Report on ESF/LESC Exploratory Workshop

The Polar Regions and Global Biodiversity Change

by
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(Workshop Convenor, British Antarctic Survey)

Madingley Hall, University of Cambridge
21-22 May 2001

CONTENTS LIST

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***full address of all participants included at the end**

ESF/LESC EXPLORATORY WORKSHOP

The Polar Regions and Global Biodiversity Change

Madingley Hall, University of Cambridge

21 - 22 May 2001

PROGRAMME

MONDAY 21 MAY

1000 - 1020	**Introduction and welcome**	**Alistair Crame**
1020 - 1030	**ESF and LESC**	**Steve Albon**
Part 1: An Introduction to Polar biodiversity		
1030 - 1100	**The polar regions in a global context**	**Alistair Crame**
1100 - 1115	***Coffee break***	
1115 - 1200	**Key biodiversity issues in the polar marine realm**	**Wolf Arntz, John Gray**
1200 - 1245	**Key biodiversity issues in the polar terrestrial realm**	**Kevin Newsham, Phil Wookey**
1245 - 1300	**Discussion**	
1300 - 1400	***Lunch***	
Part 2: Five Subthemes in Polar Biodiversity		
1400 - 1445	**1. Marine ecology**	**Riccardo Cattaneo-Vietti**
1445 - 1530	**2. Terrestrial ecology and dispersal mechanisms**	**Clare Robinson**
1530 - 1600	***Tea Break***	
1600 - 1645	**3. Fossil record and climate change**	**Jane Francis**
1645 - 1730	**4. Molecular techniques**	**Christoph Held**
1730 - 1815	**5. Databases and quantitative techniques**	
1815 - 1915	**Wine reception**	
1915	***Dinner***	

TUESDAY 22 MAY

Part 3: A Review of Key Polar Biodiversity Issues

0900 - 0945	**Review of Day 1**	**Alistair Crame**
0945 - 1045	**Breakout groups**	
1045 - 1115	***Coffee Break***	
1115 - 1200	**Reports from each breakout group**	
1200 - 1300	**Overview and advice on developing funding proposals**	
1300 - 1400	***Lunch***	

Part 4: The Way Ahead

1400 - 1530	**Working groups develop ideas and themes for future projects And collaborations; an ESF Network or Programme?**	
1530 - 1630	**Plenary session; future plans; maintaining contact**	
1630 - 1700	**Summary and close of meeting**	**Alistair Crame**

Introduction

When we think of biodiversity on a global scale we are often drawn directly to the species-rich systems of the tropics. How has the distribution of either tropical rain forests or coral reefs changed in recent years, and are we on the brink of a human-induced mass extinction? And yet our global perspective of biodiversity is shaped just as much by the high-latitude and polar regions as the low-latitude and equatorial ones. If it were not for the low diversity patterns seen in the former regions then the high diversity of the latter would be meaningless; these are two sides of the same biological coin.

So how widespread is low biodiversity in the polar regions; does it occur in all the principal terrestrial and marine groups; how did it come to be; and how stable are these polar communities to global change? These are the sorts of questions that prompted the holding of an international, interdisciplinary workshop entitled "The Polar Regions and Global Biodiversity Change" at Madingley Hall, University of Cambridge on 21-22 May 2001. Sponsored by the ESF/LESC within their scheme of Exploratory Workshops, the meeting was attended by 26 delegates from nine separate EU countries. Together they represented a cross-section of biologists and palaeobiologists with a wide variety of research interests, and extensive experience of working in both Arctic and Antarctic regions. A two-day programme was constructed in such a way as to give participants the opportunity to compare and contrast their approaches to polar biodiversity science, and formulate a programme for possible future collaboration.

The Polar Regions in a Global Context

At the start of the meeting, the convenor, Alistair Crame, outlined a number of ways in which the polar regions contributed to our understanding of global biodiversity issues. Large-scale biodiversity patterns figured prominently here, with some illustrations of the classical pattern, seen in many plant and animal groups, of high diversity in the tropics and much lower values towards both poles. Latitudinal gradients in taxonomic diversity are one of the major patterns of life on Earth at the present day, but how steep and regular are they away from the North American and north-west European continents? In particular it was emphasised how little we still know about latitudinal gradients in the southern hemisphere, in both the marine and terrestrial realms.

There is a growing acceptance that these large-scale patterns and gradients are the product of a substantial historical legacy. In some cases this may involve a timespan of thousands of years, and in others millions, or even tens of millions, of years. If this is indeed the case, then it suggests that two basic evolutionary processes were in operation: either the rate of speciation was higher in the tropics, or the rate of extinction was higher at the poles (or, perhaps, both these processes operated in parallel). But can we actually prove this? Although we often infer that speciation is higher in the tropics and extinction at the poles, empirical data sets are in short supply. Both biologists and palaeobiologists can contribute to this important debate.

Crame went on to suggest that there was an important link between ecology and polar biodiversity. What are the ecological and physiological adaptations that allow certain organisms to thrive in harsh polar climates? Of particular importance here is a better understanding of key processes such as cold hardiness and seasonality. In addition, there is the crucially important field of ecosystem function in the polar regions. Here, at least in the terrestrial realm, are some of the simplest ecosystems known on Earth, but are they more or less susceptible to global change? This is an opportunity to develop some critical empirical data sets with which to test basic ecological theory.

Alistair Crame summarizing discussion points

Polar biodiversity scientists are often in a position to make a series of unique comparisons between Arctic and Antarctic organisms, communities and biotas. This can be done on a variety of spatial and temporal scales and has the potential of highlighting processes of biological differentiation on a global scale. How similar are Arctic and Antarctic communities in both species diversity and species composition? Can any differences be related to the obvious fact that, whereas the Arctic is an ocean surrounded by continents, the Antarctic is a continent surrounded by ocean? It also has to be borne in mind that major ice sheets have been present for an order of magnitude longer in the Antarctic than Arctic (i.e. 40 my as opposed to approximately 4 my). The phenomenon of bipolarity was included in this section, and an important recent study on marine planktonic foraminiferans cited which clearly demonstrated gene flow across the tropics at the present day or in the very recent past. Bipolar biotas may be traced back in the fossil record to the Late Palaeozoic era (i.e. approximately 290 my).

In his final point, Crame emphasised the importance of climate change to almost all aspects of polar biodiversity study. Global climate changes on scales that range from the decadal to tens of millions of years, but are always likely to be most keenly felt in the sensitive polar regions. Crame hinted at a fundamental link between global climate change and the origin and maintenance of major diversity patterns. At the other end of the temporal spectrum, the link between present day global warming and the stability of modern polar ecosystems is a research topic of the highest priority.

In the discussion session that followed it was pointed out that many factors can affect the nature of latitudinal gradients. Just using latitude *per se* could mask important regional variations in taxonomic diversity, and 60°N is not directly equivalent to 60°S (i.e. there are important differences between the two hemispheres). It was also pointed out that most standard estimates of taxonomic diversity are strongly biased by sampling effort. However, one measure that is not is based upon branch lengths within either a phylogenetic tree or Linnean classification scheme. Such measures of 'taxonomic distinctness' concentrate on measuring the relatedness of higher taxa and ignore the evenness component of diversity.

Key Biodiversity Issues in the Polar Marine Realm

At the beginning of his presentation on Antarctic marine biodiversity, Wolf Arntz emphasised the strong influence of geological history on what we see at the present day. As well as getting colder, Antarctica has become progressively more isolated over the last 50 million years. It is now completely surrounded by the Antarctic Circumpolar Current, and the Polar Frontal Zone represents one of the major boundaries in the world ocean. Nevertheless, despite this relative isolation, Arntz described some species-rich assemblages from the high Antarctic (i.e. Southern Weddell and Ross Seas). Some of these are rich in sponges and show a distinct three-dimensional structure; is there a process of slow colonization and ecological succession here that allows complex communities to be built up? Trophic diversity within these Antarctic benthic ecosystems needs further detailed study.

A second presentation on marine biodiversity, by John Gray, returned to the theme of taxonomic diversity gradients. He cast doubt on whether a number of well publicised latitudinal and depth gradients actually existed, for the sample sizes on which they were based are too small to make generalisations about any particular latitude or depth zone. We were using ecological-scale samples to try and answer evolutionary-scale questions. A consideration of the different scales of diversity (i.e. within-habitat, between-habitat and regional) could yield crucial information on the relative roles of local and regional processes. Using a Norwegian Sea data set, Gray had found evidence of a positive relationship between local and regional diversity, indicating that regional processes (such as geographical dispersal and historical accumulation) must influence local values.

Key Biodiversity Issues in the Polar Terrestrial Realm

Kevin Newsham reminded the meeting that biodiversity values were uniformly low in the Antarctic terrestrial realm. Such plant and animal communities as existed there were also extremely isolated, and possibly vulnerable to even minor changes in global temperature. One of the biggest temperature rises known from the continent is the 2°C one from the Antarctic Peninsula region over the last 50 years. However, as Newsham pointed out, this is considerably less than the diurnal variation experienced by these taxa and it is by no means certain what the long-term effects may be. It is likely that small temperature rises could have short-term effects on both generation times and population sizes and a series of field and laboratory studies were underway to assess these. Changes in atmospheric ozone levels over the polar regions could have a profound influence on biodiversity.

Phil Wookey showed that, whereas levels of inter-specific diversity were low in Arctic tundra ecosystems, levels of intra-specific diversity could in fact be high (especially in certain plant taxa). Wookey reviewed the various physical factors influencing tundra diversity patterns, showing that micro-climate, light levels, topography and substrate all played a role. Biological factors were examined too, and it was evident that geographical isolation played a part in the construction of these Arctic terrestrial communities; there was only a limited number of immigration/invasion pathways. Turning to aspects of the functional stability of the tundra communities, Wookey suggested that there was some field evidence from Alaska to indicate that they could resist a certain degree of climate change. It was suggested that a likely response to global warming was changes in geographical ranges rather than extinction. Interestingly, the point was made that, as in the Antarctic, recent global warming in the Arctic is far from uniform; some areas are actually getting colder! Ozone depletion also affected the Arctic and there had been significant recent increases in atmospheric nitrogen levels. Two aspects of the Arctic tundra ecosystem that made them particularly attractive for study were the short growing season and the presence of fine-scale environmental gradients.

Five Subthemes in Polar Biodiversity

i) Marine Ecology

Riccardo Cattaneo-Vietti introduced this theme by describing the shallow-marine and shoreline habitats of Terra Nova Bay, Ross Sea, Antarctica. Despite its high-Antarctic position (–75°S), some 1200 species (all groups) have been recorded from this region. However, some groups, such as crustaceans and ascidians, are poorly represented in comparison with other high Antarctic regions. Most of the major groups are of comparatively low diversity, but high abundance/biomass. At Terra Nova Bay there is a high degree of patchiness in benthic assemblages, and certain taxa, such as several species of sponges, the bivalve *Adamussium colbecki*, the spionid polychaetes and the red algae *Iridaea cordata, Phyllophora antarctica* and *Clathromorphum lemoineanum*, seem to act as 'keystone species' within the littoral ecosystem.

Cattaneo-Vietti and other researchers from Italy, USA and New Zealand, within the SCAR framework, are planning to investigate a latitudinal transect from ~72°S to 78°S along the Victoria Land coast. This will be used to collect data and information regarding the latitudinal distribution of species and communities, and to test the polar focussing hypothesis, and progressive emergence of benthic assemblages with increasing latitude.

Krzysztof Jazdzewski has compared numbers of polychaetes and amphipods from a single locality in the South Shetland Islands, West Antarctica with those known from the whole of Adelie Land, East Antarctica. The West Antarctic site is much more diverse, raising the spectre of the presence of diversity 'hotspots' in the Antarctic. Jan Marcin Weslawski demonstrated similar comparisons in the Arctic between Svalbard and Franz Josef Land.

Carlos Pedrós-Alió provided some important evidence on levels of marine microbial diversity. He reminded the meeting that, in terms of higher taxa, most biological diversity consisted of microbes! Levels of species diversity in the polar regions were still uncertain, but the application of modern molecular techniques was suggesting that some taxa have widespread, maybe even cosmopolitan, distributions. Dispersal mechanisms of marine microbes needed urgent further investigation.

ii) Terrestrial Ecology and Dispersal Mechanisms

Clare Robinson raised the fundamental question of whether microbial communities are differentiated in the polar regions; is there a different subset of species there, and are they fewer in number than at lower latitudes? Her studies of Arctic fungal communities showed that in many respects they were very similar in composition to lower-latitude, temperate ones. There was evidence of lower taxonomic diversity in polar regions but some at least of this might be attributed to decomposition. More studies of key fungal species are necessary, as is further investigation of dispersal mechanisms. It would appear that some taxa can be transported long distances, although in these cases the numbers of propagules were low. Studies undertaken by Birgit Sattler indicate that microbes actively growing in atmospheric clouds can be transported over long distances and can therefore contribute to the dispersal of still viable bacteria to remote areas. Consequently, permanent ice caps of polar lakes (i.e. Dry Valley Lakes, Antarctica) and various glaciers can be seen as habitats for microbes that are very sensitive to environmental change.

Further discussions over dinner in the Madingley Hall dining room

iii) Fossil Record and Climate Change

Jane Francis demonstrated that, if you go far enough back in time, then both polar regions were once covered with dense, temperate forests. For example, during the mid- to late Cretaceous (100-65 million years ago) fossil forests, plus evidence of a rich marine life, pointed to mean annual temperatures (MAT) of 16°-20°C for the Antarctic Peninsula region. Conditions cooled somewhat in the ensuing Eocene (50 million years; MAT ~9°C) but in the Arctic the presence of large *Metasequoia* forests plus crocodiles, alligators and other reptiles points to a MAT of 12°-15°C. We know that climate has cooled in a series of distinct steps in the polar regions over the last 50 million years, but what we do not know are the floral and faunal responses to it. Were there one or more mass extinctions, or just a series of gradual expulsions?

iv) Molecular Techniques

Using a series of marine invertebrate examples, Christoph Held reviewed the fast-growing field of molecular systematics and phylogenetics. Relatively slowly evolving genes, such as 16S rRNA or COI, can be used to investigate the spread of taxa such as the isopod family Serolidae through the southern hemisphere (on geological timescales). Held has also discovered a considerable amount of intraspecific variation in such groups and wonders if this might be pointing to a degree of 'hidden' speciation? Microsatellites are much faster evolving molecular markers that can be used to characterise individuals within populations. Some interesting patterns of local variation were observed in the Antarctic using this technique, including some potentially significant ones with depth.

v) Databases

Almost all types of biodiversity scientist need to store large amounts of data in the most efficient way, and Claude de Broyer summarised the various methods for doing this. Databases can be either site- or species-oriented, and used for compiling inventories/assessments, monitoring change and conservation/management. De Broyer showed details of his own very extensive database for amphipods and suggested that, in this and many other major groups, our compilations for the Antarctic were rather better than those for the Arctic. It would seem to be important to try and set up some sort of polar biodiversity network to facilitate the exchange of available data sets. We could also use such a network to highlight the contribution of the polar regions to global initiatives such as the Convention on Biological Diversity, DIVERSITAS and the Global Biodiversity Information Facility.

A Review of the Key Polar Biodiversity Issues

At the start of the second day we attempted to review key issues in the study of polar biodiversity. At the outset it was felt to be important to have a clear understanding of why we should study polar systems in general, and the following points were emphasised:

- they cover approximately 20% of the Earth's surface
- they are hugely important in climate regulation
- they are very sensitive to climate change
- they are pristine areas
- we still know little about the structure and function of polar ecosystems
- they are subject to an array of different forcing functions

To take the discussions further, we then split into two groups: one to discuss key issues in the marine realm and the other in the terrestrial and freshwater ones. Each group then reported back to a plenary session.

Key Biodiversity Issues in the Polar Marine Realm

1. Patterns and scales of biodiversity

- We need more information at all levels, from molecular to assemblages.

  Diversity should be studied in relation to both latitude and depth.

  Besides raw counts of taxa we need information on numbers of individuals, species ranges, levels of recruitment, etc.

- Our coverage of the Antarctic in particular is very patchy and needs to be made more systematic.

- Evolutionary history/rates of evolution. Are rates of speciation or extinction (or both) significantly different in the polar regions

2 Functional role of biodiversity

Even though it may be inherently difficult to study certain aspects of functional diversity in the marine realm, it was felt to be important that we try.

- What is the role of polar ecosystems in relation to that of other ecosystems?

- Can we identify key/keystone species?

- We need to learn a lot more about microbial structure and function in the marine realm.

- δN^{15} studies may help food web analysis.

- We should make use of 'natural experiments' such as polynias, iceberg scouring, and recruitment blooms.

3 Climate Change and biodiversity

- Need for more baseline data.

- If global warming occurred, would we see a marked change from silica-based to carbonate-based ecosystems?

- An interdisciplinary workshop would be a good way of taking this whole issue forward (see below).

To pursue these three key issues we also discussed some practical ways as to how the work could be accomplished.

Necessary tools to do the job:

- standardise sampling techniques
- improve databases
- promote an interdisciplinary approach
- develop modelling at all levels
- develop flagship sites?

It was thought that it would also be necessary to:

- develop a network
- organise a Euroconference
- establish a Web information system for polar biodiversity research

Key Biodiversity Issues in the Polar Terrestrial and Freshwater Realms

1. Is it low biodiversity?

a) For some groups it undoubtedly is, but for others we simply don't know.

2. Do we have sufficient knowledge to describe patterns of biodiversity in the polar regions?

a) Possibly in the Arctic but almost certainly not in the Antarctic.

b) Much still to be learnt about microbial patterns.

3. Why is there not more diversity in the polar regions?

a) There is a series of obvious physical constraints; low niche heterogeneity; time constraints - i.e. time since last glaciation or deglaciation.

4. How will biodiversity in the polar regions respond to global change?

a) Polar regions are particularly sensitive to climate change; ozone and nitrogen levels; Arctic-Antarctic comparisons; make use of the comparatively simple ecosystems.

5. Global change - what happens when it warms?

a) Changing habitat availability; increased activity/abundance; changing competitive balance?

6. Some other issues that were discussed:

How resistant are polar communities to the removal of certain trophic groups?

How do we use palaeo-changes for predictions of the future?

What are the effects of human activities/tourism on polar and alpine regions? Consider both effects on existing species and the introduction of new ones.

Synopsis

There then followed what was perhaps the most difficult session of the whole workshop, when we tried to blend together a set of key issues that covered both the marine and terrestrial realms, and the research interests of a large group of biologists. Could we reach a consensus on a set of topics that really highlighted the importance of the polar regions to global biodiversity studies?

At first our discussions were rather wide-ranging and unfocused, with, understandably, a number of people emphasising the importance of their own particular subject area. Nevertheless, a broad pattern of agreement slowly emerged that was centred on three main themes. In a way, each of these themes blends into the others but parts of them are sufficiently distinct to warrant separate identifications. These three subject areas are described in turn below.

1 Patterns of Biodiversity

Almost all of us had an interest in patterns of biodiversity, at one scale or another. After all, it is variation (or variability) that lies at the heart of the definition of biodiversity and this is often most easily expressed in the study of patterns. To some, the patterns of interest are only small-scale, or local, and may involve nothing more than the study of a small environmental gradient in an Arctic tundra community or Antarctic lake. For others there are larger-scale, or regional, comparisons to be made when whole tracts of the Arctic or Antarctic are compared with other parts of the Earth's surface, and at the largest scale of all we have the contribution of the polar regions to our knowledge of global biodiversity patterns.

The Madingley Hall conference venue

There was general agreement that we needed to find out far more about the nature of Arctic and Antarctic diversity patterns. How unique are they, how were they formed, and over what sorts of timescale? There were wide-ranging interests in the study of diversity gradients, which could again vary in scale from a few centimetres to thousands of kilometres. We could look at gradients in latitude, altitude (on land) and depth (in the sea) using many different approaches. It was emphasised strongly that future polar biodiversity studies must use standardised sampling and analytical techniques.

2 Functional Biodiversity

We also felt that it was crucially important to understand how polar ecosystems worked. Does their generally simple nature mean that they are more or less resistant to global change? What is the role of key species, and can we study them in both the field and laboratory? It might be possible, for example, to establish a network of biodiversity manipulations which investigated the alteration, removal or addition of various components.

In both the marine and terrestrial realms we are only just beginning to understand the role of microbes in polar ecosystems, and this promises to be an exciting area for future studies. With the rapid development of various molecular techniques it has been possible to demonstrate a remarkable degree of both inter- and intra-specific variability in the polar regions. How do these microbes interact with higher trophic levels?

It will not necessarily be easy or straightforward to carry out functional biodiversity studies in the polar regions and wherever possible we should make use of natural experiments and palaeo-records.

3 Polar Regions and Environmental Change

A common theme uniting all polar biodiversity scientists is their interest in global change. Again, a very wide range of timescales is involved here, from days to weeks at one end of the scale to tens or even hundreds of millions of years at the other. What are the effects of both global warming and cooling on population sizes, community structure, rates of immigration/emigration and rates of speciation/extinction? Linked with global change we should be looking specifically at changes in factors such as topography, albedo, gas fluxes, primary production, sea level and ocean currents (e.g. NAO, ENSO). In addition we need to learn more about the nature of extreme events (volcanic eruptions, tsunamis, etc.) in the polar regions.

Are stenotopic polar taxa more susceptible to extinction? Because both polar regions are isolated (and the Antarctic especially so) many species have literally 'nowhere to go' if their ambient conditions change significantly; range retractions or expansions may not be an option. Although we know that both polar regions were once covered by dense, temperate forests, we do not know the rates at which various vascular plant taxa were eliminated. Temperature has declined at an incrementally slow rate over geological timescales in the polar regions and there are no indications that they are in any way more prevalent to mass extinctions.

Conclusions and Way Forward

We believe that we identified three major topics that were of global significance for biodiversity studies:

1) Patterns of biodiversity in the polar regions

2) Functional biodiversity of the polar regions

3) Polar regions and environmental change

There was general agreement that these themes could be addressed by marine, terrestrial and freshwater specialists alike, as well as by both biologists and palaeobiologists. Each one of them offers opportunities for truly interdisciplinary collaborations and the chance to make a series of unique Arctic-Antarctic comparisons. There was scope here to make some important, innovative contributions to global biodiversity science.

There was a general feeling that the three identified themes would make ideal subjects for a linked series of workshops. As much as communicating final results, we wanted to compare and contrast methodologies between such areas as the marine and terrestrial realms and the Arctic and Antarctic. What are the key methods for estimating levels of polar biodiversity; how should we construct our experiments to investigate ecosystem stability; and what are the appropriate timescales for investigating global change?

This led us on directly to consider the idea of applying for an ESF-sponsored Network. We tentatively adopted a network title of 'Polar Biodiversity' and thought that the workshops should be in a planned order: patterns of biodiversity first, then functional biodiversity and finally biodiversity and global change. A first workshop on 'Patterns of Polar Biodiversity' was provisionally targeted for May 2003 in Oslo (and hosted by John Gray).

It should be emphasised that we did also discuss the possibility of an ESF Programme and recognised that our three themes could also be taken forward in this way. We felt that we would be able to meet the essential criteria of scientific excellence and strategic interest, but were uncertain as to how easy it would be to co-ordinate funding applications to a variety of national agencies.

In discussing a linked series of workshops we thought that it was particularly important to highlight the relationship between polar biodiversity and global change. We wanted to learn much more about the physical processes of climate change in the polar regions, as well as their biological consequences. To this end we were very attracted to the idea of applying for a EURESCO Conference with a title such as; 'Driving Forces behind Polar Biodiversity', or 'Past Climate Change and Present Biodiversity'. The aim of such a conference would be to invite a range of polar climatologists, climate modellers, oceanographers, geophysicists and geologists to interact with their biological counterparts. How had the polar seas formed; what are the past and present circulation patterns in both the oceans and atmosphere; and how can we predict what might happen in the future? There was scope here for a truly interdisciplinary meeting attended by leading experts from around the world.

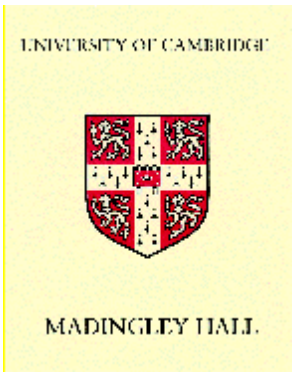
In conclusion, we decided that we would like to go forward with applications for both an ESF-sponsored Network and a EURESCO Conference. To do this, we established a Core Steering Group comprising the following members:

Alistair Crame	UK Chair
Wolf Arntz	Germany
Christian Brochman	Norway
Claude de Broyer	Belgium
Riccardo Cattaneo-Vietti	Italy
Jane Francis	UK
Carlos Pedrós-Alió	Spain
Birgit Sattler	Austria
Jan Marcin Weslawski	Poland
Phillip Wookey	Sweden

We also agreed to establish an interactive 'Polar Biodiversity' web page and Alistair Crame offered to host this at the British Antarctic Survey. He also indicated that he would apply to the European Polar Board for any incidental costs incurred in setting this up.

Acknowledgements

We are very grateful to the European Polar Board for encouraging our application for an ESF Exploratory Workshop and to the ESF/LESC for generously funding it. Alistair Crame would like to thank Hoc Baldock, Huw Griffiths and Katrin Linse for their help in running the meeting and the British Antarctic Survey for secretarial/office support. Madingley Hall proved to be a very stimulating venue and we are grateful to the Conference Manager and staff for their hospitality.



ESF LESC Exploratory Workshop on Polar Biodiversity

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