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Recommendations for future directed research to describe the biodiversity of the Ross Sea region

Graham Fenwick and Janet Bradford-Grieve

Final Research Report for
Ministry of Fisheries Research Project ZBD2000/01
Objective 2

(*Revised*)

National Institute of Water and Atmospheric Research

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Report Title:	Recommendations for future directed research to describe the biodiversity of the Ross Sea region.
Authors:	Graham Fenwick and Janet Bradford-Grieve
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5. Project Leader:	Janet Bradford-Grieve
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7. Executive Summary

1. This report develops recommendations on communities or habitats for future directed research to improve knowledge of the biodiversity of the Ross Sea region of Antarctica. It is based on a detailed literature review of Ross Sea marine biodiversity completed under Objective 1. This report addresses Objective 2. Although biodiversity and fisheries management underlie the Ministry of Fisheries' responsibilities in the Ross Sea, human pressures was not a dominant criterion in selecting communities for research under Objective 2.
2. Biodiversity knowledge advances by an iterative process of research, theory development, prediction and testing. All types of research, from highly focussed taxon-specific investigation to studies of the functioning and structure of communities and ecosystems as a whole, are integral to this process. Such research can involve working with existing data and collections, doing new work in the field, or working within the umbrella of some larger, initiative, such as the Victoria Land Latitudinal Gradient Project involving multi-disciplinary scientists from at least New Zealand and Italy.

3. Communities are treated as synonymous with habitats for this review, largely because there are few well-defined, discrete communities in each of the major habitats within the Ross Sea. Coastal zone communities are recognised as those inhabiting 0-500 m depth within 10 km of the shore.
4. Communities/habitats for potential investigation included the sea ice community, plankton, intertidal biota, benthos, fish, seabirds and marine mammals. Two of these, plankton and benthos, are divided into coastal and oceanic communities or habitats.
5. Eight criteria were identified for evaluating Ross Sea region marine communities on their priorities for future directed biodiversity research. These were state of current knowledge, exposure to human impacts, spatial extent, species richness, biotic abundance, ecological importance, logistical resources required to do the necessary research, and value or relevance of information on the community to end users of the knowledge.
6. According to these criteria, coastal zone (0–500 m depth, < 10 km from shore) communities or habitats should be given highest priority for future investigation because, with the exception of some oceanic fishing activities, human pressures are likely to be greater inshore, coastal zone communities are more likely to differ than those offshore which, where well enough known, tend to be pan-Antarctic, biodiversity is generally higher in coastal waters, there are excellent opportunities to collaborate with other science programmes in coastal waters, and on-going research at multiple locations within successive years is more practical.
7. Within the coastal zone, sea ice communities and coastal benthos should be accorded highest priority for future research. Next highest in priority for research are krill, especially in the vicinity of Balleny Islands, then fish and other larger predators (fish, birds, seals, whales). Deeper water (oceanic) benthos and plankton are considered lower priorities for future research.
8. Future research on lower priority communities should be re-evaluated whenever there are opportunities to use existing data or collections, or to receive significant support, such as collaborative research opportunities from other nations or agency, or when there is a significant change in key evaluation criteria (e.g., commercial deepwater trawling commences in the region).

8. Objectives

Objective 2. On the basis of the review conducted in 1 above (A review of the current knowledge describing the biodiversity of the Ross Sea region), make recommendations on communities that could be the subject of directed research to describe the biodiversity of the Ross Sea region in future years.

9. Methods

As attached.

10. Results

As attached.

11. Conclusions

As attached.

12. Publications

As attached.

13. Data Storage

Contents

1. Introduction

This report addresses the second of three objectives of a project aimed at reviewing the current knowledge of the biodiversity[1] of the Ross Sea. Overall, this review is intended to provide a platform for directing future research to further the Government of New Zealand's environmental policies and interests in the Ross Sea region of Antarctica (historically known as the Ross Dependency).

Objective 1, a detailed review of information describing the marine biodiversity of the region, laid the foundations for Objectives 2 and 3. These latter two objectives seek recommendations on future directed biodiversity research in the region, based on findings from the review completed under Objective 1. Objective 2 focuses on biodiversity research that is not immediately related to human impacts, whereas Objective 3 focuses on identifying communities that are or are likely to come under pressure from human activities in the near future.

1.1 The brief

This report addresses the second objective of a comprehensive review of the marine biodiversity of the Ross Sea region of Antarctica commissioned by the Ministry of Fisheries. Objective 1 was a wider review of the current knowledge of the region's biodiversity. The brief for Objective 2 requested:

> "recommendations on communities that could be the subject of directed research to describe the biodiversity of the Ross Sea region in future years".

In requesting proposals for the overall review and in subsequent correspondence (letter 2 May 2001), the Ministry of Fisheries reiterated that research to be recommended under this objective should be distinct from that sought under Objective 3 (marine communities at risk). However, given the context of the overall project and the Ministry's responsibilities, research recommendations under Objective 2 should be relevant to New Zealand Biodiversity Strategy and the Ministry of Fisheries' Marine Biodiversity Programme (J. Burgess, pers. comm., Dec 2001). Therefore, these research recommendations do not simply focus on communities "that are under high pressure or likely to come under high pressure from human activities in the near future" (Objective 3). Instead, they focus on communities and habitats that are more removed from immediate pressures, but not necessarily immune to or protected from human pressures now or in the future.

1.2 Context for research opportunity evaluation

To develop the context for recommendations for future directed research in the Ross Sea region as detailed in this report, we précis the Vision and four Goals of the New Zealand Biodiversity Strategy. The Ministry of Fisheries is charged with facilitating achievement of the Vision. Therefore, we have focussed on identifying possible research in the Ross Sea region that would advance this Vision.

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[1] Biodiversity was defined as the variety of genomes, species, and ecosystems occurring in a geographically defined area (NIWA 2000).

1.2.1 The New Zealand Biodiversity Strategy

In February 2000, the New Zealand Government released its Biodiversity Strategy, detailing the Biodiversity Vision and four biodiversity goals, as well as action plans and strategic priorities. The Strategy specifically includes the marine environments of the New Zealand mainland, its various outlying islands, and of the Ross Sea region of Antarctica.

The Biodiversity Vision and Goals

> **"A Vision for Aotearoa – New Zealand**
>
> New Zealanders value and better understand biodiversity;
>
> We all work together to protect, sustain and restore our biodiversity, and enjoy and share in its benefits, as the foundations of a sustainable economy and society;
>
> Iwi and hapu as kaitiaki are active partners in managing biodiversity;
>
> The full range of New Zealand's indigenous ecosystems and species thrive from the mountains to the ocean depths; and
>
> The genetic resources of our important introduced species are secure, and in turn support our indigenous biodiversity.
>
> **Goal One: Community and individual action, responsibility and benefits**
>
> Enhance community and individual understanding about biodiversity, and inform, motivate and support widespread and coordinated community action to conserve and sustainably use biodiversity; and
>
> Enable communities and individuals to equitably share responsibility for, and benefits from, conserving and sustainably using New Zealand's biodiversity, including the benefits from use of indigenous genetic resources.
>
> **Goal Two: Treaty of Waitangi**
>
> Actively protect iwi and hapu interests in indigenous biodiversity; and build and strengthen partnerships between government agencies and iwi and hapu in conserving and sustainably using indigenous biodiversity.
>
> **Goal Three: Halt the decline in New Zealand's indigenous biodiversity**
>
> Maintain and restore a full range of remaining natural habitats and ecosystems to a healthy functioning state, enhance critically scarce habitats, and sustain the more modified ecosystems in production and urban environments; and do what else is necessary to
>
> Maintain and restore viable populations of all indigenous species and subspecies across their natural range and maintain their genetic diversity.
>
> **Goal Four: Genetic resources of introduced species**
>
> Maintain the genetic resources of introduced species that are important for economic, biological and cultural reasons by conserving their genetic diversity."
>
> (www.doc.govt.nz/conservation/The-New-Zealand-Biodiversity-Strategy, February 2000)

Relevant themes for future research in the Ross Sea region are:

- better understandings of biodiversity by both individuals and society at large,
- protecting and sustainably using biodiversity, and
- that this understanding and protection should include a full range of indigenous ecosystems, habitats, species and subspecies from ocean depths to mountain tops.

Further, the understanding is not simply scientific understanding, but an understanding by society at large, so that people generally, comprehending their effect upon and dependence on biodiversity, are motivated to conserve biodiversity. Such conservation, under the Convention on Biological Diversity (which underpins Goal Three), should be of natural habitats and ecosystems as the best means of conserving species and their genetic diversity.

1.2.2 Ministry of Fisheries' imperatives

The Ministry of Fisheries' Marine Biodiversity Programme is part of the overall New Zealand Biodiversity Strategy. Its stated aims are "to improve understanding of New Zealand's marine biodiversity by improving the management of marine biodiversity information, increasing our knowledge of selected marine communities – including Antarctica's Ross Sea and threats to coastal and marine biodiversity" (www.fish.govt.nz/sustainability/biodiversity/introduction.htm).

2. Approach

2.1 Definitions

Biodiversity: Knowledge of the biodiversity encompasses not only qualitative knowledge of its flora and fauna, but also a quantitative knowledge of its communities/ assemblages, the functional inter-relationships of species within these, and their interactions with the physical environment. These functional inter-relationships may include trophic interdependence or habitat interdependence. Knowledge of the factors leading to resilience or vulnerability of species and communities to natural and human disturbance is also extremely important in making management decisions related to sustainable use.

Ross Sea region: Following the report for Objective 1 (Bradford-Grieve & Fenwick 2001), the Ross Sea is defined as occupying the area between Cape Colbeck (150° W) and Victoria Land (160° E) within the 3000 m isobath (south of 60° S) and encompassing the Balleny Islands. It includes the sea beneath permanent and semi-permanent ice in the region, notably the Ross Ice Shelf.

Communities: The request for proposals used the term "communities" to describe the units of importance for this objective. Within the context of this project, we interpret this use of "communities" to encompass any group of marine species populations that occurs together, generally comprising mosaics of assemblages at different stages of recovery from disturbance. Also, as used here, the term communities is generally synonymous with habitats, since the species populations present in a habitat are largely dependent on the habitat's physical and chemical characteristics, as well as its inherent biological properties.

2.2 Identification of knowledge gaps and research opportunities

Knowledge gaps were identified from the scientific literature of the region and specialist knowledge of similar habitats in other seas, including Antarctica. Authors of some papers on aspects of Ross Sea biology and contributors to the Objective 1 report identified questions or issues that they considered worthy of attention. Many of these questions have been included, especially if future research on the issues raised were likely to add new biodiversity information for the region.

Other gaps in our knowledge of the Ross Sea region became apparent when compiling the BioRoss database and species lists for each main marine habitat. These gaps are described below.

3. Knowledge gaps

There are two general approaches to understanding the ecology of marine communities and ecosystems. In looking for explanations of observed distributions, one approach is to work from the general to the particular. This is akin to a systems approach, where the focus is on a community or an ecosystem. The alternative approach is to first see animals and plants as the sum of their morphological, natural history, and physiological characteristics, building up understandings from these particulars to develop generalities about populations and communities. Taxonomic, biogeographic and life-history investigations are examples of the latter, very tightly focused approach, that provide fundamental knowledge of biodiversity and its distribution patterns. Both approaches have inherent strengths and limitations and, when used together, provide complementary insights into biodiversity at several levels, especially interactions between ecosystem elements, including the physical factors which drive ecosystem processes. A combination of both approaches, therefore, seems best for developing knowledge of the Ross Sea region biodiversity.

3.1 Community-focussed research needs

All identified communities in the Ross Sea require further research, especially research that is quantitative, to enable adequate assessment of threats to biodiversity and sustainable management. Furthermore, the biodiversity of some communities requires further investigation to determine whether the different assemblages present represent distinct communities or simply variants of a more ubiquitous, but plastic community. For example, the marked patchiness of the shallow water benthos on rubble bottoms in McMurdo Sound may be due to long recovery times from numerous small-scale natural disturbance events in the past, rather than the presence of distinct communities, each responding differently to environmental conditions. Even where communities appear distinct, there is usually inadequate knowledge of their quantitative structure and function, and variations in time and space. Thus, there are numerous, often wide gaps in knowledge of the biodiversity of the region's marine communities. Several of the more obvious research needs are outlined in Appendix 1.

3.2 Taxon-focussed research needs

Sound definition of the fundamental elements of biodiversity (i.e., species and genera) is essential to almost all biological investigations. Without the ability to make reliable statements about the identities of taxa or resources present, especially key species, or the compositions of major communities, much biological work becomes meaningless. Further, replication, one of the main elements of scientific advancement, becomes impossible. In the words of Paul Dayton (1990: 674), the pre-eminent Antarctic benthic ecologist, "all evolutionary, biogeographical, and ecological research absolutely depends on competent systematic research".

Work on the taxonomy (and systematics) of Ross Sea biota is still far from complete. Many species have been described, but others are still inadequately known or completely undescribed. The review of the region's biodiversity (Bradford-Grieve & Fenwick, 2001) highlighted a number of key gaps in taxonomic knowledge of the Antarctic benthos. Groups that have been well investigated include: sponges, Foraminifera, Bryozoa, echinoderms, molluscs, and algae. Significant gaps in knowledge include the Cnidaria (Coelenterata) and several crustaceans, notably amphipods, cumaceans and isopods. Most meiobenthic organisms are very poorly known and deserve attention (e.g., harpacticoid, cyclopoid and poecilostomatoid copepods, podocopid ostracods, protozoans, nematodes and annelids). These gaps could be filled, in part, from existing collections (see Appendix 2) and/or in a targeted or opportunistic manner depending on priority given to a community/taxa. Any new collecting for taxonomic investigations ideally should be nested within natural history studies and broad-scale sampling of key habitats.

Note that while some species are small in size (e.g., copepods), population sizes and biomasses may be huge over the total region. Further, many of these small animals grow and reproduce very rapidly over summer months so that, collectively and cumulatively, they represent a significant amount of living tissue that is vital to the food chain. Thus, neither the size of individuals, nor the biomass present at one point of time, is necessarily a reliable indicator of a species' importance in the Ross Sea marine ecosystem.

At this stage, taxonomy-based investigations should be aimed at achieving several biodiversity objectives, rather than simply producing lists of taxa for the region. As far as practical, they should produce fundamental information on species, such as their specific habitats (e.g., living in the oscula of the sponge *Sphaerolylus antarcticus*) and associated taxa, quantitative abundances, biomasses and sizes, and develop detailed information on geographic and bathymetric distributions. Whilst this is rarely practical when working from past collections, it should be a vital part of taxonomy-based investigations using new collections. Further, the resulting data should be incorporated into electronic databases, preferably linked to GIS applications, and made available to the Ministry of Fisheries' National Aquatic Biodiversity Information System and key international databases, such as that in preparation by the Australian Antarctic Division and others associated with SCAR and DIVERSITAS (e.g., the Belgian National Research Programme's on the Antarctic's Reference Centre for Antarctic Marine Biodiversity).

Studies of life-histories and their diversities within individual taxa or communities, whilst often intriguing and adding an additional layer to biodiversity knowledge, should generally be accorded lower priority for investigation. The obvious exception is where one or more species' life histories are tightly coupled with key aspects of community ecology. For example, significant planktonic/pelagic predators (e.g., Antarctic silverfish and Ross Sea toothfish) appear so abundant and important in the dynamics of the whole marine ecosystem that focussed investigations of their biology and ecology should be given priority. Particularly significant for ecologically important species are estimates of age, fecundity, population growth and mortality rates and dispersal, because these factors largely dictate the potential for recovery following natural or anthropogenic disturbance. In some instances, detailed investigations of ecologically important species (e.g., the keystone predators that control composition of the McMurdo sponge community (Dayton 1972; Dayton et al. 1974)), including aspects of their life-histories (e.g., gonad size, ova size), may provide clues to incipient changes in the habitat and its community before these changes become apparent at community levels. Investigations of such bio-markers holds considerable promise.

Several important taxon-related research needs are outlined in Appendix 2.

3.3 Implementing research opportunities

Given the substantial logistical resources required to carry out research in the Ross Sea marine environment, it is important to seek alternative means of acquiring biodiversity information that may not involve dedicated trips to Antarctica. Some of these alternatives and the nature of research possible are identified below.

3.3.1 Using existing data and collections

Although the original data gathered by the various faunal and floral studies in the Ross Sea may not be readily available, key elements of it, if not the entire data set, can be reconstructed from some studies. Such data offer opportunities for re-analysis using more recent methods and re-interpretation. In other instances, notably many taxonomic investigations, there is a lot of information in the literature, but much of this has never been extracted or analysed to explore ecological, biodiversity or biogeographic questions. These opportunities should not be overlooked, especially in view of the high costs of collecting data anew in Antarctic regions.

a. Improved knowledge of flora and fauna

Much of our present knowledge of the Ross Sea region's biodiversity results from the detailed work on collections made by early scientific expeditions (e.g., the British Antarctic (Terra Nova) Expedition 1910–13). However, while collecting continues, analysis of collections has received lower priority in recent years. In particular, many of the numerous benthic collections made by the various Eltanin cruises and other US research cruises in the Ross Sea remain largely unexamined (Picken, 1985; Bradford-Grieve & Fenwick, 2001). Collections from New Zealand expeditions and cruises, notably the Endeavour cruises of 1958–60, have been incompletely investigated. These collections represent significant resources awaiting analysis.

b. User-friendly tools for identifying key taxa

The work of many taxonomic experts is not readily accessible to ecologists and the scarcity of accessible, user-friendly identification tools presents a substantial impediment to biodiversity research. The records and descriptions of particular floras and faunas are often scattered widely in different publications published over more than 100 years. Scientists now have opportunities to synthesize their work and to create more user-friendly identification tools. There are now computer-based systems (e.g., Linnaeus II, Delta) for developing and running interactive, illustrated keys that are easy for ecologists to use (e.g., see www.crustacea.net).

c. Quantitative definition of marine communities/ assemblages

As part of Objective 1 of this contract, we created a relational database (BioRoss) of the marine biota reported from all collecting locations in the region. Although much work remains to make BioRoss comprehensive and up to date, this database is potentially a significant resource on the distribution of the biota and for identifying communities using modern, statistically-based community analysis programmes (e.g., Primer).

Very useful conclusions could be developed from these data, even though it may be impractical to add all of the old collection records to the BioRoss database, because translating original identifications into modern nomenclature is very costly. For example, these data could be used to define the qualitative species richness at sampled points, and to identify major communities, especially using taxonomic distinctness measures (Warwick & Clarke, 2001). Also, analyses of data on the distributions of specific groups (e.g., Bryozoa) using distinctiveness metrics may clarify broader scale distribution patterns and facilitate understanding the degree of endemism within the Ross Sea region.

More useful data for identifying and quantifying communities could be obtained by completing analysis of more recent collections from the region that have not been analysed at the community level.

d. Understanding ecosystem energy flows

Abundances or standing stocks may be poor indicators of the trophic importance of some elements of an ecosystem. For example, a group that has a relatively small biomass may superficially seem to be unimportant. But a species with a low standing stock (biomass), and high production/biomass ratio could produce much more living biomass than is evident from its standing stock alone. Such groups (e.g. squids) are very important, especially if they are a dominant food item in an ecosystem.

Therefore, another essential aspect in understanding the resilience and vulnerability of Ross Sea biodiversity is determining the rates of biological processes occurring there, the production/biomass and consumption/biomass characteristics of the biota, and knowledge of the standing stocks of functional groups of the biota. Recent research has examined such processes occurring in the Ross Sea, especially at the beginning of the food web (e.g., Faranda et al., 2000; Smith & Anderson, 2000; Anderson & Smith, 2001).

Models can be powerful tools for understanding ecosystems (Knox, 1994). In the past, a few models have been applied to the Ross Sea. Green (1975, 1977) created and refined a compartment, linear donor-controlled model of the Ross Sea pelagic ecosystem. This model was extremely complex, required additional data, and did not include benthos. More focussed models of selected components of ecosystems are likely to prove more useful, at least in the next decade (Howard-Williams, pers. com. February 2002). A steady-state, balancing model (Ecopath with Ecosim) is now readily available (http://www.ecopath.org/). These models deal solely with energy transfer between compartments within ecosystems and they can be used successfully to illustrate the potential consequences of removing specific groups of predators (e.g., fish). This type of model should be used to investigate the trophic links and dynamics of the Ross Sea ecosystem over broad space and time scales. Such research would help to translate information on food web functioning into terms relevant to resource managers, particularly for management of fisheries. Such models could also show where further information is needed and allow informed judgements on the vulnerability of the Ross Sea system.

3.3.2 New field work

Obviously, existing data and collections are inadequate to address many of the information gaps and research opportunities outlined above, especially functional ecology. New fieldwork is essential, especially to investigate of the spatial distributions and temporal changes in key communities and resources at different scales and for characterising and quantifying trophic and other relationships and rates important in ecosystem functioning. In the Ross Sea, many of these relationships and rates are strongly linked to physical factors, particularly sea ice dynamics, which also require investigation.

Both shore-based and ship-based investigations are essential for future research in the region. Further, in order to maximise efficiencies, it will be important to use remote-sensing technologies extensively. These include towed video/still camera sleds, ROVs (Remotely Operated underwater Vehicles), sonar image analysis, digital side-scan sonar, QTC-Impact, telemetry, satellite imaging, as well as other technologies.

3.3.3. Collaborating with international programmes

a. Latitudinal ecosystem responses to climate across Victoria Land

Much is to be gained from nesting New Zealand projects within other international programmes. The rationale and underpinning for a proposed programme to investigate latitudinal gradients in the Ross Sea is given in Berkman et al. (2001). The April 2001 workshop, held under the auspices of SCAR, aimed "to establish common research themes among diverse Earth system scientists with a view toward:

1. providing the scientific and logistic framework for a coordinated interdisciplinary research initiative along the north-south trending Victoria Land coastal region of Antarctica; and
2. describing marine-terrestrial biocomplexity along the latitudinal environmental gradient of Victoria Land, Antarctica, as a global barometer of climate change" (Berkman et al., 2001: 1).

This report points out how the proposed programme links with other research programmes in the Antarctic and Southern Ocean, such as those proposed by New Zealand (Peterson & Howard-Williams, 2001), Italian and US scientists (see also http://www.antcrc.utas.edu.au/scar/programmes.html). The workshop concluded that "The programme is ideally suited for a biocomplexity initiative because it reflects the "*interplay between life and its environment*" across:

- a latitudinal gradient that parallels the predominant trend of ice-sheet expansion and retreat associated with global climate changes;
- time in a region where habitats and ecosystems were re-established after the ice-sheet retreated at the end of the Last Glacial Maximum (around 13,000 years ago);
- ecosystems living at the liquid margin of life where climate changes have an amplified impact on the liquid-solid phases or water; and
- pristine and disturbed ecosystems responding to human impacts from local sources (such as research stations) and global sources (such as the ozone hole and global warming).

Moreover, the coastal zone along Victoria Land has an extensive history of ecosystem and environmental research (albeit generally lacking in integration) that dates back to the historic expeditions of the early 20th century. This rich background of research activities and momentum from the scientific community provide that framework for designing and implementing an interdisciplinary and international research initiative along the latitudinal gradient of Victoria Land, Antarctica" (Berkman & Tipton-Everett, 2001: 10).

Although the overarching aims and rationale of the three national programmes on latitudinal gradients in the Ross Sea are probably broader than the Ministry of Fisheries' biodiversity needs in the region, access to results from all international participants seems certain to repay New Zealand's relatively small contribution.

b. Co-operation with other national Antarctic programmes

Co-operative research programmes in the Ross Sea region between individual or teams of New Zealand scientists and those from other nations may be one way to increase the rate of biodiversity knowledge acquisition. Recent discussions (March 2002) between the national Antarctic research programmes of New Zealand and Italy focussed on joint logistics and joint ship voyages to cover future marine biodiversity research in the Ross Sea.

Note, because many species and deeper water communities are pan-Antarctic, some research under taken elsewhere (e.g., in the Weddell Sea by Germany) may be relevant to the Ross Sea region, although ecological rates may need checking locally. Thus, collaborative research with researchers working beyond the Ross Sea may also contribute knowledge useful to our understanding of Ross Sea biodiversity.

Whenever any joint research projects develop, it would seem appropriate to encourage the research to address biodiversity needs identified here and to request that any data be stored in a readily accessible database within New Zealand.

c. Research with CCAMLR

Whilst all of the research proposed here is likely to be of potential interest to the Commission for the Conservation of Antarctic Marine Living Resources, opportunities for undertaking research in the Ross Sea in association with CCAMLR appear very limited. CCAMLR has no funded research programmes, but some New Zealand scientists are working with some CCAMLR member nations on Antarctic research initiatives.

4. Criteria for evaluating communities and issues to research (Section 5)

As a second step in attempting to identify communities/habitats for future research, a set of criteria against which each alternative could be evaluated was sought. This was not straightforward. Especially problematic was the issue of the nature of a good biodiversity research programme. For example, should a biodiversity research programme aim to describe all entities at increasingly coarser levels of aggregation, or should it attempt the opposite? Alternatively, should it overlook the detail to focus on the higher-level energy flows between habitats and communities and then proceed to understand the overall system in more detail?

This section explores the development of biodiversity knowledge, and then examines one international biodiversity research programme as an authoritative interpretation of the term and description of the nature of a biodiversity programme. A set of criteria is then developed from this and the Ministry of Fisheries' imperatives.

4.1 Biodiversity knowledge and research

4.1.1 Development of biodiversity knowledge

At least six broad types or levels of biodiversity knowledge and research can be identified:

1. intra-species genetic diversity,
2. species or other taxon diversity (usually qualitative),
3. community composition (usually quantitative),
4. variation of community composition in space and time,
5. processes causing changes in community composition, and
6. processes integrating communities into ecosystems.

These different levels represent knowledge at increasingly higher levels of biological organisation, and extensions of the taxon-focused versus community-focused dichotomy identified above (Section 3). Ideally, research should progress from finer scale knowledge of individual taxa to the broader scale understandings of ecosystems overall, but this is impractical in practice. Instead, knowledge of broader scale biodiversity is often developed by extrapolations from similar systems and by focussing on a few taxa as key players in the ecosystem's ecology. The process is iterative; research at all levels is incorporated into prediction and testing to integrate understandings across levels and scales in space and time. Biodiversity research, therefore, does not necessarily advance by first knowing what is present and subsequently understanding how entities interact.

All of these types of biological diversity are important. The question then is: what type of research and knowledge is most needed to help manage biodiversity? Or, how can we manage for the long term what's there, without knowing how the whole ecosystem functions? The converse seems equally pertinent: how can we manage the whole ecological system and its processes without knowing the entities involved and their roles?

Species are the most fundamental units of biodiversity because they are the smallest self-contained, self-replicating entities from genetic, evolutionary and ecological perspectives. Thus, it can be argued that they should be the primary focus for managing biodiversity. However, species tend to be tied to particular habitats and ecosystems, so that managing biodiversity requires managing not just individual species, but also the habitats, communities and ecosystems to which they are inextricably linked. Ecologically, species interact with others and their habitats to form communities of multiple species and ecosystems of many communities. The processes occurring within an ecosystem are fundamental to the presence of a species within that ecosystem. On this basis, ecosystems should be a primary focus for managing biodiversity, but, in reality, we almost never gather comprehensive information on the ecological roles of all species within an ecosystem.

In practice, different levels of research tend to take place simultaneously and understandings of ecosystem functioning emerge from studies of key species and communities, as well as extrapolations from other, better known ecosystems. This approach, especially when used iteratively, seems to be effective because it allows early evaluation of an ecosystem's functioning based on very incomplete data, as well as more detailed understandings as more specific and more complete information become available.

4.1.2 Biodiversity research at international level

The International Union of Biological Sciences has established an international programme of biodiversity sciences, named DIVERSITAS. This programme has established broad goals and projects that are very relevant to the New Zealand Biodiversity Strategy. It provides an authoritative, international perspective on the way forward for biodiversity research that may serve as a useful model for developing New Zealand's Ross Sea marine biodiversity programme.

The DIVERSITAS goals are:

- "to promote integrative biodiversity science, linking biological, ecological and social disciplines in an effort to produce socially relevant new knowledge;
- to provide the scientific basis for an understanding of biodiversity loss, and to draw out the implications for policies for conservation and sustainable use of biodiversity" (Anon. 2001: 16).

DIVERSITAS proposes to achieve these goals via the three core projects, each with more specific foci, of its science plan (Table 4.1.3) (Anon. 2001: 17; www.icsu.org/DIVERSITAS/plan.html). The plan will be implemented by synthesising existing knowledge, identifying important knowledge gaps and emerging issues, promoting new research initiatives, fostering links between countries and disciplines, investigating policy implications of biodiversity science and communicating these to policy makers and international conventions.

Each Core Project of the science plan comprises two or more foci and these are interpreted simplistically in Table 4.1.3 (italics). The specific detail of Core Projects 1 and 2 are particularly pertinent here. Core Project 1 implicitly recognises the importance of taxonomy and monitoring in present-day biodiversity research. It also encourages research on poorly known taxa, promotes the development and adoption of new methods, links phylogeny with functional ecology, seeks to understand the ecological and evolutionary processes that shaped biodiversity in the past, aims to understand the effects of human-induced changes to biodiversity on ecological structure and processes, and aims to predict and evaluate the consequences of biodiversity change on ecological services.

Core Project 2 seeks to assess the impacts of biodiversity changes by extending current knowledge to other trophic levels and ecosystems, assessing the effects of biodiversity changes in combination with other environmental changes at larger scales, and extending current research to focus on the impacts of biodiversity change on the supply of ecological goods and services to human societies, so that the future consequences of biodiversity change can be understood and predicted.

It is important to note that, although a directed research effort may speed the rate at which much of the necessary information is acquired, it will be impossible to specify, a priori, all of the elements necessary to understanding the ecological basis of biodiversity. Thus, curiosity-motivated research seems likely to retain a role within a programme of directed research aimed at addressing the foci of Core Projects 1 and 2.

4.2 Research opportunity evaluation

The brief for this report (Objective 2) requires recommendations on communities for future research. Given the importance of this future research and the obvious desirability of making sound decisions that incorporate different perspectives, a non-routine decision-making process involving the evaluation of alternatives on a set of objective criteria could be used. The identification of appropriate criteria for evaluating the different alternatives (research gaps) is a critical step. For this reason, the authors reviewed the Ministry's biodiversity objectives and criteria, as well as discussing this issue with representatives from the Ministry of Fisheries (Jacqui Burgess) and Antarctica New Zealand (Dean Peterson) to explore these criteria.

4.2.1 Actions for marine research

Under the New Zealand Biodiversity Strategy, the Ministry of Fisheries recognises several actions for marine research relevant to its aims, most of which are pertinent to the Ross Sea region. These include protecting marine habitats and ecosystems, improving knowledge of marine ecosystems, sustainably managing marine resources, investing in research to fill gaps in our knowledge and understanding of biodiversity relevant to key threats and enhanced management of indigenous biodiversity (see Appendix 3 for details of these actions).

4.2.2 The Ministry of Fisheries criteria

Based on the above aims and desired actions, the Ministry of Fisheries employs a standard set of criteria for evaluating the merits of proposed research projects for Antarctica and New Zealand under its Marine Biodiversity Medium-term Research Plan (see Appendix 4 for detail). According to these criteria, each research project must do some or all of:

- Improve our current knowledge of our marine biodiversity.
- Address issues that are a priority for achieving sustainable management of the marine environment.
- Provide information that will be accessible and useful to those who need it in management/actions.
- Contribute to our ability to carry out scientific research on marine biodiversity.
- Focus on communities in the Ross Sea region that are considered under pressure from human impacts, have been the subject of little or no research, are considered unique, and/or are considered representative.
- Foster collaboration with international research initiatives.
- Seek to assist research initiatives of other NZ institutions or agencies.
- Generate data that are suitable for inclusion in a National Aquatic Biodiversity Information System.

Although these criteria are not strictly relevant here because they have been established for choosing among research projects and only one of them is concerned with identifying communities/habitats for research priority, they clarify some of the objectives that the Ministry seeks to achieve when selecting specific research projects. Hence, communities/habitats identified for future directed research should be selected with the following criteria in mind: (a) focus on communities/habitats that are considered under human pressures, are poorly known or considered unique or representative; (b) address issues that are a priority for sustainable management; (c) foster collaboration with international research initiatives; (d) assist the research of other New Zealand institutions or agencies.

The criterion for identifying communities/habitats ((a) above) that should receive priority attention for research uses four sub-criteria: human impacts, current knowledge, uniqueness and representativeness. The latter two are difficult to use as criteria for selecting communities because both terms are ambiguous and very difficult to evaluate for many Ross Sea communities, simply because we lack sufficient knowledge of them. Uniqueness implies one of a kind, but may include communities with some rare or unusual species, some spectacular species populations or otherwise charismatic species, and/or occur in restricted geographic areas. Similarly, representativeness may mean typical, common, unremarkable, or covering large areas, but it can be used to describe an example of a rare or unusual community, but never one that is unique.

Given the ambiguities surrounding terms like uniqueness and representativeness, four more precise, semi-quantifiable evaluative criteria that capture key dimensions of a community's or habitat's biodiversity are used instead. These are spatial extent, species richness, biotic abundance, ecological importance (see Section 4.2.4).

4.2.3 Additional criteria for evaluating Ross Sea biodiversity research

There are two other criteria used in evaluating marine biodiversity research projects. Logistical requirement is a significant criterion for Antarctica New Zealand. Potential value to end-users of research information was identified as another important consideration in decision-making on which projects receive funding. The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) was seen as a key end-user and, although New Zealand has not been a significant research contributor historically, it was recognised that the Commission's needs should be considered when selecting future communities and habitats to research. In addition to the Ministry of Fisheries and Antarctica New Zealand, other end-users of Ross Sea region biodiversity information recognised included the:

New Zealand Ministry of Foreign Affairs and Trade,
New Zealand Ministry for the Environment,
New Zealand Department of Conservation,
New Zealand fishing industry and those of other countries,
New Zealand science community,
The New Zealand public (and, presumably, people of the world),
The Commission for the Conservation of Antarctic Marine Living Resources
Scientific Committee on Antarctic Research (SCAR),
United States Antarctic Research Programme,
Italian Antarctic Research Programme, and
Other nations' Antarctic science programmes.

Thus, as well as the explicit criteria established by the Ministry of Fisheries and Antarctica New Zealand, other criteria are emerging as important, so that the total set of criteria used is likely to evolve over time.

4.2.4 Overall criteria

In terms of selecting communities or habitats as priorities for research, the above actions and criteria translate into these considerations:

Current knowledge. Communities or habitats that are poorly known should receive early attention for investigation.

Human impacts. Communities that are exposed to or likely to be exposed to human impacts should be accorded priority for research. For example, communities that may be harvested, damaged or otherwise disturbed by fisheries activities.

Spatial extent. Communities that are believed to cover large geographic areas are probably functionally important, even though the total biotic abundance and species richness (see below) may be quite low. Also, communities that cover small geographic areas, as multiple discrete areas or as a single area, may be vulnerable to environmental change. Communities with either of these spatial extents should receive priority for investigation.

Species richness. Communities with high numbers of species (biodiversity "hot-spots") are often regarded as special and traditionally receive priority for research. This seems to be due to their perceived greater biodiversity value. Communities with naturally low diversities may be less resilient to environmental disturbance and, therefore, could equally be accorded research priority, specifically because of their vulnerability.

Biotic abundance. Abundance of the biota in a community alone is a poor criterion for assigning priorities for researching communities because density, biomass and a combination of biomass and density are not clear indicators of the functional importance of a community and relate little about its diversity. By convention, however, we tend to value communities with high densities simply because of their abundance.

Ecological importance. Priority should be given to researching communities that are ecologically important to the overall ecosystem functioning. Subjective assessments of ecological importance should consider primary production, secondary production and energy exports from the community, provision of habitat and influences on particle and chemical fluxes, as well as the community's spatial extent.

Logistical resources required. The New Zealand Antarctic Research Programme operates with finite logistical resources and does not have vessel funding. In selecting among research projects/programmes, the limited nature of these resources and the implications for other research should be considered. Thus, joint international research programmes that involve sharing logistics are favoured.

Value and relevance. The perceived relevance or value of the research results to the Ministry of Fisheries, as well as to other users of the results, including other scientists, may be considered. Specifically, the research should produce knowledge that is relevant to the assessment and management of human impacts and to the various end-users, as well as relevant to the current knowledge, the specific character and ecological importance of the community itself.

5. Recommendations for future research

In the first instance, future Ross Sea marine biodiversity research should focus on communities and ecological processes that allow us to measure their biodiversity attributes and understand their vulnerability, responses and resilience to environmental variability (both natural and human induced). Particular importance should be given to integrative work that builds on our present level of understanding (see Section 3.3.1d).

We recommend that the coastal zone (see Section 5.1 for definition) marine environment should be the focus for the Ministry of Fisheries' future biodiversity research in the Ross Sea region. First, on-going research in successive seasons and years can be undertaken from shore-based operations that may be moved to different locations within McMurdo Sound during the same season, and appears logistically feasible for Antarctica New Zealand. Note that there is also considerable scope for vessel-based research within the coastal zone and for sharing vessels between national programmes. Second, many of the taxa characteristic of more oceanic and deeper waters are also found in shallower waters, especially in the southern Ross Sea. Third, biodiversity is generally higher in coastal waters and regional differences in populations and communities are more likely here than in oceanic habitats. There tend to be more species within communities and more different communities and habitats in shallower waters, but there is little empirical understanding of the processes driving this higher diversity, further emphasising the need for integrative research. Fourth, additional ecological (e.g., benthic primary production and export) and physical processes (e.g., anchor ice, platelet ice and iceberg scour disturbances) operate in coastal waters and seasonal effects are generally more pronounced. Fifth, there are excellent opportunities for future research in the Ross Sea coastal zone to link and build synergies with a multidisciplinary research initiative (the Latitudinal Gradient Project) examining ecosystem responses to latitudinal climatic gradients under the hypothesis that "ice-driven dynamics control the structure and function of biological systems near the limits of life at high latitudes" (Berkman et al., 2001: 13).

In addition, the Ross Sea coastal zone is more likely to face direct human pressures than many deeper water communities, unless commercial fishing in deeper waters occurs on larger scales or involves destructive methods, such as trawling. Although communities facing human pressures are to be covered under Objective 3 of this contract, biodiversity conservation and management in the face of human pressures underlies the entire Ministry of Fisheries Marine Biodiversity Programme. Further, Ross Sea marine ecosystem productivity and functioning is very closely tied to sea ice. Consequently, understanding how communities within this system function under and respond to changing sea ice conditions, will provide a better basis for determining the extent and biological effects of local coastal impacts and of climate change and climate variability.

Issues for research identified within each of the communities/habitats below are not intended as strictly prescriptive. Instead, they are intended to highlight information gaps and the likely focus of research on each. These issues generally overlap with the gaps identified in the analysis for this objective (Objective 2) that are summarised in more detail in Appendices 1-2.

Communities/habitats are listed below in order of priority (highest priority first) for future directed research. These priorities do not imply that research on any lower priority community should be avoided. Rather, we believe that research on some of the lower priority communities should proceed, albeit with fewer resources and, wherever practical, taking advantage of opportunities to use existing collections or information and/or share resources with other projects or programmes. In particular, research on oceanic communities and fish should be supported whenever shared use of appropriate vessels already committed to operating in the region make this feasible. Joint New Zealand-Italian ship voyages in the Ross Sea are already under discussion (D. Peterson, Antarctic New Zealand, pers. comm.).

Note, although these research opportunities are focussed on communities or habitats and that priorities are assigned to these only, taxon-based research is considered implicitly. Such research is critical to understanding communities and, therefore, also must be part of future research effort.

5.1 Coastal and oceanic research

For the purposes of this programme, the coastal zone is defined as the water mass between high tide level and the 500 m isobath (approximating the seaward margin of the continental shelf) and lying within about 10 km of the shore (Fig. 5.1). This approximates the neritic zone at more temperate latitudes.

Shallower coastal environments are more heterogeneous over several spatial scales and may be more vulnerable to human impacts, indicating that communities at shallower depths should be studied before those in deeper coastal zone waters, all else being equal. In addition, the seasonal fast ice and dense pack ice characteristic of the Ross Sea region are very vulnerable to long-term climate change. This ice apparently exerts a powerful influence over almost every biological process within the coastal zone. Thus, it is important to begin to understand relationships between these processes, sea ice conditions and other physical processes in this environment, so that some longer-term consequences of climate change can be predicted.

Ross Sea oceanic environments appear to be part of the broader-scale circum-Antarctic environment of the Southern Ocean, with little in the way of barriers to the movement of organisms between regions. Thus, most species are regarded as circum-continental in distribution, with the same ecological processes operating in much the same way, albeit at different levels, throughout this environment.

For these reasons, as well as the possibility of continuing some coastal research in McMurdo Sound regardless of vessel availability, research in oceanic environments should be accorded a lower priority, but not excluded from consideration. In particular, any opportunities to undertake relevant research on oceanic communities based on existing data or collections, or using resources (notably vessels) available from other New Zealand or international Antarctic programmes should receive higher priority.

5.2 Coastal benthos: Priority 1

Comprehensive understandings of quantitative benthic biodiversity, the functioning of benthic communities and the pattern and place of this biota within the overall Ross Sea ecosystem is still lacking, despite several investigations of the region's benthos. Thus, there is much to be learned at fundamental levels, as well as about the drivers of spatial heterogeneity at several scales (especially sea ice) and the contribution of benthos to the functioning of the region's marine ecosystem as a whole.

Perhaps one of the more remarkable aspects of biological communities is their highly heterogeneous nature over different spatial scales. These appear to result from differences in substrate type, disturbance history, oceanography, depth, distance from shore and ice conditions. Thus, there are several different benthic assemblages within this coastal zone and several issues yet to be resolved, despite the considerable amount of research already completed on a few assemblages (Dayton, 1990). In particular, analyses using existing data may help to resolve the identities of coastal zone benthic communities.

Future research could add specific detail to and/or complement research in progress. An example, which is building on such research, is the NZ-FRST/MFish supported ICE-CUBE project which aims to:

- develop sampling protocols for estimating the relative abundance of macro-algae and epibenthic macro-invertebrates involving video-image analysis.
- quantify patterns of biodiversity (macro-algae and epibenthic macro-invertebrates), benthic community (bivalves and echinoderms) structure (size, age), and trophic relationships (average diet) at various locations to determine how community productivity is linked to community structure and biodiversity along a productivity gradient (i.e., latitude or the Victoria Land coast).

In the medium term marine biodiversity research in the coastal zone of the Ross Sea could build on the results of such programmes where progress has been consistent with MFish, FRST and Antarctica New Zealand's priorities for research in the region.

Future vessel dependent research projects will depend on relatively rare events of ship availability, especially to investigate deeper coastal benthos, or to investigate shallower benthos on larger scales and/or in areas that would otherwise be inaccessible. Future research that develops or adapts new techniques with wider application for marine research in the region should be encouraged wherever appropriate.

5.3 Sea ice community: Priority 1

The sea ice community, biota living in and on the highly irregular underside of sea ice, appears to be one of the larger gaps in our knowledge of the Ross Sea region's biodiversity, yet it is thought to play a major role in initiating the summer phytoplankton blooms and as a refuge for life-history stages of some important zooplankton (e.g., *Euphausia crystallorophias*). Because of its dependence on sea ice at the water surface, the extent of this community varies widely with sea ice conditions, making it very vulnerable to environmental change.

Future research on this community or habitat should aim to build basic knowledge of its biodiversity and functional ecology, with particular emphasis on research interfacing with and complementing understanding of the physical drivers of variations in species richness, quantitative community composition, productivity, trophic relationships and export of organic material to the plankton and benthos.

While much useful research on this community can be conducted from fast ice, future work should investigate sea ice communities further from shore and extend research beyond the fast ice season by using appropriate vessels. Thus, this community should be accorded highest priority for research when ship time is available, especially for investigations beyond McMurdo Sound. Also, the possibility of using small boats close to shore (perhaps paired, with appropriate operational procedures and back up on stand-by) to research the community once the ice has become more fragmented in late season should not be discounted.

5.4 Role of krill in the Ross Sea ecosystem: Priority 2

Krill (*Euphausia superba* and *E. crystallorophias*) play a central role in Antarctic marine ecosystems because their large, often concentrated populations convert phytoplankton production into animal tissue of a size that is readily captured and consumed by several larger predators, including fish, birds, seals and whales. This is true in the Ross Sea also, especially in the vicinity of the Balleny Islands, where dense concentrations of krill shift with seasons and ice conditions. Although their general distribution patterns and abundances have been studied, there is scope for more research. The focus of future research should be to understand the dynamics of krill populations across the region in more detail, with special attention to the relationships between climate (and latitude), ice conditions, primary productivity, krill population ecology and larger predators.

5.5 Fish, birds and other large predators: Priority 3

Relatively little is known of the Ross Sea fish communities, notably beyond the coastal zone. Certainly, more species are now known as a result of commercial fishing activities over the past few years. However, there has been no intensive exploration of some of the major fish resources of the region, especially by trawling. Detailed investigations of some of the major commercial (Antarctic toothfish) and potential commercial species (Antarctic silverfish) are required. These include not only surveys of stocks in the region, but also detailed investigations of their population biologies and life histories, as well as similar studies of their main prey and predators.

Again, there is considerable synergy and benefit to be gained by linking future research on fish biology and ecology to the proposed latitudinal gradients programme because this provides an over-arching focus leading to more complete understanding of the system as a whole.

As one of the most conspicuous elements of the Ross Sea marine biota, birds have attracted a lot of attention, yet there is still much to learn about this community. They are important in the overall ecosystem because they are amongst the top predators, have voracious appetites, consume large quantities of several important species, are highly mobile, many are very long–lived, and they re-locate nutrients within the region. All birds return to land to breed where they are exposed to a further set of environmental constraints. Thus, birds are very vulnerable to environmental change.

Despite this, and the long history of ornithology in the region, there are some very large gaps in our knowledge of birds. Most of the research on birds has been conducted on land, so that, although the breeding biology of those that breed in more accessible areas is well known, we know relatively little about where and how they feed. Research in other regions of Antarctica has filled some of the fundamental gaps for some species, but yet others remain. The Latitudinal Gradient Project suggests a new focus to integrate future bird research into the broader context of ecosystem functioning and climate change.

Much the same is true for future investigations of seals and whales. Knowledge of their biology and ecology is largely transferable from studies of the same species elsewhere in Antarctica, so that future investigations should be focused around latitudinal effects as predictors of the consequences of global climate change.

5.6 Oceanic benthos: Priority 3

Sampling of deeper water benthos in the Ross Sea has been extremely sparse. Analyses of the samples taken are mostly far from complete, so that the very broad descriptions of deeper water benthic communities in the Ross Sea are unreliable and grossly inadequate. Given the very large areas covered by these benthic communities and our poor knowledge of them, they are accorded a medium priority for investigation, even if they prove to be very similar to benthic communities elsewhere around Antarctica.

The poor state of knowledge of deeper water benthic communities in the Ross Sea region makes it meaningless to attempt to identify specific communities for research. Instead, identification and characterisation of communities in this general habitat should be the first priority for research. This and other important issues for research of deeper water benthic communities in the Ross Sea are outlined in Appendix 1.

There are excellent opportunities for international collaboration to study oceanic benthos in the Ross Sea region. New Zealand, Italian and US scientists have all independently published on and maintain continuing interests in Ross Sea benthos. The New Zealand Latitudinal Gradient Project and the prospect of joint vessel research indicate that collaborative investigations of oceanic benthos are likely and should be supported as a means of rapidly increasing knowledge of these communities.

5.7 Plankton: Priority 4

Plankton are best studied and understood in their broadest context because most Ross Sea planktonic organisms are freely interchanging members of the total Antarctic planktonic community. Although there has been substantial work on Antarctic plankton from open waters, there is still much to learn about plankton in the coastal zone, especially throughout the western Ross Sea and under fast ice. Future proposals must demonstrate a knowledge of past research to assure the Ministry that old ground is not being covered.

There is scope to integrate future plankton research in the region into the proposed Latitudinal Gradient Project, especially if the emphasis of the work is on the relationship of plankton communities to sea ice and focused on the coastal zone.

6. Conclusions

In developing recommendations on communities that could be the subject of directed research to implement the Ministry of Fisheries' Biodiversity Research Plan and the New Zealand Biodiversity Strategy for the Ross Sea, numerous significant gaps in knowledge of the region's biodiversity were identified. Research to fill these gaps can be either community-focused or taxon-focused, each type of research complementing the other. Opportunities for doing some of this research include using existing data and collections, new fieldwork and collaborating with research programmes undertaken by other nations or international agencies.

Biodiversity knowledge emerges from both building up details to develop understandings of the whole system and from studying whole systems at successively finer levels of detail. Both approaches are complementary in a well-designed, comprehensive biodiversity research programme. Such a programme includes research to inventory diversity or richness at various spatial and temporal scales to determine the components of biodiversity and their variation in time and space as its foundation. It also requires research to understand functional inter-relationships between species, communities and their environments, so that biodiversity changes can be predicted from anticipated environmental changes.

Eight criteria were identified for evaluating communities or habitats for future directed research in the Ross Sea region. These were status of current knowledge, the likelihood of human impacts, spatial extent, species richness, biotic abundance, ecological importance, logistical requirements, and the perceived value or relevance of the research results to end-users, especially the Ministry of Fisheries.

Based on these criteria, it is clear that communities in the coastal zone should receive highest priority for future research because they are more vulnerable to human impacts and their biodiversity is more likely to differ from that of equivalent communities in other regions of Antarctica. Considerable relevant and valuable research can be carried out from shore-based operations, although ship-based research also is essential from time to time. In addition, by focusing in this zone, New Zealand scientists can contribute to the Latitudinal Gradient Project, a multi-disciplinary research umbrella linking marine, terrestrial and aquatic biodiversity to climate, as well as sharing in the wealth of detailed physical and other environmental data that will result from other aspects of this programme.

The sea ice and coastal benthic communities should receive highest priority for research based on evaluations using the criteria listed above (Section 4.2.4). By developing a programme covering both habitats, a better understanding of the functioning of the overall coastal zone ecosystem can be developed, thus making a major contribution to future management of the region. Priority also should be given to research that helps place krill and large predators in the context of the Ross Sea ecosystem, especially investigations that increase understanding of the factors driving biomass and production of functionally important species.

Note, these priorities do not mean that research into the biodiversity of the region's oceanic communities should not occur. Rather, any resources not required for coastal zone research should be immediately diverted to support oceanic research in the region. For example, if an international partner provides logistical support for New Zealand's coastal zone research, then priority should be given to supporting research on the region's oceanic communities (krill, fish, birds, benthos), especially if a vessel is available.

7. Acknowledgments

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Table 4.1.3. Summary of the DIVERSITAS Science Plan (after http://www.icsu.org/DIVERSITAS/plan.html).

The DIVERSITAS Science Plan

Core Project 1: Understanding, monitoring and predicting biodiversity change.

Focus 1.1 Assessing current biodiversity. *Or, how much biodiversity is there?*

Focus 1.2 Monitoring biodiversity changes. *Or, how is biodiversity changing?*

Focus 1.3 Understanding and predicting biodiversity changes. *Or, why is there so much biodiversity and what causes it to change?*

Core Project 2: Assessing impacts of biodiversity changes.

Focus 2.1 Impacts of biodiversity changes on ecosystem functioning and ecosystem services. *Or, how does biodiversity change affect what we get from the environment?*

Focus 2.2 Impacts of biodiversity "changes" on human and livestock health. *Or, How does biodiversity change affect us directly?*

Core project 3: Developing the science of conservation and sustainable use of biodiversity changes.

Focus 3.1 Evaluation of effectiveness of the protective measures and incentives for achieving the conservation and sustainable use of biodiversity. *Or, are present mechanisms for conserving biodiversity effective?*

Focus 3.1 Establish scientific approaches for optimising multiple uses of biodiversity, considering possible trade-offs between economic and environmental goals. *Or, how can we use biodiversity to optimise both economic and ecological goals?*

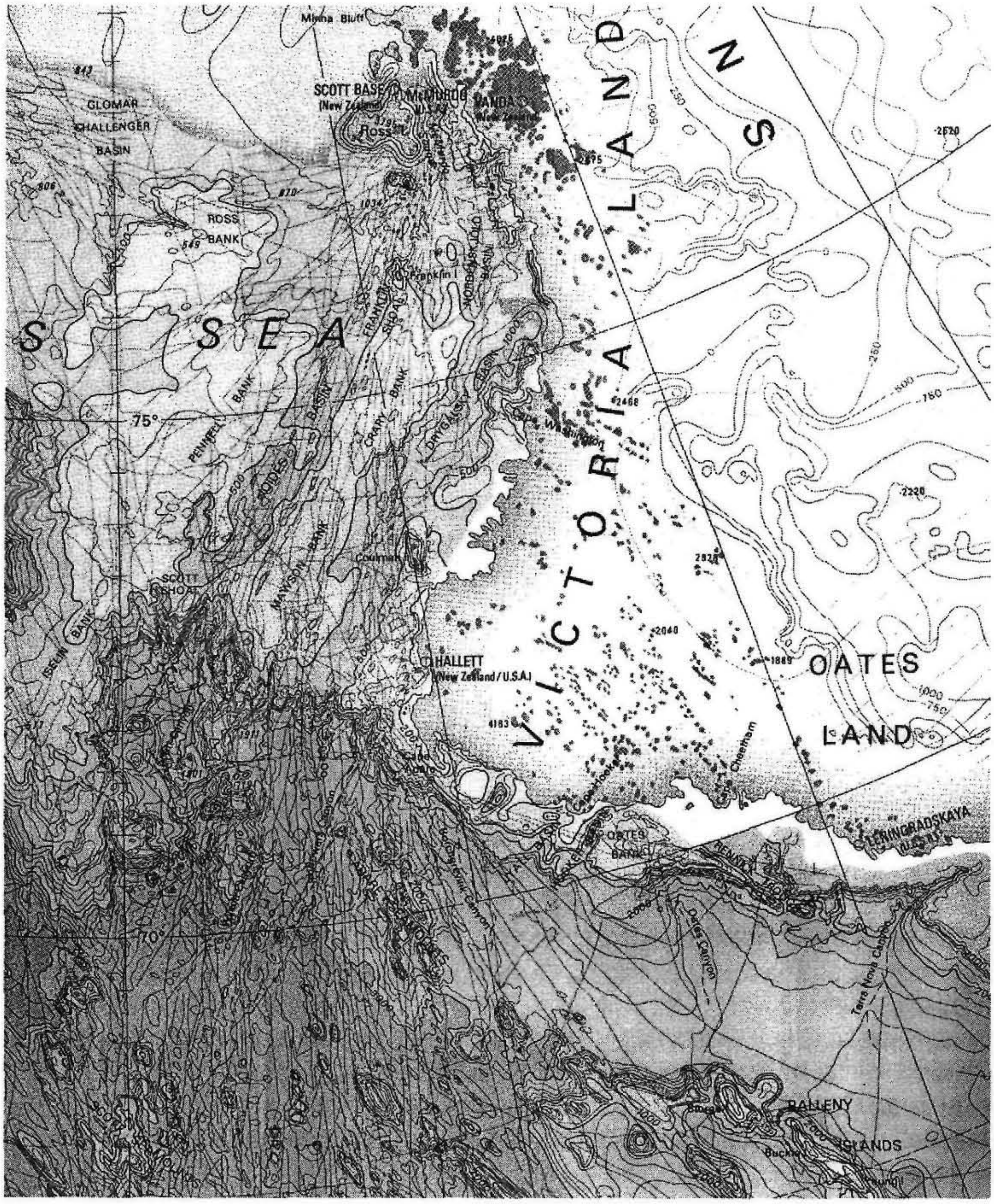

Figure 5.1. Map of the Ross Sea showing extent of the coastal zone (areas within 500 m depth and 10 km of land).

Appendix 1. Outline of some important gaps in the knowledge of Ross Sea marine biodiversity from a community perspective, identified from the review of the biodiversity of the region (Objective 1).

Community-focussed research needs

Most major communities within the Ross Sea region need further work on species richness, community identification and definition, spatial and temporal variation, and functional ecology. Thus, instead of summarising all biodiversity information gaps for each community, we have attempted to identify major information gaps and opportunities for research each community.

1 Plankton

Development and succession of phytoplankton within water column habitats of the Ross Sea are known in part from direct investigation, but also based on inferences from similar communities elsewhere in Antarctica. Thus, there is still much detail to confirm. Also, there is only some knowledge of temporal and spatial variations in phytoplankton patterns and of the factors underlying both the patterns and their variation from year to year.

Bacteria in the water column have been investigated only as biomass, so there are significant opportunities to understand the quantitative nature of their role in the ecosystem in terms of utilising dissolved organic carbon, recycling nutrients and as food for microzooplankton. There is a similar need for investigations of the microzooplankton. These heterotrophic dinoflagellates, ciliates and micrometazoans feed mostly on small phytoplankton (Cyanobacteria, nanoflagellates) and bacteria. Their roles in carbon cycling through the ecosystem are likely to vary considerably in space and time, so that it is important to understand factors underlying their variations in order to model their performance and predict the consequences of environmental variability.

Many species occur in the region's zooplankton, notably copepods, euphausiids, amphipods, ostracods, chaetognaths, ctenophores, pelagic Nemertea, heteropod molluscs and tunicates (Appendicularia, Thaliacea). Most of these are known from elsewhere in Antarctica waters so that their taxonomies are quite well resolved, although identification tools for non-taxonomists are needed. Their ecologies are often inferred from studies elsewhere or from other species. The major gaps in our knowledge of these members of the zooplankton centre on their trophic relationships, their spatial and temporal abundances and the factors driving variations in their abundances. Consequently, long-term, survey-based monitoring, ideally using some remote-sensing technologies, are a priority.

2 Fast ice (tide crack)

This biota includes a seasonal succession of unicellular algae: *Pyramimonas* sp. dominated in spring, whereas diatoms predominated over summer. There is no information on bacteria, protozoans and other microzooplankton within the fast ice community. Some zooplankton species, notably copepods, appear restricted to this habitat. Although a good start has been made on understanding the characteristics of this community much remains to be done to determine how important it is in the overall functioning of the Ross Sea ecosystem.

3 Sea Ice

Diverse diatom floras occur in sea ice in and near McMurdo Sound, with some differences in species presence and abundance with locations. There is limited information on the processes driving sea ice algal development in the Ross Sea, productivity, trophic interactions with bacteria and microzooplankton, and the contribution this community makes when ice is melting to the water column system. Results to date show that this is a very important part of the Ross Sea ecosystem. There is much scope for more research on this community. The metazoans of sea ice communities (harpacticoid and calanoid copepods, amphipods, and doubtless other animals) have hardly been investigated in the Ross Sea region. Much remains to be learned about this fauna, their life histories, and about their role in the food web.

4 Sea floor

The role of benthic communities in energy and nutrient cycling within the Ross Sea ecosystem is largely unknown and has not been included in models to date. That organic carbon reaches the bottom from overlying plankton is well recognized, but there is little understanding of the quantities reaching the bottom communities in different habitats, how much of this is metabolized by the benthos, what proportion accumulates in sediments, and the pathways and quantities that re-enter the water column via fish, other large predators, re-suspension and dissolution.

There are significant research opportunities for mapping the spatial extent of bottom communities using acoustic mapping technologies (e.g., QTC-Impact and digital side-scan sonar) in conjunction with remote video and still frame photography and direct sampling for ground-truthing. These techniques allow mapping on any spatial scale from detailed maps covering just tens of square metres to large-scale maps based on interpolations from variously spaced runs to over much larger areas in less detail. Such research can be especially powerful if used in conjunction with more traditional benthic ecology methods as an initial calibration and offers the opportunity to map and monitor large areas of the Ross Sea, especially in areas susceptible to natural and human-induced changes.

a. Intertidal habitats

Shores south of Terra Nova Bay appear to lack any biota, except where brackish lagoons occur. Further north on the continent, especially at Cape Hallett, as well as at the Balleny Islands and probably Ross Island, shores are likely to be free of ice for longer periods each summer, so that some biota may be present. Certainly, macroalgae are lacking (Zaneveld, 1966b, 1968), but diatoms and smaller invertebrates may be present. This appears to be a gap in our knowledge of the region.

b. Sublittoral (0–30 m depth) benthos

Hard bottoms

The biota of shallow, hard bottoms in McMurdo Sound is moderately well-known in a qualitative sense for a few locations, but there is a dearth of quantitative information (Table A1.1). Several studies provide useful descriptive accounts of various communities and some quantitative information, but few accounts report either relative or absolute abundances of all species within these. Further, full species lists, even of the macrofauna, tend to be lacking, with most investigations reporting on either a specific taxon or just the larger, more conspicuous species. One of the few studies that sought to quantify the benthos focussed on selected groups and reported abundances for rather arbitrary taxa (e.g., live gastropods <1 mm long; live brachiopods) only (Dearborn, 1965). Other important studies (e.g., Dayton et al., 1974; Dayton, 1989; Battershill, 1989) provided quantitative data on larger, more conspicuous species only.

Benthic research at Terra Nova Bay has taken the more classical approach of developing descriptions of the patterns of benthos through quantitative measurement of species abundances, and studying the ecology and biology of selected species. Also, there was a deliberate attempt to investigate the biota of each major habitat. The result is a better understanding of the overall biodiversity of most communities with lists of species and their absolute abundances. Work here has also examined variations in benthos between years and at different locations at any one time, thus providing useful baseline data.

Thus, there are numerous opportunities for further research of shallow hard bottom benthos within the Ross Sea. Quantitative study of total benthos is needed to define communities and habitats at various places on Ross Sea shores and to understand variation in these communities over time, especially between years. There is limited understanding of the functioning and resilience of many shallow, hard-bottom communities and their links to and dependence upon planktonic communities.

Grazing on macroalgae: Dense beds of macroscopic algae occur at some places within the Ross Sea, but there is little direct evidence of the utilization of this plant material by the fauna. Dayton (1990) reported dense beds of macroalgae at Cape Evans, but noted that high densities of the sea urchin *Sterechinus neumayeri* did not graze on these. He also found these urchins aggregated on coralline crust at Granite Harbour (Dayton, 1990), indicating that they browse on benthic microalgae, rather than macroalgae. Two areas for investigation arise from these observations. First, what is the role of sea urchins in structuring shallow, Antarctic benthic assemblages? In temperate environments, sea urchins frequently play a key role in structuring algal communities, at least at patch scales (Dayton, 1985), so it is tempting to speculate on their role in the Ross Sea. Second, what is the fate of macroalgal production in the Ross Sea? Macroalgae are abundant at several locations within the region, but little is known of the utilization of this resource by any associated fauna or communities more remote from the sites of algal growth.

Phytal fauna: The phytal fauna and the associate food webs are only poorly understood for the Ross Sea region. Further, there is no detailed understanding of the utilization of algae in Ross Sea food webs. At a different level, the taxonomy of the phytal fauna is poorly known. For example, six of the ten (60 %) polychaetes and five of the six (83 %) amphipods collected from algae in Terra Nova Bay appear new to science (Gambi & Mazella, 1991).

Sponge community biodiversity: The sponge communities of McMurdo Sound, especially those on spicules mats, are largely unique to Antarctica and appear to support a complex community of plants and animals (Dayton & Oliver, 1977). However, although this community has received considerable scientific attention as a result of Dayton's seminal works on predator effects on community composition, there has been no detailed quantitative investigation of this community aimed at providing a comprehensive account of its biodiversity, despite the huge densities of animals found here (Dayton & Oliver, 1977). After all that has been written on this habitat, we still have little understanding of the diversity of diatoms or smaller polychaetes or crustaceans found on the spicules or among the larger sponges and other sessile invertebrates. Also, we have no understanding of the smaller scale interactions or processes within this community. For example, what, if any, invertebrates feed on these spicule diatoms? What is the fate of this primary production? Nor do we have much knowledge of the spatial extent of this community elsewhere in the Ross Sea.

Soft bottoms

There are very few studies of the biodiversity of shallow soft bottoms in the Ross Sea (Table A1.1), in part, probably, because soft bottoms are relatively uncommon in shallow waters long the shores of Ross Island. In addition, the few soft bottom benthos investigations in McMurdo Sound (Dayton & Oliver, 1977; Lenihan & Oliver, 1995) present very superficial analyses of the biota, contributing little information on the biodiversity overall. The primary investigation of Terra Nova Bay benthos (Gambi et al., 1997) provides useful biodiversity information, including a full list of macrofaunal species and their densities, at two locations, and indicates that penguin guano may increase benthos abundance and diversity.

There is a clear need for additional studies within McMurdo Sound and elsewhere along the shores of the Ross Sea. Indeed, we have scant indication of the extent of soft bottoms in near-shore environments and little idea of their variation within the region. Further, we know nothing about the role of soft bottom benthos in larger scale ecosystem processes in the region. There are several opportunities for future research of this habitat, therefore. Again, any such investigations should report basic quantitative biodiversity information, in addition to any other more novel findings.

Oligotrophic benthos biodiversity: Dayton & Oliver (1977) reported a marked east-west difference in the nutrients and biodiversity in McMurdo Sound. They observed marked differences in densities of total benthos and developed the conceptually-appealing explanation that the benthos of the west side of the Sound was oligotrophic compared with the east. Since their work, however, some contradictory evidence has appeared (Stockton, 1984; Dunbar et al., 1989; see also Bradford-Grieve & Fenwick, 2001). This suggests that the benthos and water column productivity on the west side of McMurdo Sound is spatially heterogeneous, and requires more work for useful generalization. Clearly, a more thorough investigation of the benthos using conventional approaches, including replicate sampling, full faunal analysis (including biomass), quantitative analysis and presentation of results (i.e., publication of a species list), is required to clarify this issue.

c. Deeper (30–3,000+ m depth) coastal and offshore benthos

The nature and distribution of deeper benthos within the Ross Sea (Table A1.2) is poorly known. Certainly, Bullivant's (1967b) work provided a useful start and Dell's (1972) additions began to add some much needed biological detail. However, the proportion of the taxa at each station so far described for each assemblage is very small, leaving us with a very inadequate understanding of their true biodiversities and of the reliabilities of the communities identified. Some work on the original collections has been completed since Dell (1972) and many more benthic samples have been collected from other stations in the region.

Thus, knowledge of the deeper Ross Sea benthic communities (Table A1.2) can be improved dramatically on two fronts. First, the database created as part of this work could be completed used as a source of more complete data on all benthic stations within the Ross Sea and the extracted data should be subjected to a more rigorous, statistical analysis to re-investigate the compositions and distributions of Ross Sea benthos. Second, a lot of work remains to be done in completing identifications of material already collected from the Ross Sea. Although there will inevitably be a number of taxonomic problems and new taxa discovered among these collections, this should not present an insurmountable hurdle in working up these collections more completely so that more detailed analyses of faunal compositions and distributions can proceed. Rather than attempting to work up all groups of animals from these collections, it may be prudent and more economical to proceed by focusing on selected groups, particularly those that are more diverse, more abundant and/or more important ecologically.

The result of such a meta-analysis using current statistical techniques would not only provide a fairly comprehensive understanding of the different communities present in the Ross Sea, but also a broad understanding of their spatial distribution and geographic extent. Further, distinguishing the different communities would facilitate understanding of the diversity of habitats within the region and the underlying factors that influence differences in community composition. This then, would provide an initial assessment of rare communities and habitats, their locations and sizes – vital information for managing the region's biodiversity.

d. Benthos under permanent ice

Biota beneath the Ross Ice Shelf suggests that this habitat is akin to deep-sea systems with short food chains that are reliant upon allochthonous energy and dominated by scavengers. However, there appear to be some unique organisms beneath the Ross Ice Shelf and the possibility of some autochthonous productivity merits further exploration. The taxonomy of even the few collections made to date is incomplete and could receive attention, simply because, until this is completed, we cannot know whether this fauna actually is special.

Table A1.1. Summary of major studies of Ross Sea benthic communities or habitats (strictly taxonomic papers not included). Nature of investigation: D, descriptive; S, partly quantitative; Q, quantitative. Any variability investigated: N, nil; S, spatial; Ts, seasonal; Ty, between years.

Community/ habitat	Depth (m)	McMurdo Sound	Terra Nova Bay	Other	Variability	Taxa reported	Reference
Shallower hard bottoms							
Hard bottoms	0–40+	D		D	S	macroalgae	Zaneveld 1966b,c, 1968
Hard & soft bottoms	6–43	Q			S	microalgae	Dayton et al. 1986
Hard bottoms	0–25	S			S	macroalgae	Miller & Pearse 1991
Hard bottoms	1–16		Q		Ts	*Iridaea coradata*	Cormaci et al. 1996
Hard bottoms	0–70		S		Ts	macroalgae	Cormaci et al. 2000
Hard bottoms	0–60	D			S	macrofauna	Dayton et al. 1969, 1970
Sponge assemblage	33–60	S			N	macrofauna	Dayton 1972
Sponge assemblage	30–60	Q			Ty	macrofauna	Dayton et al. 1974
Hard bottoms	15–30	Q			Ty	Sponges, asteroids	Dayton 1989
Hard bottoms	0–16		Q		S	macrofauna, phytobenthos	Gambi & Mazella 1991
Hard bottoms	0–16		Q		S, Ty	macrofauna, phytobenthos	Gambi et al. 1994, 2000
Hard bottoms	0–150		S/Q		N	macrofauna	Cattaneo-Vietti et al. 2000a
Shallower soft bottoms							
Soft bottoms	20–40	S			S	macrofauna	Dayton & Oliver 1977
Soft bottom	3–21	Q			S	macrofauna	Lenihan & Oliver 1995
Soft & hard bottoms	6–43	Q			S	microalgae	Dayton et al. 1986
Soft bottoms	23–273		Q		N	macrofauna	Gambi & Mazella 1991
Soft bottoms	20–220		S/Q		N	macrofauna	Cattaneo-Vietti et al. 2000a
Soft bottoms	23–194		Q		S	Polychaetes	Gambi et al. 1997

Table A1.2. Summary of major studies of Ross Sea deeper water benthic communities or habitats (strictly taxonomic papers not included). Nature of investigation: D, descriptive; S, partially quantitative; Q, quantitative. Any variability investigated: N, nil; S, spatial; Ts, seasonal; Ty, between years.

Community/ habitat	**Depth (m)**	**McMurdo Sound**	**Terra Nova Bay**	**Other**	**Variability**	**Taxa reported**	**Reference**
Hard & soft bottoms	3–860	Q			N	Selected macrofauna	Dearborn 1965
Hard & soft bottoms	60–3577	D		D	S	Selected macrofauna	Bullivant 1967
Soft bottoms	35–250	Q		Q	S	macrofauna	Lowry 1976
Hard & soft bottoms	25–1100		Q		S	Molluscs	Cattaneo-Vietti et al. 2000b
Soft bottoms	23–1100		D/S		S	Polychaetes	Cantone et al. 2000
Soft bottoms	450–810			Q	S	macrofauna	Gambi & Bussotti 1999

Appendix 2. Outline of some important gaps in the knowledge of Ross Sea marine biodiversity from a taxon perspective, identified from the review of the biodiversity of the region (Objective 1).

1 Planktonic algae

Although the open-ocean algae, notably diatoms, are quite well-known taxonomically, several other elements of the Ross Sea phytoplankton remain poorly known. These lesser known groups, also poorly known for other oceans and often cosmopolitan in distribution, include the picoplankton (Prochlorophyta, small Cyanobacteria), non-thecate dinoflagellates and various flagellates. The importance of these microalgae in the Ross Sea ecosystem suggests that they should be a priority for further research, but, if largely cosmopolitan, then it seems preferable to clarify their taxonomy and ecology in more temperate waters first.

2 Fast ice and sea ice algae

Diatoms dominate the flora of these habitats and their taxonomy seems reasonably well-known. There has been some investigation of community dynamics and variation, but more work is required to clarify the processes and their drivers quantitatively.

3 Benthic algae

Three species of algae occurring at several locations throughout McMurdo Sound exhibit quite marked depth zonation: *Iridaea cordatum* is restricted to shallower depths (3.5–10 m), *Phyllophora antarctica* to intermediate depths (5–18 m), and *Leptophytum coulmanicum* dominates below this (>18 m depth) (Miller & Pearse, 1991). Possible reasons for their different depth ranges included different tolerances of anchor ice, different irradiance requirements for growth, and different tolerances of late summer reductions in salinity from melt water (Miller & Pearse, 1991). Herbivore activities were discounted as a cause because Miller & Pearse (1991) found little evidence of any animals grazing on these algae. Macroalgal zonation in temperate waters appears to result from a complex of interacting factors, many of which are absent in the Ross Sea. Consequently, this zonation presents a fascinating opportunity to understand the causes of such patterns in a simplified environment.

Dayton (1990) reviewed the depth occurrences of foliose algae in Antarctica and the Ross Sea. Foliose algae appear absent from Hut Point Peninsula, although a few plants of *Phyllophora antarctica* occurred at McMurdo Station. At points further north along the shores of Ross Island, Dayton (1990) reported increases in macroalgae abundance and species diversity, leading him to speculate that McMurdo Station approximates the southern-most limit for macroscopic algae. No mechanism for this southern limit was suggested, but this issue merits attention.

Along with these observations, Dayton (1990) noted remarkable depth maxima for macroscopic foliose algae in Antarctic waters, including the Ross Sea. Foliose algae grow well to at least 60 m depth at Cape Evans, the shallowest depth for *Ballia callitricha* appears to be 37 m, and Wagner & Zaneveld (1988) reported many collections from over 300 m depth, including *Monostroma hariotii* from 348 m depth off Possession Island in the Ross Sea. As in most seas, algal depth limits will be limited by light availability in the Ross Sea. However, Heywood & Whitaker (1984) considered that because the initial stages of photosynthesis are light, rather than temperature dependent, and respiratory rates are reduced by low Antarctic temperatures, the photosynthetic compensation point will be reached at lower light intensities, thus, allowing algae to grow at greater depths under cold conditions compared with warm conditions (assuming equivalent water clarity). The implication that growth and depth maxima for benthic algae in Antarctica are limited by light (Dayton, 1990) merits closer investigation.

4 Foraminifera

Foraminifera are abundant components of Antarctic benthos, but very little is known of Foraminifera biology and their importance to the benthos community, especially effect of carnivorous foraminiferans in consuming larvae of other larger benthic organisms. In particular, there is a scarcity of quantitative investigations based on random sampling to investigate key aspects of living faunas (see Table A2.1). For example, replication of the study of the effects of the Scott Base outfall on foraminiferans (Anderson & Chagué-Goff, 1996) using conventional quantitative sampling with replication at randomly located stations and a more thorough analysis of the results using methods currently used in benthic ecology (e.g., the PRIMER software package) would almost certainly provide far more meaningful and useful understanding of the outfall's effects. Including other elements of the smaller macrofauna and meiofauna within the sampling and analysis would strengthen such a study.

5 Sponges

The Antarctic sponge fauna is perhaps one of the taxonomically better known in the world, although knowledge of the distribution of sponges in the Ross Sea is no better than it is for many other groups in marine invertebrates.

Given the longevity of some of the larger sponge species and their abilities to both grow and shrink in size, there is considerable potential to monitor the sizes known individuals as indicators of changing environmental conditions over long periods of time (i.e., tens of years). At a larger scale, the quantitative compositions and geographic extents of sponge communities offer the prospect of monitoring both natural variations and human-induced changes over long time periods using remote sensing technologies (ROVs (Remotely Operated Vehicles), QTC-Impact, digital side-scan sonar, etc.), especially because their sessile nature, large size and conspicuous macroscopic characteristics mean that species and individuals can often be recognised without direct examination.

6 Bryozoa

Although one of the better known groups of Antarctic marine invertebrates, more Bryozoa are certain to be discovered from the Ross Sea in future. Perhaps the greatest gap in our knowledge of bryozoan biodiversity is description of the combinations of species occurring together, their abundances relative to each other and to other benthic organisms and comparison of these assemblages with equivalents from elsewhere in Antarctic waters. Ideally, much of this information would be gathered along with equivalent information on other major benthic organisms as a means of understanding the quantitative diversity of major benthic communities overall.

Given the importance of Bryozoa as reef-builders and habitat-creators within the Ross Sea, there is considerable merit in monitoring the compositions and spatial extents of bryozoan-dominated bottoms. Again, remote sensing technologies offer substantial promise for such purposes, given the difficult working depths, water temperatures and bottom types.

7 Polychaeta

Ecologically, polychaetes appear to be very important in the benthos of the Ross Sea region, especially on soft bottoms and among biogenic structures where they may comprise up to 75 % of the fauna (Dayton & Oliver, 1977; Gambi & Bussotti, 1999), although few studies have examined this in any detail. Such studies usually need to be supported by a taxonomist because there is no single comprehensive guide to the polychaete fauna for non-specialists and many new species records are likely.

The distributions of polychaete species within the region is poorly known and, because most species are inconspicuous, their distributions can be determined only by direct sampling and examination of specimens. The shallow-water, reef-building serpulid polychaete (*Serpula narconensis*) is known from the region, but reefs of the species remain unreported to date. Identification of any *Serpula* reefs and mapping their extent will be important because of their fragile nature.

Given the numerical dominance of polychaetes in the region's benthos, knowledge of their feeding ecology and growth rates is important. To date, there have been few such investigations. Also, studies of polychaetes should be an important part of any longterm investigations of changes in natural communities.

8 Mollusca

The region's molluscan fauna seems quite well known taxonomically, but there is considerable scope to increase knowledge of species distributions. Again, there is no comprehensive guide to the fauna, presenting a barrier to developing further knowledge of the group. More work on the ecological importance of this group is required. At present, we understand the ecological importance of few of these animals. The exceptions are some of the larger, shallow-water species (e.g., *Adamussium colbecki, Limatula hodgsoni, Trophon longstaffi*), but, even these require more attention.

9 Crustacea

As an important although less conspicuous component of the benthos and plankton within the region, they require considerable further attention. Many of the species present are small, but occur in vast numbers and grow rapidly so that their total productivity is very high. Thus, crustaceans, particularly planktonic euphausiids, copepods, ostracods and amphipods, are a major component of the Ross Sea marine ecosystem.

The taxonomy of planktonic copepods is quite well known, as is that for the most other planktonic crustaceans. Identification guides, preferably interactive, electronic keys with comprehensive illustrations, should be developed to make the fauna easier to study. Medium-term, baseline investigations of community compositions, densities and productivities are needed to characterise the fauna and energy flows through this important component of the planktonic ecosystem. More detailed information on seasonal distribution patterns and life-histories are required for the many seasonally migrant species or species that live in conjunction with sea ice. Detailed modelling of the dynamics of major plankton groups based on these data should follow to predict the effects of emerging human pressures.

Only two, well-known euphausiids occur in the Ross Sea: *Euphausia crystallorophias* occurs closer to shore, usually in depths <300 m, whereas *E. superba* inhabits more offshore waters. The huge biomasses of these moderate-sized, herbivorous crustaceans, especially *E. superba*, has lead to several investigations, so that their biology is partially known with some details yet to be understood completely. However, better knowledge of their spatial and temporal variability, longevity, and the drivers of such variations present a significant research opportunity.

Benthic crustaceans are relatively poorly known compared with their planktonic counterparts, even though they may comprise more than 80 % of individuals present within a community (Dayton & Oliver 1977). Most large species are well known taxonomically, but there are likely to be several smaller species that are largely unknown. Identification tools are lacking. Species distributions within the region are poorly known. There is scant information on life histories, feeding ecology, growth rates and trophic relationships, so their importance in the ecosystem overall is largely unknown. However, a few species are clearly the dominant scavengers in many habitats (e.g., lysianassid amphipods beneath the Ross Ice Shelf and in McMurdo Sound), and it is likely that other more specialised feeders exert similarly important influences within their specific habitats and niches.

10 Echinodermata

The echinoderms are among the taxonomically better-known groups of marine invertebrates from the Ross Sea region, but tools for their identification, notably comprehensively illustrated interactive keys, are lacking. Knowledge of their distribution within the region is still sparse and should be filled out with the aid of keys whenever practical. Because most of these animals are relatively large and usually conspicuous, they lend themselves to easy monitoring in a range of habitats via remote sensing technologies, such as ROVs or camera sleds. Population distributions, densities, size-frequencies, etc. of key species and selected communities would all be valuable as part of wider monitoring to detect changes at multiple levels.

Further, there is considerable opportunity to understand the ecologies of key taxa, especially those that are important in controlling the composition of various communities. Such investigations could be expanded to include learning about the consequences of the removal of key species or of other changes to the biodiversity of their communities.

11 Fish

The fish fauna of the Ross Sea also requires substantial further taxonomic and ecological research. As a result of by-catch from commercial activity for the Ross Sea Toothfish, a New Zealand based collection of Ross Sea fishes is being developed. First records of a number of species have resulted. Also, because this fishery operates in areas and depths not normally investigated by scientific cruises, new species have been collected. These now require formal scientific description and naming. In the process of working with this fauna, New Zealand scientists have discovered that the taxonomy of many groups (e.g., Artedidraconidae, Muraenolepididae, Nototheniidae) require careful taxonomic revision.

Extensive ecological and biological investigations of some fish species are also required. There have been no direct assessments of the stocks of any Ross Sea fish species. Thus, as potentially harvestable resources and as significant predators, the distributions and stocks of most species should be determined. Concomitantly, the sizes and age distributions of populations of the more abundant fish species, as well as their life histories should be investigated, especially for species found over shelf areas. In order to understand their functional roles in the Ross Sea ecosystem, it is also important to research key species trophic relationships. This is especially important for the Ross Sea toothfish.

12 Birds

The Ross Sea Biodiversity review highlighted that there are significant deficiencies in our knowledge of the seabirds of the region. The following indicate some of the more important areas where further research is required.

a. Status of petrels and fulmars

Very limited, if any, data are available to assess the numbers of cape petrel (*Daption capense*), Antarctic petrel (*Thalassoica antarctica*), Antarctic fulmar (*Fulmarus glacialoides*), and snow petrel (*Pagodroma nivea*) breeding in the region. In fact, there is limited information available about even the locations of breeding colonies. For example, it is not known whether the Antarctic fulmars seen ashore at the Balleny Islands were breeding or just roosting. Of particular concern is the fact that no population data are available for Antarctic petrel, a species endemic to the Antarctic waters. On the basis of observations at sea, Ainley et al. (1984) inferred that large numbers of Antarctic petrels must breed in Marie Byrd Land, but recent surveys (e.g., Broady et al., 1992) failed to locate any new colonies.

Because there is little information about the numbers of breeding pairs of these four petrel species, it is impossible to determine any trends in population size. Consequently, any changes to regional populations cannot be detected.

Long-term population surveys would be enhanced by biological data, such as breeding success, recruitment and adult survival rates, which would improve our understanding of any observed trends in population size. The value of such studies has been highlighted recently by Wilson et al. (2001) who found that trends in the population size of Adelie penguins in the Ross Sea could be explained by the extent of sea ice during the winter.

b. Role of seabirds in marine communities

With the possible exception of Adelie penguins, the role of all seabird species in Ross Sea marine communities is not known in any detail. This is despite the fact that, as highly visible top predators in the marine food chain, they probably provide the easiest means of detecting changes in the ecosystem brought about by global warming or human fishing activities. Therefore, research into these seabird communities should include investigations of the oceanographic conditions where each species forages and the principal prey of each seabird species. Such studies should take into account changes in foraging area and prey with season, breeding cycle and breeding status of the birds.

c. *Feeding biology of Ross Sea seabirds*

Ainley et al. (1984), Ainley (1985) and Saino & Guglielmo (2000) provided useful information about the overall distribution of seabirds in relation to broad oceanographic features of the Ross Sea. In addition, Ainley et al (1984) reported prey items found in small samples of birds collected in the Ross Sea. However, with the notable exception of Adelie penguins, there are few quantitative data about the species composition and age class structure of the prey items of marine birds in the Ross Sea region. Likewise, with the exception of Adelie penguins from Cape Bird, little is known of the specific foraging areas used by birds of known breeding and age status and provenance.

d. *Geographic dispersal of seabirds*

Current technology allows the at-sea movements of individual birds to be monitored in terms of geographic location and depth in the water column where they feed. In addition, diet sampling allows identification of the life history stages of the prey species consumed. Consequently, the specific roles of seabirds in marine communities and ecosystems can be determined by a combination of extensive observations of birds at sea and intensive studies of particular birds of known status and provenance.

12 Marine mammals

The greatest knowledge gaps for both seals and whales are detailed understandings of their seasonal distributions and the factors underlying these distributions, although Weddell seals are now quite well known. Quantitative surveys (see Kasamatsu & Joyce, 1995) and remote sensing technologies appear to offer the best opportunities for this type of research in future. Along with details of species' distributions, more knowledge of individual species' populations and feeding ecologies is required. Such studies should examine variations over several years to understand the natural variability and reasons for such changes.

TableA2.1. Summary of major studies of Ross Sea benthic Foraminifera assemblages (strictly taxonomic papers not included). Nature of investigation: D, descriptive; S, partially quantitative; Q, quantitative. Any variability investigated: N, nil; S, spatial; Ts, seasonal; Ty, between years.

Community/ habitat	**Depth (m)**	**McMurdo Sound**	**Terra Nova Bay**	**Other**	**Variability**	**Taxa reported**	**Reference: no. stations**
Soft bottom	80–856	S			N	Foraminifera	Ward et al. 1987: 28
Soft bottom	0–30	Q			N	Foraminifera	Bernhard 1987: 74
Soft bottom	26	Q			S	Foraminifera	Mullineaux & DeLaca 1985: 25
Hard & soft bottoms	60–3577	S		S	S	Foraminifera	Kennett 1968
Soft bottom	450–2450	Q		Q	N	Foraminifera	McKnight 1962: 19
Soft bottom	210–3402	S				Foraminifera	Pflum 1966
Soft bottom	380–2815		Q	Q	N	Foraminifera	Asioli 1995: 22
Water column	50–200			Q	N	Foraminifera	Asioli & Langone 1997

Appendix 3. Relevant actions from the New Zealand Biodiversity Strategy recognised by the Ministry of Fisheries for its management of marine biodiversity (http://www.fish.govt.nz/ sustainability/biodiversity/biodiversity-medium-term-research-plan.pdf).

"Objective 1.1 Protecting indigenous habitats and ecosystems

a) Complete indigenous biodiversity survey and assessment to identify habitats and ecosystems important for indigenous biodiversity

Objective 3.1 Improving our knowledge of coastal and marine ecosystems

a) Improve our knowledge of marine species, including taxonomy, distribution, habitat requirements, and the threats to species

c) Identify the uniqueness, representativeness, and importance of the biodiversity of New Zealand's coastal and marine ecosystems

Objective 3.4 Sustainable marine resource use practices

b) Identify coastal and marine species and habitats most sensitive to harvesting and other disturbances and put in place measures to avoid, remedy or mitigate adverse effects from commercial, recreational and Maori customary fishing activities

Objective 3.6 Protecting marine habitats and ecosystems

b) Achieve a target of protecting 10 percent of New Zealand's marine environment by 2010 in view of establishing a network of representative protected marine areas

Objective 7.4 Science and research

a) Develop a process for incorporating Maori biodiversity research needs into priority setting for research at national, regional and local levels

Objective 9.1 Expand the research frontier

a) Develop and implement a coordinated research strategy to identify and fill gaps in our knowledge and understanding of biodiversity relevant to key threats

b) Invest in relevant research that contributes to better management of introduced pests and enhanced management of indigenous biodiversity" (http://www.fish.govt.nz/ sustainability/biodiversity/biodiversity-medium-term-research-plan.pdf).

Appendix 4. The Ministry of Fisheries standard criteria for evaluating proposed research for Antarctica and New Zealand under its Marine Biodiversity Medium-term Research Plan (http://www.fish.govt.nz/ sustainability/biodiversity/biodiversity-medium-term-research-plan.pdf):

"**Overall Criteria** (projects must meet at least criteria 1,2, and 3):

1. Research must improve our current knowledge of our marine biodiversity.

2. Research must address issues that are a priority for achieving sustainable management of the marine environment.

3. Information must be accessible and useful to those who need it in management/actions.

4. Contribute to our ability to carry out scientific research on marine biodiversity.

5. Baseline information on biodiversity of the Ross Sea region criteria:

a. Priority should be given to research on communities in the Ross Sea region that:
   - i. are considered under pressure from human impacts
   - ii. have been the subject of little or no research
   - iii. are considered unique
   - iv. are considered representative

b. Projects should seek to foster collaboration with international research initiatives

c. Projects should seek to assist research initiatives of other NZ institutions or agencies

d. Data must be suitable for inclusion in a National Aquatic Biodiversity Information System".