From Pole to Pole

Guido di Prisco
Cinzia Verde *Editors*

Adaptation and Evolution in Marine Environments, Volume 1

The Impacts of Global Change on Biodiversity

Springer

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Preface

The Series "From Pole to Pole: Polar Environmental Research during the International Polar Year 2007–2009" (Springer Verlag; Series Editors: Roland Kallenborn, University of Life Sciences, Norway; Guido di Prisco, National Research Council, Italy; David Walton, British Antarctic Survey, UK; Susan Barr, Directorate for Cultural Heritage, Norway) was conceived to report achievements of environmental research during the 4th International Polar Year (IPY) 2007–2009.

The major aim of this series is to provide up-dated science-based information on IPY research results and perspectives in all disciplines. It is intended as a starting point to gather information on specific environmental research topics within IPY activities, which would be difficult or even impossible to collect in another way. The volumes will provide scientific general information on the concepts, findings and scientific motivation on the various IPY projects and research activities, thereby directing the interested reader to further information dealing with the scientific aspects of the research. The scientific value of the series will grow in the years to come, because the volumes will also be available in e-book format, and a continuous up-date on references and information sources is expected for several years, supported by the Series Editors and the Publisher.

Marine Biology will provide two Volumes under the general title "Adaptation and Evolution in Marine Environments—The Impacts of Global Change on Biodiversity".

The present volume (Volume 1) will address two themes:

1. Biodiversity and the Environment.
2. Response to Stress—Adaptations.

The authors who have contributed to Volume 1 describe the concept, aim, and first findings of the respective IPY projects, providing information, equipped with exhaustive reference lists and relevant web pages, on results and research perspectives feeding into the framework of IPY 2007–2009.

We would like to express our gratitude to the authors and referees of the papers collected together in this volume.

Volume 2 will address different themes, and will be published in the next months.

Guido di Prisco
Cinzia Verde

Letter from the Editorial Team

The first two International Polar Years both failed to coordinate and distribute their assembled data adequately and to ensure its proper analysis, resulting in a less than satisfactory legacy from what had been considerable international efforts. Recognising this, the Third International Polar Year (International Geophysical Year) made extensive plans to ensure its contributions would be both accessible and used, establishing the World Data Centres as a major new initiative. In the early preparatory stages of the latest International Polar Year (IPY 2007–2009) the importance of providing for the legacy of this demanding international research effort was made clear, with priority being given to planning for well-organised dissemination and coordinated publication of the results, data evaluations and scientific findings. It was with this in mind that we proposed our publication project (IPY Project No. 79) in the form of the book series 'From Pole to Pole: Environmental Research within the International Polar Year 2007–2009' with over 50,000 scientists involved in a myriad of projects, there was an obvious need for a guide to the principal findings and the key papers within environmental science fields.

The 'From Pole to Pole' book series is intended to serve as a comprehensive publication framework for the documentation of environmental research activities performed during the IPY period. The book series is not intended to be a typical collection of original scientific project publications/chapters in the form of standard monographs. It is rather a bibliographic, science-based information source and a starting point for interested scientists and the public to access condensed information on specific environmental research topics within the IPY activities. The volumes will provide scientifically sound general information on the concepts, findings and scientific motivation of the various relevant research activities and will direct the interested reader to more detailed scientific papers, web-based information and other publications which will provide the detailed data and their analyses. The compilation of citations and references within the book volumes will be an important component for the assessment of progress in each area, and the scientific significance and value will grow as the series develops.

The volumes will also be available in e-book format, which will allow continuous up-dating of references and information sources (including Internet pages and databases) by the editorial team on an annual basis, thus keeping the works topical as a living reference source.

The forthcoming volumes (11 volumes are currently planned) will cover an extensive spectrum of environmental research including adaptation and evolution, geomonitoring, geology, cryospheric processes, polar biodiversity, polar climates, the Arctic and Southern oceans, as well as pollution and atmospheric monitoring. It is expected that this documentation will provide a comprehensive picture of most of the environmental research performed within the IPY framework.

At the first official stock-taking of the IPY during the Oslo Science Conference (OSC, June 2010)—where the findings and the implications of the research were initially evaluated—it became very clear that the IPY endeavour as a whole had proved to be an unprecedented success for polar research. IPY efforts have contributed to a new and comprehensive understanding of global environmental processes in the cryo-, hydro-, bio-, geo-, atmos- and anthroposphere, from both a social and natural scientific perspective. What was also clear at this largest-ever polar science meeting was that it would require continued efforts to make sure that the results of the IPY research would be easily available and properly documented for future research and evaluation processes.

This book series aims to make an important contribution to that documentation process. The editorial team is not only looking forward to assisting in the development of those volumes already planned, but also invites colleagues and experts to propose other topics not yet covered as potential volumes in the series 'From Pole to Pole: Environmental Research within the International Polar Year 2007–2009'.

With this first volume on the history of the International Polar Years (edited by Susan Barr and Cornelia Lüdecke), our concept has finally begun to be realised. We congratulate the volume editors wholeheartedly for an excellent historical overview of the scientific work and implication of IPY research activities during the past, and look forward to working with the volume editors and Springer Verlag to publish the remaining titles in this new series.

Aas, Norway — Roland Kallenborn
Naples, Italy — Guido di Prisco
Cambridge, UK — David Walton
Oslo, Norway — Susan Barr

Editorial Introduction

Over the past 130 years, there have been four occasions for scientists of all disciplines from around the world to join forces in concerted, international cooperative activities for explorations and investigations in the polar regions. Each of these occasions was labelled as "International Polar Year" (IPY). Every IPY produced advancement in geographical exploration and scientific knowledge, extending the understanding of many phenomena that influence global systems in the planet and paving the way to political agreements among governments.

The first volume of this Series, "The History of the International Polar Years (IPYs)", edited by Susan Barr and Cornelia Lüdecke, is an excellent historical overview of the scientific work and implications of IPY research activity in the past. We felt, however, that a short historical summary of the previous IPYs would be helpful to the reader to place IPY 2007–2009 into context, therefore we begin this Introduction with such a summary, before describing the scientific frame and the common concepts throughout the IPY research presented herewith and attempting to identify historical and international contexts.

The idea of organising International Polar Years was inspired by Karl Weyprecht, Austrian explorer and naval officer. He was a scientist and co-commander of the Austro-Hungarian Polar Expedition of 1872–1874. Weyprecht's polar experience convinced him that solutions to the fundamental problems of meteorology and geophysics were likely to be found in the proximities of the poles, and that such investigations could not be tackled by a single nation but needed coordinated international efforts. His belief set a legacy for the future IPYs. Unfortunately, Weyprecht had no chance to see the acceptance of his concepts, because he died before the occurrence of IPY.

In 1879 the International Polar Commission was established, and it was agreed that an IPY (the first) would be held in 1882–1883, to coincide with a transit of Venus across the face of the sun (December 6th, 1882). Weyprecht's pioneering concepts set an important precedent for international science cooperation. The decision to cooperate rather than compete, and to focus on scientific endeavours rather than acquisition of territory, was an audacious approach that left a lasting example for future ventures. It saw the participation of 12 countries:

Austria–Hungary, Canada, Denmark, Finland, France, Germany, The Netherlands, Norway, Russia, Sweden, UK, USA. Fifteen expeditions took place, 13 to the Arctic, 2 to the Antarctic. The Jan Mayen Island, Alaska, Greenland, Tierra del Fuego, South Georgia, Novaja Semlja, Spitzbergen were amongst the expedition targets. Fourteen meteorological stations were set around the North Pole, and the observations (meteorology, geomagnetism, auroral phenomena, ocean currents, tides, structure and motion of ice and atmospheric electricity) were integrated by over 40 meteorological observatories around the world. The enormous amount of information formed the basis of our knowledge of the Earth's magnetic field and climate. The first IPY was mostly focussed on the past and present circumpolar Arctic environment.

The need to take advantage of the new inventions and discoveries to advance geophysical knowledge led the International Meteorological Organisation in 1927–1928 to pave the way for a second IPY, aimed at investigating global implications of the newly discovered "Jet Stream". It proposed magnetic, auroral and meteorological observations at a network of stations in the polar regions that would advance general knowledge of terrestrial magnetism, marine and aerial navigation, wireless telegraphy and weather forecasting. Thus, 50 years after the first IPY, the second IPY was organised in 1932–1933. Forty-six nations participated, and brought progress to transport by air, sea and land (advent of the airplane, motorised sea and land transport), meteorology, magnetism, atmospheric science, and "mapping" of ionospheric phenomena that advanced radio science and technology. Arctic research was supported by establishing 40 permanent stations, many of which are still active today. The second Byrd Antarctic expedition (USA) established a winter meteorological station, the first research station inland from the coast, 125 miles south of Little America Station on the Ross Ice Shelf. A world data centre was created and coordinated by the International Meteorological Organisation.

The first two IPYs suffered enormous logistic difficulties. Together with harsh privations, survival was a main concern, and tragic episodes did occur. These factors of course strongly limited the amount of time devoted to science.

In the 1950s, rocketry, radar and seismography were among the issues that inspired a third IPY. The International Council of Scientific Unions broadened the issue from polar studies in the upper atmosphere to geophysical research, renaming this effort "International Geophysical Year" (IGY). Sixty-seven countries and more than 70 national institutions participated in this cooperative venture. We can consider IGY, which took place from July 1957 to December 1958, as the third IPY, occurring 75 years after the first IPY and 25 years after the second IPY. It envisaged the peaceful use of newly developed (for military purposes) technologies, with the aim to achieve research advances, particularly in the upper atmosphere. Revision of many notions about the Earth's geophysics are due to IGY's discoveries and synoptic observations. For instance, the theory of continental drift was confirmed, enabling us to understand the formation of continents and oceans. The Van Allen Radiation Belt encircling the Earth was discovered by a US satellite. In fact, IGY saw the dawn of the space age with the launch of the first satellites (1957: Sputnik I, USSR; 1958: Explorer I, USA). The first estimates of the size of Antarctica's ice sheet was obtained by traversing the continent for the first time. IGY led to strong development of research in many disciplines. The scientific, institutional, and political legacies of IGY lasted for decades, providing countless science achievements, and continue to the present. A notable political result founded on IGY was the ratification of the Antarctic Treaty in 1961, which established that the Antarctic continent would be dedicated to peaceful research.

During each of the three IPYs, scientists from all over the world came together to organise intensive scientific and exploration programmes in the polar regions, generating important advances in scientific and geographical knowledge. From laying the foundations of our understanding of nature's global systems to launching the modern space age, IPYs set the stage for many international scientific collaborations as well as a long-standing political accord.

Half a century after IGY, in 2007 the fourth IPY began (www.ipy.org). It was sponsored by the International Council for Science (ICSU) and the World Meteorological Organisation (WMO). The International Planning Group established within ICSU was co-chaired by Robin Bell and Chris Rapley. The Director of the IPY International Programme Office was David Carlson (see Volume 1 of the Series). IPY 2007–2009 has been the largest ever international programme of scientific research in the Arctic and Antarctic regions, building upon the long legacy, established in the previous IPYs, of international cooperation, scientific achievement and societal benefits.

The importance and complexity of the fourth IPY deserves adequate description of the outcomes flowing from such a vast international initiative. Two important fora have been organised to meet this target. One of them, the "IPY Oslo Science Conference", took place in 2010 in Norway. The second one, "IPY—From Knowledge to Action", will privilege the collective dissemination of the first scientific results and perspectives; this rendezvous is scheduled in 2012 in Montreal (Canada).

The Series of Springer Verlag books "From Pole to Pole: Polar Environmental Research during the International Polar Year 2007–2009" is a strong contribution for libraries of institutions of the whole world. It is ideally complementing the many articles on IPY research which are increasingly being published in scientific journals.

Marine Biology is providing its own contribution, summarising the achievements of this science area in two Volumes on "Adaptation and Evolution in Marine Environments—The Impacts of Global Change on Biodiversity". The present volume is the first one. The chapters describe investigations that pertain to IPY projects. All of them will undergo further developments in the decades to come. Field work, logistic challenges, and potential follow-up activities are included in each chapter, identifying linkages with investigations described in other chapters.

The ideas and concepts of each chapter are briefly outlined below.

The volume opens with an introductory overview describing the origin and future developments 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 assembles almost one hundred teams and covers most of Antarctic biological research in the marine, terrestrial and freshwater realms.

SCAR (www.scar.org) is the major organisation coordinating research in the Antarctic and Southern Ocean (SO) region. With SCAR's support, EBA facilitates interdisciplinary interaction for the integrated approach required for unravelling the role of the polar environments to modulate the Earth system. By feeding information, EBA enhances SCAR's ability to address key issues raised within the Antarctic Treaty System. SCAR provides an opportunity to inform non-biological disciplines of the ultimate necessity of the programme, namely to contribute to understand the impact of Climate Change on Antarctic ecosystems. Most SCAR nations participate in EBA, that acts as a major route for capacity building in new SCAR members and those with reduced logistic and financial resources, and contributes to a wide variety of international programmes. EBA includes sub-Antarctic islands, inland to remote nunataks as well as northward to the Magallanes Strait, stretches across the SO down to the deep ocean as well as the shelves, and links with northern polar studies. The objectives are to understand the evolution and diversity of life in the Antarctic, to determine how these have influenced the properties and dynamics of present Antarctic and SO ecosystems, and to make predictions on how organisms and communities will respond to current and future environmental change.

The chapter describes the EBA Work Packages, each focussed on a specific area of science. A major marine focus has occurred during IPY. Antarctica is conventionally described as having very limited terrestrial biodiversity. This exists in the form of isolated "islands" of terrestrial habitat surrounded by inhospitable ocean or ice. These fragmentary habitats provide an ideal "evolutionary laboratory", allowing questions to be addressed on both relatively short (e.g. isolation of populations during the Pleistocene) and long (e.g. post-Gondwanan) evolutionary scales. This part will be illustrated in the Series volume addressing Terrestrial Biology.

An explicit aspect of EBA is to compare and where possible integrate results from the marine, terrestrial, and limnetic environments. The programme is interdisciplinary in that it brings together a wide range of biological disciplines to tackle a series of sharply focussed questions. It utilises state-of-the-art enabling technologies in molecular biology, ecophysiology, microbiology, taxonomy and organismal biology. It liaises with the relevant physical, geological and historical disciplines to ensure regular interaction and use of the most recent data and insights in interpreting the biological results. It involves fieldwork and laboratory work, both in the Antarctic and in home institutions. It requires extensive international collaboration. Exploration of some areas requires new technologies, for example benthic landers, remotely operated vehicles (ROVs) for the deep sea, autonomous underwater vehicles (AUVs) for work beneath ice shelves.

The timing of IPY has overlapped with that of EBA; the EBA and IPY activities were conceived in parallel, and the IPY Initial Outline Science Plan (April 2004) indicated the ability of EBA to provide a significant contribution to IPY. The research and projects are all under the umbrella of EBA, and cross-linkages will continue in the future. By undertaking a focussed initiative elucidating the spatial distribution of marine and terrestrial diversity, EBA is leaving a legacy of biodiversity information and the tools with which to explore it, which is a hallmark of an IPY programme. In fact, EBA has contributed substantially to IPY.

Following the EBA introductory chapter, the contents of this volume address two main themes, which are strictly connected and complementary to each other, namely Theme 1: Biodiversity and the Environment, and Theme 2: Response to Stress—Adaptations. Before listing the first group of chapters grouped in Theme 1 (Biodiversity and the Environment), a comment is pertinent. EBA has been a Lead Project of IPY, liaising with SCAR programmes in other fields. Some SCAR projects are integral parts of EBA, and have been described or mentioned in many of the Chapters. The most important ones deserve a brief description.

The first programme is the "Census of Antarctic Marine Life" (CAML; www.caml.aq), which was performed in 2004–2010 under the auspices of the "Census of Marine Life" (CoML). Polar regions experience greater rates of climate change than elsewhere on the planet. The faunas are uniquely adapted to their extreme environments, and may be vulnerable to shifts in climate. There is an urgent need to establish the state of these communities, and in particular their diversity, if we are to understand the impact of climate change. Current knowledge of Antarctica's marine biodiversity is patchy. We know more about the surface of the moon than we do about the sea floor. Almost nothing is known about the mesopelagic, bathy/abysso-pelagic and benthic fauna of the slopes and deep-sea abyssal plains, nor about the tiny organisms (bacteria, archaea, protists, viruses, nanoplankton) in the sea and other habitats, nor about the faunas associated with hydrothermal vents, cold seeps and seamounts. CAML was a 5 year project that, during IPY 2007–2009, focussed on the ice-bound oceans of Antarctica. The coincidence with IPY made CAML a once-in-a-lifetime opportunity to conduct a comprehensive study of the evolution and biology of a vast and fascinating region of the Earth. It comprised the part of CoML that deals with the SO. Its objective was to study the evolution of life in Antarctic waters to determine how this had influenced the diversity of the present biota, and to use these observations to predict how it might respond to future change. The project integrated knowledge across all regions, biomes, habitats and fields of study to strengthen our knowledge of ecosystem dynamics in this high-latitude, frozen ocean system. Only through a multi-scale level of investigation will a better understanding of the diversity and status of Antarctica's marine life be obtained. CAML's aims included: (1) undertaking a species inventory of the Antarctic slopes and abyssal plains; (2) undertaking an inventory of benthic fauna under disintegrating ice shelves; (3) undertaking an inventory of plankton, nekton and sea-ice associated biota at all levels of biological organisation from viruses to vertebrates; (4) assessing critical habitats for Antarctic top predators; (5) developing a coordinated network of interoperable databases for all Antarctic biodiversity data. It employed modern genomic techniques and contributed to the project Barcode of Life. It interacted with the Arctic Ocean Diversity project (ArcOD), drawing comparisons between the Arctic ocean and the SO. Reference to earlier "Discovery" voyages permitted assessment of faunal changes occurring over the past 60–70 years. CAML revealed many species new to science. Sampling sites will be revisited in the future for further comparisons. It is establishing a comprehensive Antarctic marine database. The essential element of CAML was its international structure, involving utilisation of ships of many nations. Young researchers had the opportunity to participate, at sea and in subsequent data analysis. Beginning in 2005, the Alfred P. Sloan Foundation (New York, USA) funded coordination activities for 5 years, in order to cover the IPY time frame. The importance of CAML has been referred to, and/or clearly appears in Chaps. 1, 2, 4–6, 8, 9, 11.

The second programme is the series of cruises named ICEFISH: "International Collaborative Expedition to collect and study Fish Indigenous to Sub-Antarctic Habitats". In a world experiencing global climate changes, loss of biodiversity and overfishing, the biotas of the Antarctic and the sub-Antarctic offer compelling natural laboratories for understanding the evolutionary impact of these processes. Since IGY (1957–1958), fish biologists from the Antarctic-Treaty nations have made impressive progress in the knowledge of the Antarctic ichthyofauna. However, research integration into the broader marine context has been limited, largely due to lack of access to sub-Antarctic fishes. The latter, in particular those of the dominant suborder Notothenioidei, are critical for a complete understanding of the evolution, population dynamics, eco-physiology and eco-biochemistry of their Antarctic relatives. The ICEFISH programme was designed to fill these critical gaps in our knowledge. Many of the authors of Chaps. 1, 4, 6, 8, 11 realised the importance of the initiative, and took advantage of the possibility of working on a large number of commonly unavailable species. Before the initiation of IPY, ICEFISH-2004 (www.icefish.neu.edu) was the first comprehensive international survey of the sub-Antarctic marine habitat of the South Atlantic sector, onboard the icebreaker R/V Nathaniel B. Palmer; fishing at Burwood Banks, Falkland Islands/Islas Malvinas, Shag Rock, South Georgia, South Sandwich Islands, Bouvetøya, and Tristan Da Cunha, at depths ranging from tide pools to the abyss (5,400 m). The aims were: (1) systematics and evolutionary studies to relate sub-Antarctic notothenioids to their Antarctic relatives through morphological, molecular and cytological analyses; (2) life-history strategies and population dynamics to characterise the composition, distribution, habitat preferences and diets of the sub-Antarctic species, and larval recruitment; (3) physiological, biochemical and molecular-biology studies of organ and tissue systems to analyse the evolutionary basis of the adaptations of high-Antarctic notothenioids relative to their ancestral stock; (4) genomic resources of sub-Antarctic notothenioids.

Because notothenioids occupy high trophic niches, they constitute an important sentinel taxon for monitoring the impact of climate change on loss of biodiversity and on community dynamics, and of depletion caused by marine fisheries in the SO. ICEFISH contributes to better understanding the effect of this impact by adding the essential contribution provided by the knowledge of the sub-Antarctic within the SO scenario. It also contributes to development of a baseline understanding of these ecosystems, one against which future changes in species distribution and survival may be evaluated judiciously. Sampling provided voucher specimens of sub-Antarctic fishes, deposited in museum collections around the world, as well as genomic resources for polar marine biologists.

The outputs of ICEFISH comprise training PhD students, media coverage, publications, congress proceedings, input to databases (e.g. Genebank), to CCAMLR (Convention on the Conservation of Antarctic Marine Living Resources), ANDEEP-SYSTCO (see below), interactions with other SCAR programmes: for example, it addresses a specific part (marine ichthyofauna) of the SCAR programmes EBA and CAML. ICEFISH is also important to undertake comparative studies on the biogeography, evolution, and adaptation of fishes thriving in the Antarctic—sub-Antarctic latitudinal gradient, and in the Arctic (being thus relevant to TEAM-Fish, see below, and Chap. 3). As an intermediate geographical system between the polar extremes, the sub-Antarctic and its marine fish fauna will provide vital information pertinent to a global synthesis of the characteristics of marine ecosystems.

The third programme (Chap. 2) is "ANtarctic benthic DEEP-sea biodiversity: colonisation history and recent community patterns—SYSTem COupling" (ANDEEP-SYSTCO), crucial for EBA and CAML (and CoML). It requires a far greater effort than what can be achieved by any single nation. It builds on international and interdisciplinary investigations to add an innovative aspect to polar biological research by involving scientists from atmospheric science, climatology, hydrography, planktology, physical oceanography, geophysics, geology, sedimentology, bathymetry, etc. to shed light on atmospheric-pelagic-benthic coupling processes, using innovative technology, e.g. modern satellites, very fine-meshed plankton samplers, novel sea-bed landers, ROVs, plankton suctors, etc., and to train a new generation of polar scientists. Important issues to address are: measurements of atmospheric parameters such as aerosols, ozone, reflectivity, UV irradiance, or volcanic activity (SO_2 will inform about the particle load of the atmosphere, and the magnitude of light penetration); influence of atmospheric processes on plankton in the water column, of the biogeochemistry of surface water on primary productivity, biomass and diversity of nanoplankton, vertical changes in the plankton community to abyssal depths; biology of abyssal key species; role of the bottom-nepheloid layer for recruitment (larvae) of benthic animals; influence of quantity and quality of food sinking through the water column on abyssal life; functional morphology and physiology of abyssal animals (measurements of ^{15}N and ^{13}C to estimate the trophic position of dominant pelagic and benthic animals, to determine carbon flow to the consumers); effects of sedimentology, biogeochemistry, and pore water on benthic life (palaeontology); sedimentation rates and processes over time (bathymetric mapping).

Chapter 2 also describes deep-sea isopod biodiversity in the SO. The SO deep sea does not bear any barriers isolating its fauna from adjacent deep-sea basins. Isolation between shelf and deep-sea faunas is reflected in the habitat faunal composition. The SO deep-sea fauna is the least studied, and its species richness, patterns of distribution, endemism and interesting faunal characteristics are outlined in this chapter, with the first attempts to explain the driving forces of the patterns, including coupling processes between the pelagic and benthic realms. In the framework of EBA-IPY, ANDEEP-SYSTCO conducted the first comprehensive survey of megafaunal, macrofaunal and meiofaunal deep-water communities in the Atlantic sector of the

SO. The programme addresses the processes responsible for the differences in biodiversity, investigating the ecology of dominant abyssal species, examining the functioning of abyssal communities, and trying to understand atmospheric-pelagic-benthic coupling processes and gain initial insights into the trophic structure of the SO deep sea. Based on current climate change, potential future scenarios are hypothesised, and the importance of biodiversity studies is emphasised for the establishment of a robust benchmark against which future faunal changes can be measured.

Turning to the Arctic, the history, current status and prospects of the EBA-IPY TUNU Programme (current acronym, TEAM-Fish: "TUNU-Programme: Euro-Arctic Marine Fishes—Diversity and Adaptation"), an ongoing international scientific effort that addresses the diversity of species, populations and communities in Arctic marine fishes across the Euro-Arctic region, is outlined in Chap. 3. TUNU (East Greenland in modern Greenlandic language), organised and managed by the University of Tromsø, studies the climate and the marine fish fauna of the North-East Greenland Fjord Systems. The diversity and distribution of fish species in NE Greenland is practically unknown. The warming trends reported for Arctic waters and—in particular—NE Greenland fjords make studies of the fish fauna and its response to climatic changes an unprecedented challenge for Arctic marine ecology. This is the scientific background of this multi-year programme, conducted with the ice-strengthened R/V Jan Mayen as operational base. Genetic and demographic structuring, trophic relationships and physiological adaptations are viewed on a broad evolutionary time scale and in the context of novel climate and human stressors. Baseline transects for long-term monitoring cover hundreds of stations in NE Greenland. A growing TUNU Collection (Bergen Museum) forms an exceptional reference for detailed taxonomic and phylogenetic studies of Euro-Arctic fishes. TUNU includes PhD students and scientists from the EU, USA, and Russia. The following three main goals make up the scientific framework of TUNU: (1) to conduct a zoogeographical mapping and quantify the marine fish fauna at selected sites along the NE Greenland coast, between 77°N (Danmarkshavn) and 70°N (Scoresby Sund), and from the innermost part of the fjords to the continental slope; (2) to gather basic hydrographical data—e.g. depth profiles of temperature, salinity, and density—at the sites; (3) to revisit and repeat investigations at key sites to obtain long-term data on possible interannual changes in fish-composition and hydrographical regimes. TUNU is interdisciplinary and multidisciplinary, in the sense that the distribution and diversity of fishes is closely linked to genetic (molecular genetics, cytogenetics), physiological (blood chemistry, metabolism) and hydrographical studies. TUNU investigates fjord systems in NE Greenland that are pristine from a scientific point of view. The sea-ice cover has been significantly reduced in the area during the last three decades and this makes NE Greenland an excellent site to study effects of a changing marine environment on the marine fauna. Many Arctic fish species are physiologically adapted to live within a very narrow thermal zone (from −1.8 to +1°C), and even slight increases in temperature (and concomitant reductions in salinity) are deemed to have profound effects on their composition (diversity) and spatial distribution.

The role of sea ice on the life history of *Pleuragramma antarcticum* is analysed in Chap. 4. The life of marine plants and animals is influenced by sea ice, which in polar fish has driven the evolution of biological responses that allows them to avoid freezing. The discovery that *P. antarcticum*, a fish playing a pivotal role in the coastal system, uses seasonal sea ice as nursery ground, stimulated research to understand its life cycle and the relationship with sea ice. Evidence from IPY activities highlights that such relationship is a major feature in its early life history and reproduction, calling for future work on predictions about impacts that changes in the sea-ice dynamics may have on the coastal Antarctic ecosystem.

Factors such as gene flow, mutation, genetic drift and selection affect the evolution of biodiversity (Chap. 5). The structure of the fish populations of the SO should be homogenised by the Antarctic Circumpolar Current. Some species do indeed show evidence for strong connectivity, with genotypes being shared across the full range. However, species-specific life-history traits influence the patterns of most taxa such that distinct populations are identified. In some cases, fishing and climate change impact the genetic structure in a measurable way. Hence, management measures are recommended. Quota systems have been implemented for some time, and marine protected areas are progressively being identified.

Molecular phylogeny has changed systematics, allowing better taxonomy in molecular trees. IPY has stimulated coordinated access to the Antarctic for large population samplings. Although not the only criterion, barcoding is modifying the flow chart of taxonomy, leaving routine identification to the barcode tool. Barcodes consist first in sequencing a gene of reference (for most vertebrates the mitochondrial gene encoding cytochrome oxidase I) for well identified specimens deposited in collections. Barcoding of Antarctic fishes is rapidly increasing. Identifications of notothenioid eggs and larvae are increasingly reliable. Taxonomy of notothenioids is therefore alive and well; the names of some genera should disappear to render their stem genus monophyletic. Taxonomy is facing deep changes in its interactions between traditional morphology-based taxonomic skills and DNA sequence-based approaches through "integrative taxonomy". Although dominant, notothenioids are not the only taxonomic component of the Antarctic fish diversity; they account for 90% of the biomass of the shelf and are the most studied Antarctic fishes, but there are also liparids and zoarcids. Gene amplification, sequencing and computing power are driving the rise of phylogenetics, providing criteria to know whether a monophyletic group of species is reliable. Each dataset has a source of potential errors with regard to species interrelationships; recovering the same clade from independent data is a strong indication of reliability. The phylogeny of notothenioids is now clear at the level of genera and at the interspecific level, except for the family Nototheniidae. All this is discussed in Chap. 6, together with the description of the 8 families of the suborder and their species interrelationships. Other important evolutionary issues (species flocks, dating of notothenioids, their origin) are also discussed.

Theme 2 (Response to Stress—Adaptations) assembles the second group of chapters.

Within IPY, the recognition of the role of the polar habitats in climate changes, that has awakened great interest in the evolutionary biology of polar organisms, is duly taken under consideration. The latter are exposed to strong environmental constraints, and it is important to understand how they have adapted to cope with these challenges and to what extent their refined adaptations may be upset by current climate changes. As in the previous theme, all contributions, although tackling a range of different organisms, geographical sites, adaptations (from molecules to organisms and communities), are clearly complementary.

In conjunction with evolutionary cold adaptation, the concept of "disaptation" is discussed in Chap. 7. Endemic Channichthyidae (icefishes) live permanently at or near freezing and are a paradigm of disaptation among adult vertebrates, because of their loss of hemoglobin and, in some species, myoglobin (see also Chap. 11). Therefore ice fishes, as natural "knockouts", permit to analyse the epigenetic compensatory mechanisms and their multilevel integration in this original phenotype. The functional significance of the cardio circulatory compensations (hypervolemia, near-zero hematocrit, low blood viscosity, large-bore capillaries, increased vascular diameter, cardiomegaly and large cardiac output, high blood flow with low systemic pressure and resistance) to face the challenge of hypoxia induced by the loss of respiratory pigments, are highlighted in this chapter. The phenotypic plasticity/vulnerability of this exceptional fish family may open new scenarios in environmental and evolutionary physiology.

A major question in polar biology is to understand whether vertebrate and invertebrate organisms have the genetic opportunity to adapt, and/or the physiological plasticity to tolerate new climate conditions. Identifying the key adaptations allowing survival is a complex task, as recalled in Chap. 8. In fact, "adaptation" itself is a slippery concept, but we will leave the debate on this provocative statement to other occasions. Undoubtedly one key adaptation is the fish ability to avoid freezing in seawater, constantly below the freezing point of the body fluids, by year-round biosynthesis of antifreeze compounds capable to block the growth of ice microcrystals inside the organism. This is particularly important for fish living in shallow water or around ice sheets and shelves where supercooled water generates showers of small ice crystals. Other adaptations are less clear-cut. The reduced enzyme activity at lower temperatures is a general problem, but presumably there are several ways to mitigate this effect. Cold denaturation is also likely to be problematic; again, experience suggests there are many ways to provide solutions. Going back to the introductory general question, rapid warming is under way in the Peninsula region, and is expected to happen soon in the rest of the continent. In this scenario, will Antarctic fish be able to cope with the current changes and survive? Although this is another question that is difficult to answer, there is some experimental evidence suggesting that a mere increase in temperature is in itself survivable. But any temperature change will be accompanied by important changes in ecological niches, that are likely to become the dominant factor. The latter