Introduction. Antarctic ecology: from genes to ecosystems. Part 2. Evolution, diversity and functional ecology

The Antarctic biota has evolved over the last 100 million years in increasingly isolated and cold conditions. As a result, Antarctic species, from micro-organisms to vertebrates, have adapted to life at extremely low temperatures, including changes in the genome, physiology and ecological traits such as life history. Coupled with cycles of glaciation that have promoted speciation in the Antarctic, this has led to a unique biota in terms of biogeography, patterns of species distribution and endemism. Specialization in the Antarctic biota has led to trade-offs in many ecologically important functions and Antarctic species may have a limited capacity to adapt to present climate change. These include the direct effects of changes in environmental parameters and indirect effects of increased competition and predation resulting from altered life histories of Antarctic species and the impacts of invasive species. Ultimately, climate change may alter the responses of Antarctic ecosystems to harvesting from humans. The unique adaptations of Antarctic species mean that they provide unique models of molecular evolution in natural populations. The simplicity of Antarctic communities, especially from terrestrial systems, makes them ideal to investigate the ecological implications of climate change, which are difficult to identify in more complex systems.

Keywords: glaciation; genomics; adaptation; speciation; climate change

1. INTRODUCTION

Antarctic ecology: from genes to ecosystems was stimulated by the increasing impact of new approaches, including genomics and ecosystem modelling, on our understanding of the evolution and functioning of Antarctic ecosystems, especially in response to global climate change (Clarke et al. 2007a). The two thematic volumes aim to integrate recent developments in our understanding of protein structure and gene expression, organismal physiology and ecology, through to ecosystem-level processes and the evolution of entire ecosystems. Such an approach also requires consideration of a range of scales in terms of organismal size (microbiota to the largest animals on earth), system organization (molecules to biological communities and entire ecosystems) and time (physiological responses to historical changes in geography and climate). Volume 1 focused on patterns of abundance and diversity (Barnes & Conlan 2007; Brandt et al. 2007) and ecosystem function (Ducklow et al. 2007; Murphy et al. 2007; Smith et al. 2007) at large scales in Antarctic marine ecosystems and reviewed the current evidence for climate change and its likely consequences in Antarctica (Clarke et al. 2007b). It emphasized the connections between and within ecosystems and the communities they comprise (e.g. Barnes & Conlan 2007), including the influence of the physical environment and the wider-scale earth system on the Southern Ocean (e.g. Murphy et al. 2007).

2. THIS ISSUE

Here we present volume 2 of Antarctic ecology: from genes to ecosystems. This volume addresses the evolution of the terrestrial and marine biota of the Antarctic, and explores the relationships between genome function, physiology and ecology. A recurrent theme is how evolutionary (genomic) and physiological constraints of individual Antarctic species influence the response of communities to climate change. Building on these themes, and the wider ecosystem analyses presented in the first volume, a number of papers examine how interactions of species within communities determine the response to environmental variability and change, including the impacts of harvesting.

Environmental change is not simply a phenomenon of the past; in the past, orbitally forced climatic variation (e.g. Naish et al. 2001; Zachos et al. 2001; Florindo et al. 2003) has played a pivotal role in driving evolution in the Antarctic biota through natural selection and fragmentation of populations (Clarke & Crame 1992). The evolution of the Antarctic biota over geological time-scales is specifically addressed by Rogers (2007). This paper demonstrates how past climate change has been critical in setting patterns of diversity and population structure observed in Antarctic communities today, placing other papers in the two volumes in a historical context. Cheng & Detrich (2007) extend this evolutionary view by considering the molecular adaptations of the notothenioid fishes to low temperature. These fishes have undergone a spectacular radiation in the Antarctic, forming a marine species flock, and dominate the fish fauna of the continental shelf in terms of biomass and abundance. Cheng & Detrich (2007) consider how physiological adaptation in notothenioids may constrain physiological performance and also limit the ability of polar organisms to respond to rapid climate change. Pörtner et al. (2007) extend this consideration to an integrative view of physiological adaptation to the Antarctic environment from the
molecular to whole-organism level across a range of taxa. They also consider how thermal specialization affects ecologically important traits such as growth, reproduction and development.

The next two papers address microbial diversity in Antarctic ecosystems. Murray & Grzymski (2007) review marine bacterial and archaeal ecology in Antarctica, showing that while bacterioplankton diversity rivals that in other ocean systems, there is a distinct biogeographic signal among polar phylogenotypes. Analyses of large insert environmental genomic libraries and whole genome sequencing of Antarctic micro-organisms have revealed molecular adaptation to the cold as with larger organisms discussed by Cheng & Detrich (2007) and Pörtner et al. (2007). Laybourn-Parry & Pearce (2007) examine the microbial and metazoan biota of freshwater systems. As with marine ecosystems, molecular methodologies are revealing previously unknown diversity in freshwater micro-organisms, with different groups showing contrasting levels of endemism in Antarctica. However, as a result of harsh environmental conditions, these systems often show a low diversity, especially for metazoans.

The papers by Chown & Convey (2007) and Wall (2007) explore terrestrial ecosystems in the Antarctic. Chown & Convey (2007) identify a biogeographic discontinuity between the Antarctic Peninsula and continental Antarctica reminiscent of the ‘Wallace Line’ of Southeast Asia (Brown & Lomolino 1998). They also reveal that despite their low diversity, Antarctic terrestrial communities show a high level of spatial and temporal variation, and they explore the consequences of climate change in such communities. Wall (2007) explores interactions among the above-ground and belowground components of the terrestrial ecosystem of the McMurdo Dry Valleys region, one of the most extreme environments in the world. She also considers the responses of these (and other) ecosystems to climate change and the existence of ‘tipping points’, where small alterations in the physical environment can cause irreversible changes to occur in such systems, driving them to less resilient states. Both papers demonstrate that, as a result of their relative simplicity, Antarctic terrestrial habitats have important things to tell ecologists about how low diversity regions operate, how communities are assembled and how they respond to climate change.

The Antarctic marine ecosystem is influenced not only by climate variability and change (at a range of spatial and temporal scales) but also by the effects of harvesting over more than two centuries; the historical consequences of which are still ongoing. The last two papers of the volume focus on responses of the Antarctic marine ecosystem to such disturbances and review the development of sustainable management regimes. Trathan et al. (2007) examine the influence of interannual environmental variability on the population dynamics of higher trophic-level predators, providing fundamental insights into how such systems respond to variation. Kock et al. (2007) examine the development of management regimes that have sought to ensure the sustainable exploitation of Antarctic marine species while taking account of the consequential effects of harvesting on the food web; part of a pioneering development of the ecosystem-based approach to management of exploitation. Although the current fisheries are well regulated (as described by Kock et al. 2007), the possibility exists that the system may not recover in the sense of returning to its previous state. It is possible that we have shifted the Antarctic marine system from one dominated by the great whales to another dominated by fur seals and squid. Only time will tell, and the extent to which the ability of the system to respond to a relaxation of harvesting will be affected by climate change is completely unknown. The next challenge in the development of the ecosystem-based approach to sustainable management is to take into account not only how Antarctic ecosystems operate but also how they respond to climate variability and change, as documented by the papers in this volume.

3. CONCLUDING REMARKS

The evolutionary history of the Antarctic biota makes it unique in terms of understanding the mechanisms of evolutionary change at the level of the genome. Adaptation to life at extremes involves physiological trade-offs that may constrain responses to present climate change. Furthermore, the simplicity of some Antarctic communities and the potentially low level of functional redundancy among the species they comprise make them highly suitable for unravelling the complex interactions and feedbacks that occur in a changing world. The Antarctic Peninsula and Scotia Sea regions are showing some of the strongest relative increases in air and sea temperatures globally. Antarctic communities may provide an important early warning of the potential perturbations to ecosystems that may occur elsewhere in the world, but are difficult to identify and understand owing to higher levels of biological diversity and the confounding effects of other human impacts. The present and previous volumes demonstrate that the Antarctic will remain at the forefront of research in evolutionary biology, ecology and the ecosystem impacts of climate change now and in the future.

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