Conclusions

This book adds to assembling the outstanding contribution of Marine Biology to IPY. The quality of research, the frequent international collaborations and the remarkable boost in pursuing multidisciplinarity are values that also characterise Volume 2 of "Adaptation and Evolution in Marine Environments—The Impacts of Global Change on Biodiversity". These values help in having the contribution of Marine Biology be considered as an invaluable component of the general scientific outcome of IPY 2007–2009.

The responses of cold-adapted polar organisms provide information to analyse the effect of changes in general, and foresee their impact at lower latitudes. In this general scenario, all research reported in the eleven chapters is under the umbrella of the international, multi- and cross-disciplinary programme "Evolution and Biodiversity in the Antarctic—The Response of Life to Change" (EBA). Launched by the Scientific Committee for Antarctic Research (SCAR) in 2004, EBA covers most of Antarctic biological research in the marine, terrestrial and freshwater realms. EBA's relevance to Global Change underscores the importance of this programme in environmental research during IPY. EBA addresses the impacts of change on Antarctic biodiversity, evolutionary adaptations and community dynamics, with the ambitious aim to extrapolate the implications and seek forecasts concerning the whole planet.

The programme envisages links with the Arctic. The latter is undergoing rapid climate change, with progressive and fast decrease of sea and land ice, only matched—for the time being—by what is happening in the Antarctic Peninsula. The similarities and, conversely, the differences that the northern and southern polar environments are revealing as consequences of current global warming suggest that, in the context of future polar research, initiatives that envisage bipolar activities and investigations will become more and more common, especially considering the key role of Antarctica in driving the climate of the whole planet, on one hand, and on the other the growing political and socio-economical importance of the Arctic. The official polar international institutions, namely

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SCAR and IASC (International Arctic Science Committee, www.iasc.info), are well aware of the importance of this trend, and have been customarily holding joint meetings since several years. An increasing number of national institutions is following this trend. The research projects reflect this factor, in that they increasingly include collaborative bipolar activities. At least five of the eleven chapters of this Volume underscore the importance of bipolar research and Arctic/Antarctic comparisons in studying adaptations to the impacts of current global climate change. This aspect is also a hallmark of IPY.

Climate change and its effects on biological systems, evolution and biodiversity in a changing environment is a major multi-disciplinary theme; as such, it has been the primary target of EBA's sponsored research. EBA's wide umbrella has fulfilled its outstanding coordination role for many years, providing fertile ground for organisation and multi-national efforts, but now needs to be replaced by more focussed projects. EBA is approaching 2013, the end of its planned lifespan. Since 2009, the EBA community has been planning the course EBA's philosophy will take in future polar science, Now is the time for achieving progress and proceed further. The Antarctic biology community is proposing two programmes on distinct but complementary aspects of polar biology, across marine, freshwater and terrestrial environments: "State of the Antarctic Ecosystem (AntEco)", and "Antarctic Thresholds—Ecosystem Resilience and Adaptation (AnT-ERA)". This is the legacy of EBA, and the key to keep understanding and protecting biodiversity. The cooperative and cross-disciplinary structure, in particular for evolutionary and biodiversity information, is a long-term legacy and must be retained. Antarctic research is very expensive: it must be excellent, relevant, multi-national and well planned.

This development will inherit the message and values of the mother programme, and keep feeding inputs into IPY 2007–2009, just as EBA did, to conquer its deserved place in the history of international polar science.

Cinzia Verde
Guido di Prisco

Perspectives and Implications

The SCAR (www.scar.org) international, multidisciplinary biology programme "Evolution and Biodiversity in the Antarctic—The Response of Life to Change" (EBA) sponsors the chapters of this Volume 2 of "Adaptation and Evolution in Marine Environments—The Impacts of Global Change on Biodiversity" of the Series "From Pole to Pole: Polar Environmental Research during the International Polar Year 2007–2009". The EBA and IPY activities were conceived in parallel, and EBA was chosen by the IPY Science Plan as a Lead IPY Project. Assembling almost one hundred teams and covering most of Antarctic biological research in the marine, terrestrial and freshwater realms, the EBA community is now submitting proposals for more focussed developments.

EBA continues to contribute relevant science to the Antarctic Treaty System, highlighting the need to understand the impact of change on Antarctic ecosystems, relating the biology to the northern polar regions and liaising with physics, climatology, earth sciences and history. In pursuit of its mission to protect biodiversity, studies in both the field and the laboratory help to predict how organisms and communities will respond to current and future environmental change. Taking advantages of new technologies and especially of the development of molecular approaches, EBA is a continuing reminder of all of the best qualities of IPY.

The contributions, organised as three parts of this volume 2 (Part I: Biodiversity Evolution and Data Management; Part II: Evolution: A Molecular Perspective; Part III: Monitoring and Management.), are all in the framework of EBA. They are interconnected and complementary. Studies often merge into wider programmes, e.g. CAML, the part of CoML that deals with the Southern Ocean (SO). The importance of CAML has been referred to in 8 of the 11 chapters of Volume 1.

Further essential information on the accomplishments of CAML is summarised in the two chapters of Part I: Biodiversity Evolution and Data Management (history, organisation, targets, main expeditions, main results, workshops, coordination with SCAR-MarBIN, DNA barcoding, legacy). After five years,

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the legacy of CAML, funded by the Alfred P. Sloan Foundation, includes inventories, biodiversity databases, and extensive use of genomic techniques (Barcode of Life), that will allow us to answer important questions on marine genetic diversity and distribution of species and their links with areas north of the Polar Front. Thanks to a strong interaction with the sister project, Arctic Ocean Diversity (ArcOD), which addressed the census of Arctic marine biodiversity, comparisons can be drawn between differences in ecological structure and dynamics of of the Arctic Ocean and the SO. CAML revealed many new species. Sampling sites from which biodiversity data were obtained will be re-sampled in the future to track changes in marine biodiversity. Specimens to be used for research for many years to come will be collected. Data sets will be freely accessed (http://data.biodiversity.aq). The Southern Ocean Observing System (SOOS) will coordinate multi-disciplinary pan-Antarctic long-term monitoring which will help to assess the impacts of global change on these SO ecosystems.

IPY generated massive amounts of data, which need to be interrelated to understand complex problems such as environmental change and its impact on Antarctic biodiversity. The SCAR Marine Biodiversity Information Network (SCAR-MarBIN, www.scarmarbin.be), and the new Antarctic Biodiversity Information Facility (ANTABIF, www.biodiversity.aq) will be especially important in this with active data management to ensure that ANTABIF will maintain universal open access to biodiversity data.

The SO and the Antarctic continent pose extreme survival challenges for organisms, from bacteria to vertebrates. Considering the strong environmental constraints that polar organisms had to face to successfully cope with progressive cooling over millions of years, evolutionary adaptation has been, and will continue to be, a major theme of research in IPY. Climate change is calling for more and more work on the consequences that even a slight modification of the climate may entail for cold-adapted organisms, whose physiology has previously succeeded in adapting to allow species to escape extinction. It will be essential to increase our understanding of how polar organisms have adapted to cope with past challenges, to what extent adaptations may be upset by current changes, and—most important—whether it will be possible to minimise future threats of extinction, at our latitudes. Whilst terrestrial species are adapted to very variable conditions, marine species face more severe problems, because the large thermal capacity of water means that the most stable thermal environments are aquatic. Although warming will occur in the atmosphere to a much greater extent, the impacts of even a small increase in temperature in a marine environment are likely to affect organisms and their biodiversity much more severely. Therefore, studies on marine organisms seem likely to provide the most important insights into adaptation.

Part II (Evolution: A Molecular Perspective) comprises five chapters. Polar science is taking advantage of the development of molecular biology, that now has the potential to revolutionise evolutionary biology and ecology, and provides the tools to explore the function of individual genes and to use DNA barcode sequences to maximise taxonomic and geographic coverage. Changes in polar regions may lead to extinctions, and a reference baseline of sequences is under way, also thanks to CAML; it will be possible to focus on gaps, set priorities for the most important taxa and avoid duplicated collections, and make use of molecular phylogeny in drawing evolutionary trees. Thanks to "omic" technologies, new biochemical pathways, evolutionary adaptation and tolerance/resistance to extreme conditions can now be investigated, gaining insights into how low temperatures may affect the physiology of vertebrates and invertebrates, in particular of microorganisms, thereby shedding light on microbial adaptations to cold.

Chapter 3 deals with evolution in the SO in a global context. In the SO, with the exception of studies on vertebrates and commercially valuable species, molecular ecology and phylogenetics are in their infancy. Yet they are transforming our understanding of connectivity within the ocean itself, and between the SO and other oceans, including the Arctic. At least half of the findings stem from DNA barcoding, in most cases with the help of CAML. Molecular ecology should focus on additional genes and markers (nuclear markers, including microsatellite markers). To date, microsatellites have been developed for only a few invertebrates: krill, some isopods, and three octopus species. Future molecular studies should also include haplotype networks and look for network patterns that can be predicted under different refugial scenarios at glacial maxima. Investigations should also look for congruent patterns between nuclear and mitochondrial markers and seek evidence in molecular signatures for recent population expansions. They may also be able to confirm that historical seaways acted as a conduit for gene flow.

Species bipolarity has raised the intriguing question whether co-specific Antarctic and Arctic populations evolved independently, since separation between the Arctic and Antarctic regions or genetic continuity is ensured by trans-tropical gene flow. Classical approaches (morphology, analysis of genetic variation) have limitations. Ciliates are ideal organisms to analyse the breeding structure of microbial populations and obtain data which satisfy the interbreeding criterion on which the Darwinian concept of species is founded. Living laboratory material can readily be available in unlimited amounts. Chapter 4 describes how ciliates govern gene exchanges through sexual conjugation. Breeding analyses of Antarctic, Fuegian and Arctic populations of a species show that they are genetically interconnected by gene flow and form a unique interbreeding species. These strains share the same gene pool, indicating that bipolar populations may maintain genetic continuity in spite of ecological discontinuity and ensure a pole-to-pole gene flow by the cold currents that cross the equatorial depths. Nuclear and mitochondrial ribosomal gene sequences and single nucleotide polymorphisms (genetic markers of the evolutionary history) need to be elucidated. Polymorphisms may reflect natural hybridisation between Arctic and Antarctic populations, and may also be able to interact *via* signalling cross-reactive pheromones (synthesised to promote mating and growth), whose structures secure wide-range dispersal in any environment.

Such molecular approaches will be invaluable in evolutionary and ecological studies. Gene flow, genetic drift, selection, and other factors, affect the evolution of biodiversity. The ACC ought to homogenise the structure of populations of the SO, and strong connectivity is indeed found for some species, with genotypes being shared across the full range. However, species-specific life-history traits influence the patterns of most taxa such that distinct populations can be identified.

The next two Chapters deal with the physiological and physico-chemical role of temperature, a fundamental driver in shaping biotic and abiotic factors.

Chapter 5 discusses the concept of oxygen and capacity limited thermal tolerance (OCLTT), looking at brachyuran and anomuran crabs. These live at the border of the polar oceans and have settled in "warmer" water bodies, excluded from permanent life at the coldest temperatures. A cause/effect understanding of thermal limitation and adaptation at various levels of biological organisation is crucial in elaboration of how climate has shaped the functional properties of the fauna. Crustaceans are a group where such cause/effect understanding is still in its infancy. They may display features resulting from excess oxygen availability rather than cold-induced oxygen limitation. Further studies ought to explore whether sub-polar species show a trend to uncouple oxygen shortage from capacity limitation at low threshold temperatures. This approach suggests that the patterns of oxygen and capacity limited thermal tolerance are linked with life-history consequences typically seen in permanent cold. Future research needs to address these interrelationships, and also to consider how climate challenges not only involve temperature changes but also the effect of additional stressors, e.g. ocean acidification. These aspects are largely unexplored. A relevant question is whether high CO_2 concentrations exert negative effects on physiological processes modified during cold adaptation. OCLTT reaches the ecosystem level, where biotic interactions shape ecosystem structure and functioning. Interacting species coexist where thermal niches overlap. Each species will be affected by changing conditions, with consequences on coexistence and competitiveness. Therefore, studies must also address the consequences of thermal stress for species interactions. Comparative research should look at the changes in species-specific sensitivities and performance of interacting species with the goal of identifying the mechanisms causing relevant shifts in interactions. Temperature is the prime candidate for building a matrix on which to understand effects of other stressors (hypoxia, CO_2, etc).

The rate of growth of a microorganism is related to the rate of the metabolic reactions, catalysed by enzymes that require proper folding and stability. Chapter 6 stresses that thermodynamic analysis is of primary importance, since activation entropy and energy make reactions possible. In thermophiles, high temperatures favour reaction rates, but also induce unfolding/misfolding. Proteins have slightly modified their structure to resist high temperatures, while folding is assisted by chaperones. In psychrophiles, the main problem is to secure metabolic fluxes. This problem has been solved through evolution of enzymes displaying lower activation energy and lower thermal dependence of the activity. Limitation of the tools permitting folding at low temperature is correlated with reduction of physico-chemical constrains that can counteract folding and also with the energetic care to limit protein synthesis. The high number of enzymes with a key role in all these aspects underscores the need for thermodynamic characterisation. Comparison between phylogenetically related bacteria in freezing and non-freezing habitats may help to understand whether extreme environments require adaptations at species level, or the action of a few genes is sufficient for defining the preference for a given environment.

Part III assembles five chapters. Monitoring and Management are an extremely important field of activities, because they yield tools that are essential to advance knowledge in virtually all other fields of biological science.

In Chapter 7 we learn about the benefit of satellite technology in investigating seals thriving in both polar environments. Many species are pelagic except for breeding and moulting, unlike those staying in close proximity to the coast or the ice edge, where they can be observed throughout the year. Satellite-linked dive recorders permit us to learn about the whereabouts and behaviour of ecologically and economically important pelagic species, as well as about seasonal distribution and diet composition. Satellite-linked dive recorders can elucidate location and diving behaviour throughout the year in the Arctic and Antarctic, determining haul-out patterns, useful in converting aerial sightings into population numbers. Besides implications in ecology and population dynamics, such investigations have socio-economical importance especially in the Arctic, where some species impact on the economy of coastal communities. The North Atlantic and the Barents Sea-White Sea hold some important fish stocks, so the ecological and economical implications of millions of seals will benefit from further investigation.

Chapters 8 and 9 complement each other and deal with monitoring and management issues related to environmental processes, biodiversity, and environmental assessment in Admiralty Bay, King George Island (KGI). The sensitivity of Admiralty Bay is high, due to its location close to the Antarctic Peninsula, and the high risk of human impacts besides climate change. Close cooperation between operators and programmes will add value to KGI studies by providing a regional, continental and global context for interpretations and comparisons. Standardised techniques and measurements, common sets of variables, and open access to data will be essential for cross-comparison of data sets from diverse locations and scientific teams, not only at KGI but also more broadly in Antarctica. Because of the lifescience, geoscience, and physical science studies conducted at KGI, multidisciplinary integration is possible in a way that cannot be achieved at most other locations. These outcomes will benefit all national programmes in KGI. Mutually beneficial cooperation and partnerships can be realised if duplication of efforts is minimised, infrastructure and logistics are shared to reduce costs and impacts, and standard techniques and sets of variables are agreed between national scientists collaborating with each other and with SCAR. The realisation of these opportunities can only happen if there is a desire for partnerships and if bi- and multilateral agreements to advance common goals can be negotiated.

Chapter 10 discusses anthropogenic impacts on sub-Antarctic and Antarctic islands (including KGI) and the adjacent environments. Marine pollution, diversity changes caused by introduction of non-indigenous species, and global environmental changes are the main consequences of human activities. Some isolated islands remain pristine, but are threatened by human visitation. Management of marine ecosystems requires the ability to distinguish the effects of human impacts from those of climate change. Marine reserves (target areas and ecosystem reserves) are needed to monitor the impacts of global changes. Multidisciplinary studies, identification of impact origins, and long-term monitoring are needed to assess the effects of human activities on environments and biodiversity, as management tools, especially when taking biodiversity hotspots into account.

Chapter 11 conjugates behaviour, ecology and technology, in the framework of climate change. There is a need for a broad expansion (in terms of key species and geographic coverage) of Polar Life Observatories (PLOs), and also for international agreement on how they should be managed (standardisation of data collection, benchmarking, metadatabase organisation, access rights) to make them effective and promote international collaborative work. In fact, studies taking an ecosystem approach to marine dynamics are few, data time series are often short and quantitative knowledge of the dynamics of interactions between predators, prey and environment is limited. Seabirds (albatrosses, penguins, puffins) sensitive to changes are indicated as monitoring sentinels, excellent to assess ecosystem health, since we know which stocks of marine organisms they feed on. Some of the best data series existing are on birds, making them ideal models for PLOs. How they are affected by environmental changes could be the necessary tipping point to convince policy-makers and governments to respond to a major global threat. PLOs meet priorities regarding environmental protection defined by the Convention on Biological Diversity (CBD), the Intergovernmental Panel on Climate Change (IPCC), and the International Council for Science (ICSU). Bio-logging devices act as monitors of prey stocks (mesopelagic fish, squid, krill, etc). Single penguins cannot be visually localised inside the colony, thus Radio Frequency IDentification (RFID) antennae are carried by remotely controlled robots that can circulate among penguins.

Polar regions experience greater rates of climate change than elsewhere. Ecosystems are adapted to extreme environments, and may become vulnerable. Research will continue to increase our knowledge of the Antarctic marine fauna of the continental shelf, the slopes and the deep sea. One of the most urgent and challenging tasks for the next decade will be to incorporate thinking from the physiological/biochemical viewpoint at the molecular level into evolutionary biology.

This view appears firmly embedded in the minds of the authors of the chapters of this Volume 2 of "Adaptation and Evolution in Marine Environments—The Impacts of Global Change on Biodiversity". What appears very clearly is the maintenance of the momentum of IPY 2007–2009 through the scientific relevance of the research performed by the authors, and the planning of future ventures, aimed at identifying impacts and threats of global climatic processes.

The concept of a "sustainable world" is essentially linked to the concept of "biodiversity". Biodiversity makes Earth what Earth is today: it makes life possible, and human life depends on the continuing variety of other life forms. It is one of the most crucial values of life on Earth, which calls for the best of our efforts to preserve it both for its own sake and as a primary support for our own future survival.

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