a blocky horizontal rock unit – the Drygalski Agglomerate – which contains evidence of shallow marine conditions and volcanic and glacial influences. It stands out around the island as a solid unit of roughly uniform thickness. It in turn has a roughly flat upper surface and it is on this surface that the volcano of Big Ben was formed, probably mainly over the last one million years.

The island is heavily glaciated with glaciers radiating from Mawson Peak. There are also glaciers on Laurens Peninsula. Maximum residence time of the ice on the island is not known but estimated at 100 years. Glaciers have been in marked and documented retreat since the occupation of the island in 1947.

About 85 km west of Laurens Peninsula lies McDonald Island which appears to have been occupied only twice by humans and thus has value because it appears pristine. Until recently, it was thought to have evolved over the last 100 000 years with the youngest known eruption age of about 35 000 years.

In 1992, pumice in large quantities washed up on Heard Island and was identical in composition to the rocks composing McDonald Island. This was taken as evidence of a submarine eruption in the area. In March and April 1997, the northern end of McDonald Island was seen in eruption.

Like so many features of the Antarctic and sub-Antarctic, there are doubts about who first saw Heard Island. Certainly it was seen and recorded by Peter Kemp from Magnet in November 1833 and by the whaler Thomas Long in 1849. John Heard, accompanied by his wife Fidelia, sighted the island in November 1853, and other records exist of sightings in 1854 and 1855, but it remained for Erasmus Darwin Rogers of Corinthian to make the first landing in March 1855. He returned soon after and began sealing operations.

Sealing flourished until 1888. During this time, sealers commonly came for a three year interval. Visiting captains commonly brought their wives but there are no recorded instances of wives going ashore on Heard Island during this period.

The island was visited in 1902 by the German Erich von Drygalski who produced the first scientific report. In January 1929, E. Aubert de la Rue wrote a geological report based on field work when he was accompanied by his wife Andrée, apparently the first woman ashore on the island. In November 1929, Sir Douglas Mawson on his British-Australian-New Zealand Antarctic Research Expedition (BANZARE) spent time on and around the island. The Australian National Antarctic Research Expeditions (ANARE) established a station on the island in December 1947 and this was occupied continuously until December 1954. There have been periodic visits for scientific reasons (Australian and international), ham radio operators, mountaineers, and in recent years, tourists.

The British did not name the island for Heard but the name was popular (under a variety of spellings) by the sealing community and it has assumed respectability by usage. Although originally claimed by the British, it was transferred to Australia by 'exchange of notes' on 19 December 1950 and Australia formally assumed responsibility in 1953.

19. The sensitivity of glaciers at Heard Island to climate change, and their recent response

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Key Words: Heard Island, glacier, climate change, modelling, Indian Ocean

Heard Island is a large volcanic cone (Big Ben, 2750 m ASL) situated in the south Indian Ocean. Its glaciers are able to provide unique information regarding climate change in a very remote and predominantly oceanic region.

While some glaciers have undergone major recession since the late 1940s, others have shown little change in extent.

Field observations are few and a number of glacier-climate modelling techniques are implemented to obtain a better understanding of glacier behaviour. It is shown that glacier retreat has typically been for those glaciers of a low elevation range. Not only are these glaciers sensitive to a balance shift, but they often have low mass flux and a large percentage of area at low elevations. These glaciers often originate at elevations not much higher than 1500 m and are largely situated on the lower flanks of the volcanic cone of Big Ben or on the Laurens Peninsula. Ablation of these glaciers is dominated by ice melt rather than calving into the sea. Steady state analysis and time-dependent glacier modelling suggests that a warming of at least 0.8°C has occurred since 1947.

In contrast, the glaciers of large elevation range (e.g. Gotley Glacier) have larger neves and their estimated balance flux at the ELA is greater. Due to the proximity of the ELA to sea-level, there is little percentage change in balance flux over the ablation area, and ice loss is largely due to calving rather than melt. Any increase in this melt component due to warming is small and has little effect on the integrated balance flux before the calving front. This is supported by the lack of recession on these glaciers.

The observed response of glaciers of varying hypsometry on Heard Island conforms well with the sensitivity of alpine glaciers to climate change, as described in previous studies. However the island has volcanic activity and, although there is little evidence to support an increase in this since the 1940s, a geothermal contribution to the observed retreat cannot be discounted.

20. Vegetation/habitat mapping and associated studies 1986-1988

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Key words: vegetation mapping, wildlife habitats, vegetation colonisation, deglaciation, wildlife/vegetation interaction, species distribution, trampling.

A series of vegetation-related studies was undertaken on Heard Island over the two summers 1986-87 and 1987-88. This work is documented in the references, which comprise published papers (Scott 1989a, 1990) and detailed unpublished field reports (Scott 1989b, c, d). The main studies are briefly outlined below.

Vegetation/habitat mapping.

Detailed vegetation/habitat mapping was undertaken during 1987-88 using aerial photos taken in 1980 and 1986-87 (Scott 1989d). Vegetation was mapped by habitats, ie with relation to its use by wildlife, in recognition of the close relationship between a number of the vegetation communities and the animal and bird populations using them (Scott 1989b, c). The majority of ice-free areas were field-mapped, and approximately two thirds of areas were groundchecked. Compilation of the maps, analysis of fixed-quadrat data documenting seasonal changes in wildlife/vegetation interactions, and analysis of the vegetation community/habitat data, is in now in progress after a gap of some years. The vegetation community data complements that of Bergstrom, and collaboration on further analyses is planned.

Vegetation colonisation after deglaciation.

Analysis of vegetation transect data collected from seven glacial retreat zones indicated four main patterns of primary colonisation (Scott 1990). Deglaciation patterns since 1947 were mapped using airphotos and field investigations. A series of longterm transect sites and photo-points were established, and predictions for further changes were made. The occurrence and distribution of the cosmopolitan grass Poa annua is of particular interest.

Patterns in distribution of vascular plant species around the island.

Separate ice-free areas act as "mini-islands" affecting distribution patterns of some vascular species, while changes in distribution of some species have been noted (Scott 1989a, 1990). This work complements Bergstrom's documentation of bryophyte distribution patterns.

Seasonal growth studies and effects of human trampling on Azorella selago.

A series of seasonal growth measurements of the cushion plant *Azorella selago* was undertaken over a range of habitat conditions, as well as measurements of foot trampling in *Azorella* "cushion-carpet" vegetation on fixed sites over two seasons (Scott 1989c). The data can be used to predict short and longterm effects of human trampling impact on this vegetation community.

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21. Marine biota of the shore communities of Heard Island – history of investigation, relationships to other regions, and future work

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Studies of the shore communities of the sub-Antarctic region have variable emphases with some areas receiving more concentrated effort than others, for example Macquarie Island, the Kerguelen Islands, Marion and Prince Edward Islands, and South Georgia. An impetus for the work in these remote areas is the establishment of a permanent or long-term base. The abandonment of a base at Heard Island in the 1950s has left Heard Island somewhat in isolation, with the gathering of ecological information relying on intermittent expeditions.

The biota of the Heard Island shores have characteristics in composition and local distribution that are typical of the sub-Antarctic biogeographical region. The shores are dominated by algae and these are the main organisms that set visually obvious zones down the shore. Lichens form a fringe area at the top of the littoral zone. These zones are only part of the story. There is a rich flora and fauna within and across these zones; however studies to date at Heard Island have primarily been concerned with recording what is there, drawing associations with the biota of the southern ocean, describing the distribution of littoral organisms, and a study of the standing crop of the giant kelp, *Durvillaea antarctica*. Some experimental work has been done offshore in relation to epifaunal growth on artificial substrate (rope fibre) and the survival of fauna in *Durvillaea* holdfasts. Findings from previous work have shown affinities for the Heard Island biota with the sub-Antarctic region, despite the location of the island south of the Antarctic Convergence.

Further work on Heard Island requires the following themes:

(1) To continue collections of marine biota to add to the assessment of the biogeographical origins and affinities of the benthos of this island;

(2) To concentrate on particular biota for quantitative measurement of population structure. The selected species will be ones that have shown sensitivity to disturbance in other sub-Antarctic locations, thereby establishing baseline levels for any future analysis of possible changes to the benthic community structure of the shore of Heard Island, from both climatic and human influences;

(3) To investigate the reproductive modes of collected marine invertebrates, which will assist in the understanding of possible mechanisms by which these animals disperse around the sub-Antarctic ocean, either from their own propagules or by survival mechanisms on drifting kelp.

These lines of investigation will integrate with the studies proposed by S.D.A. Smith on the communities of holdfasts of *Durvillaea antarctica*, both in their attached state and as drift algae.

22. Community structure of *Durvillaea antarctica* holdfast fauna: baseline data collection

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The invertebrate fauna of holdfasts of various kelp species have proved to be sensitive indicators of the effect of human impact over a wide latitudinal range. One of the main reasons for this would appear to be the fact that the holdfast habitat provides a diversity of niches and is consequently populated by a high diversity of invertebrate taxa which respond differently to various environmental factors. Previous studies have shown that community structure changes in response to a range of environmental factors, including depth and exposure to wave action, and that the effect of these types of factors need to determined before the impacts of any anthropogenic disturbance can be reliably quantified. For example, research on the impact of a small oil spill at Macquarie Island indicated that effects were detectable in the *Durvillaea antarctica* holdfast community when other oiled habitats had recovered, but the interpretation of some of the results was hampered by the lack of preimpact data from the study sites.

Preliminary data from two small collections (10 samples in total) of *Durvillaea antarctica* holdfasts indicate that the habitat supports a diverse array of taxa at Heard Island. Further sampling from a number of locations on Heard Island will provide a quantitative baseline against which future impacts, both natural (e.g. rise in sea-temperature) and anthropogenic, can be evaluated.

The evaluation of holdfast community structure at Heard Island is also of importance in investigations of the biogeography of marine invertebrates in the Southern Ocean. It has been hypothesised that kelp rafts, coupled with the West Wind Drift, are the main dispersal mechanism for marine invertebrates in the Southern Ocean. *D. antarctica* was the most common species of kelp observed afloat during recent observations between Hobart and Macquarie Island (over 95% of the total). It can therefore be hypothesised that transport between islands, of animals associated with this species of kelp, would result in greater inter-island similarity of the species composition in the holdfast habitat than for any of the other intertidal habitats. Collection of holdfasts and data on the structure of shore communities (see related paper by R. D. Simpson) will allow a quantitative test of this hypothesis.

23. The potential for dispersal of marine invertebrates by rafts of *Durvillaea antarctica*

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Previous studies of the marine invertebrate fauna inhabiting islands within the Southern Ocean have highlighted the fact that there are a number of species with circum-polar distributions. The most popular theory to explain the wide dispersal of these taxa is that animals can be transported between islands attached to floating objects, and in particular to kelp rafts, under the influence of the West Wind Drift. There are a number of assumptions that need to be met if this hypothesis is to potentially explain invertebrate transport across the Southern Ocean. Three of these are that: (i) kelp rafts are present in sufficient abundance to facilitate dispersal; (ii) kelp rafts maintain sufficient buoyancy to be transported large distances; and (iii) invertebrate taxa living on kelp fronds or in the kelp holdfast can survive prolonged periods afloat. This study addresses the first of these assumptions.

During the summer of 1997-98, observations were made from the *Aurora Australis* on the abundance and species composition of kelp rafts between the latitudes of 46 - 53° S. Floating kelp was quantified on three transits between Hobart and Macquarie Island by counting kelp that passed within 50 m of the port side of the vessel over observation periods of one hour. The latitude and speed of the ship were noted for each kelp sighting. Data were subsequently standardised to the number of kelp rafts counted per 10 nautical miles (18.5 km). The results indicated that *Durvillaea antarctica* was the most common kelp species accounting for over 95% of rafts observed; all of the other rafts were of *Macrocystis pyrifera*. The average abundance of kelp was 3.4 rafts per 18.5 km, 30% of these with an attached holdfast. Extrapolating to the full Southern Ocean between these latitudes, and assuming that these are representative observations, this puts estimates of floating kelp rafts at a staggering figure of over 70 million, approximately 20 million of which have attached holdfasts.

This brief study suggests that there is an abundance of potential vectors for the dispersal of kelp-associated invertebrate fauna in these sub-Antarctic latitudes. Further data collection is needed to determine the actual dispersal of marine invertebrates and this can only be achieved by collecting rafts at sea and identifying and enumerating the species that are most commonly transported.

24. Current status of the seabirds of Heard Island and the McDonald Islands

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A total of 18 species of seabirds are known to breed at Heard Island and at the McDonald Islands. Another 10 species have been recorded as non-breeding visitors. There have been approximately 12 scientific visits to Heard Island since the establishment of the ANARE station at Atlas Cove in December 1947, but only 2 recorded visits to the McDonald Islands, in 1961 and 1980. There have also been visits by private expeditions, on which some scientific data were collected. Visits by ANARE during 1947-54 and 1985-86 to 1987-88 were characterised by major attempts to map and survey breeding seabird populations. Winter visits in 1990 and 1992 examined the foraging ecology and behaviours of penguins.

The review will summarise the available empirical data for all breeding species at Heard and the McDonald Islands, compiled from published and unpublished papers, narratives, field logs and other sources, under the following headings:

- distribution and abundance, conservation
- population trends and dynamics
- foraging ecology, diet and at-sea distribution/movements
- energetics and prey consumption
- general biology, timing of breeding, morphometrics

25. Heard Island Wilderness Reserve Management Plan: a self-help guide to better relations with the bureaucracy

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Two notable events have altered the status of the HIMI Territory since the last significant presence on Heard Island (ANARE 1992 winter):

- a management plan for the Territory was released in 1995
- the Territory was inscribed on the World Heritage List in 1997

World Heritage inscription was on the grounds that:

> "... this site is the only volcanically active sub-Antarctic island and illustrates ongoing geomorphic processes and glacial dynamics in the coastal and submarine environment and sub-Antarctic flora and fauna, with no record of alien species."

Australia first nominated the Territory to the World Heritage List in 1990 but a decision was deferred, partly due to the lack of a management regime. The World Heritage Bureau wanted to be confident that Australia had appropriate measures in place to preserve the values for which the Territory was inscribed. The Management Plan was instrumental in the successful nomination of the Territory in 1997. It has legal standing by virtue of the legislation that created it: the Territory of Heard Island and McDonald Islands Environment Protection and Management Ordinance 1987 (HIMI EPMO), and its parliamentary endorsement. However, it is made all the more important because of an international commitment to abide by its provisions under the World Heritage Convention.

The Plan's overarching management vision is "to allow natural processes to proceed with minimal human intervention and [to] assign highest priority to conserving [the Territory's] environment, its value to research and its unique cultural heritage". Read in conjunction with Management Goal 2: Research Support, the take home message is that permits will only be issued for research that assists in the management of the Territory, or research that demonstrably "cannot be adequately undertaken elsewhere" (although these clearly need not be mutually exclusive).

Undoubtedly many, if not the majority of the proposals to be considered by ASAC for the 1999-2000 program will qualify broadly under one or other of these categories. However, programs that can be tailored so as to more clearly meet the goals and objectives need to be encouraged. Consideration should be given, where possible, to incorporating into planning those things identified as management priorities. Instances of this are:

- 6.25. "...the extent of microscopic introductions on Heard Island is unknown but needs to be addressed by future research activities..." see Section 9.7.

- 6.28e. "When practicable undertake a comprehensive survey of the biota of the Territory, including the microflora and microfauna, concentrating on areas of human activity (past and present). Establish a monitoring program based on this survey to enable the detection of introduced species"

as well as a number of the cultural heritage strategies.

Whatever the outcome of deliberations, the ultimate test of whether a program should or should not proceed will be whether it "can be achieved without degrading the values of the Territory" (6.50, HIMI MP). The notion of degradation is value-laden and takes us into the area of research ethics. This will be touched upon in a subsequent session.

Acknowledging that this workshop is principally about *what* science might be undertaken, the limited time ashore and the limited berths available will mean that the *how* will also be under consideration at this time. In this context it is important to note that the zoning system elaborated in the management plan imposes clear constraints.

The Territory is divided into four main zones:

- Main Use Areas – Atlas Cove and Spit Bay
- Restricted Access Areas – all of the McDonald Islands, Sail Rock, Shag Rock and Drury Rock
- Wilderness and Heritage Areas – all the remaining terrestrial area
- the Marine Zone

Due to the likelihood of restrictions being imposed through the permits process on transport useage, type and extent of accommodation, careful consideration needs to be given to choice of location. Note particularly that permits will not be granted for research in the Restricted Access Zone unless it can be demonstrated to be for "essential management or compelling research purposes".