EU-PolarNet
White Paper No. 2

Footprints on changing polar ecosystems

Processes, threats, responses and opportunities for future generations

Arctic Fox *(Alopex Lagopus)*, Lena Delta *(Photo: Peter Prokosch)*

"Under extensive reshuffling of the world's biota, how should conservation goals and strategies for policy and implementation be developed to maximize long-term resilience of biodiversity and human systems? How should natural resource management across diverse, multiuse, multiscale land and seascapes be integrated to maximise resilience of both human and natural systems? How should specific threats and stressors (including their interactions) be managed while minimizing impacts on valued ecosystem assets?" Pecl et al. (2017) Science 355, 1389

Motivation and Background

Humans are increasingly leaving footprints on global ecosystems and these effects are strongly felt in the Polar Regions with largely unknown consequences. Today, we are facing a unique opportunity - the ability to build a knowledge base and provide science-based advice for decision-making in order to minimize these "footprints". We need research to characterize, quantify and minimize these footprints to secure sustainable use of ecosystem services.

Recently, the EU has acknowledged the need to carry out more research in Polar Regions, as the rate of change in polar biological systems has increased substantially in recent decades and is likely to continue on the same trajectory in the future. Such changes will have major consequences at different scales for ecosystems and societies, causing high socio-economic and ecological costs for European nations. Direct and indirect effects of these perturbations of e.g. climate patterns and ecosystem services will hugely impact Europe. Despite differences between the Arctic and Antarctic, for example the extent of human population in the area, many issues regarding the two Polar Regions can be similarly addressed.

The Polar Regions provide unique opportunities for strengthening international collaboration, and the EU can take an opportunity to lead multidisciplinary research efforts. These can contribute substantially to identifying gaps of knowledge in polar ecosystems' structure and function, predicting the rates and effects of change, assessing the risks to ecosystems, and providing advice for managing polar ecosystems. This research has the potential to initiate a virtuous circle of interactions between science, environment and society and to make a real difference, as the future trajectories of change can still be positively influenced by policy and management actions. Examples where the EU is already an active collaborator include the involvement to the activities of the Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR), and the participation of 13 European countries in the Antarctic Treaty System (ATS). Corresponding involvements in the Arctic area include the Arctic Council and its various working bodies.

Expedition Cruise tourists experience autumn colors on the West-coast of Greenland *(Photo: Peter Prokosch)*

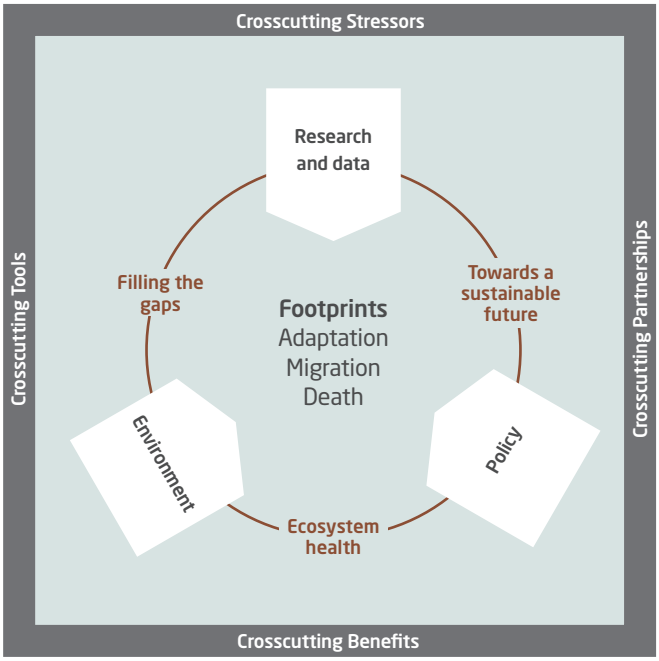

Fig. 1. Interlinkages between biological processes, threats, responses and opportunities towards a sustainable future. Crosscutting Stressors include anthropogenic climate change, ocean acidification, pollutants & contaminants, invasive species. Crosscutting Tools include funding, new technology, education and outreach. Crosscutting Partnerships include and indicate more international and interdisciplinary collaboration and coordination, and better information sharing. Crosscutting Benefits include improved infrastructure and logistics, open communication with all stakeholders, and data and benefit sharing.

The EU-PolarNet project conducted an on-line consultation to which more than 500 stakeholders from 36 countries responded. The main topics in polar biology raised by the stakeholders are covered in this white paper with a particular emphasis on the effects of global change on polar ecosystems, the need for multi-faceted, cross-disciplinary research, science-based management, and the concerns of future ecosystem services that the polar ecosystems are able to provide.

A strong initiative from the EU for supporting research should address three main objectives:

1. Improve the understanding of the current structure and function of polar ecosystems, and how they will change under predicted environmental pressures
2. Identify the most relevant ecological indicators to evaluate risks to the polar ecosystems and services they provide, especially to their biological components
3. Provide relevant and timely scientific advice to decision-makers for sustainable management of the polar areas under a changing climate

These footprints on the polar ecosystems, their impacts and possible management strategies should be approached by the above objectives, forming a logical system of information flow and chain of actions (Fig. 1). These three intertwined steps will compile, process and provide the necessary ecological science needed by White Paper No 3 Managing human impacts, resource use and conservation in the Polar Regions and White Paper 4 The Road to the Desired States of Social-ecological Systems in the Polar and complement the coupled climate models by White Paper No. 1 "The coupled polar climate system: global context, predictability and regional impacts.

Why is it important?

The often-heard saying is "What happens at the poles does not stay at the poles". Changes in polar areas have pronounced effects on lower latitudes through a variety of feedback mechanisms. The Polar Regions are strongly affected by climate change and an increased anthropogenic impact. The importance of the poles for global environment and scientific research is reflected in the dedication of the Antarctic continent to Peace and Science by the Antarctic Treaty since 1959, as well as in its status as a Natural Reserve designated by the Madrid Protocol in 1991. In the Arctic, climate stressors are mingled with multiple pressures from economic development, such as exploitation of mineral and energy resources, fishing, tourism, shipping and transport (The Arctic environment - European perspectives on a changing Arctic, EEA report n° 7/2017). Economic activities in the Antarctic are limited to tourism and bioprospecting, and in the Southern Ocean, the exploitation of marine living resources.

An important difference is evident between the northern and southern Polar Regions: there is strong connectivity between the Arctic areas via both land and sea, and the northern latitudes; whereas the Antarctic continent and the Southern Ocean are separated from other southern continents because of the strong Antarctic Circumpolar Current system. Despite their differences, both Polar Regions act as natural laboratories capable of providing valuable information about biological and ecological processes at high latitudes, due to the relative simplicity in polar ecosystem structure. Although life in Polar Regions is very challenging in many respects due to the harsh environment, these areas host an abundant and remarkable diversity of organisms, characterized by specific adaptations and fragilities. In general, living organisms have three choices to respond to the pressures imposed by rapidly changing environments: adapt, migrate or die. Polar organisms are well adapted to their environment, but they typically have limited migration options. On the other hand,

Polar Campion *(Silene uralensis ssp arctica)* in Arctic desert. Picture taken on Nordauslandet Svalbard. *(Photo: Ronald J. W. Visser)*

Loss of Ice in Greenland; Icebergs in Disco Bay *(Photo: Peter Prokosch)*

local species are also threatened by an increasing number of invasive species migrating from temperate regions. As the global climate changes, human well-being and ecosystem functions are increasingly affected by the shifting biogeography of life.

The values that are found in both Polar Regions include aesthetic values and wilderness experiences that are difficult to quantify in monetary terms but have immense human and cultural importance. Iconic polar fauna, e.g. penguins, Arctic foxes and polar bears, and the threats to their existence, have helped to raise public awareness of the high risks posed by global climate change in Polar Regions. At the same time, a wider picture of polar ecosystems and their importance must be presented in education and outreach activities, and get the public to understand and support the need of protection of all polar organisms and their environments. Moreover, both regions host important biological, genetic and chemical resources, which can be harnessed as assets for the "green economy" that can benefit both local communities and European societies (e.g. EU strategy on Blue Growth). The ecosystem services that need to be fostered include inter alia food, fresh-water and the maintenance of an equable climate, specifically provisioning of fishery products, nutrient cycling and the maintenance of biodiversity. The prerequisite for the understanding of the polar ecosystems and their services is a strong knowledge base in biology that requires EU and polar countries to generate science and understanding for conveying management solutions for future generations.

The research program proposed here is characterized by the extensive use of innovative new technologies allowing collection of scientific data from previously inaccessible areas as well as during winter. The establishment of a sustained network of long-term observatories in the Antarctic, following the experience in the Arctic, will enhance this aspect even further. The explicit transdisciplinary approach, involving the participation of biologists, sociologists, specialists of new technologies, economists, climate modellers, engineers, together with local communities, will enable development of a strong and global understanding of the interactions studied, provide a suite of tools that can be used to monitor the environment and raise warnings, and inform decision-makers on the basis of scenarios and models. A dedicated education and outreach component will be developed to ensure efficient communication and cooperation between all actors and to raise the awareness and support from the general public, including the European taxpayers.

Why now?

There is general consensus that strict climate targets set by the Paris Agreement in 2016 require immediate, qualified joint actions and adaptation at all scales (local, regional and international). Strong and accurate forecasting abilities are needed to ensure adaptation to forthcoming climatic and environmental changes. Another urgent need concerns the rate of extinction of species that is estimated to be 100 to 1,000 times more than that considered natural. Large numbers of species will likely disappear if no action is taken for their conservation, and an estimated 30% of all mammal and bird species will be threatened with extinction this century. The international aspect of research should enable solutions that transcend the local and national governance levels and coordinate them to address questions of global relevance.

Various international agreements and organizations (e.g. IPCC, IPBES) require timely and relevant scientific advice. We need long-term monitoring to understand the changes to ensure a qualified response to these requirements. A few long-term monitoring programmes are underway in the Polar Regions – showing us the enormous importance of having long term datasets from these regions. Unfortunately, large parts of the polar area have very few such programs – especially the Antarctic continent that has long been inaccessible and has a patchy network of scientific stations dating back from around 60 years. An example of an essential, successful long-term monitoring was the ozone measurement carried out at the Halley station in Antarctica, proving the existence of the ozone hole, and underpinning the Montreal protocol – one of the very successfully implemented international treaties. Thus, we need to strengthen the existing long-term monitoring programmes and implement further monitoring programs in parts of the Polar Regions particularly sensitive to a changing climate. A strong focus should be put into coordinating the programmes, ensuring interoperability of systems and securing systematic data collection, storage and stewardship following the FAIR principles to maximize the usefulness of the data.

The rapid changes in the Arctic and Antarctic ecosystems are causing widespread societal impacts. The cumulative effects of climate and anthropogenic changes, e.g. increased maritime transport, extraction activities, undoubtedly pose high risks for the polar environments and their biodiversity. However, if immediate and effective measures would be taken, sound stewardship of the Polar Regions is still possible and can make a significant difference for their future. The EU has played an important role in multilateral environmental agreements in the past, and can mobilize support for the kind of international agreements needed to address the threats to Polar Regions and their ecosystems. Indeed, the pressures and impacts are not limited by national frontiers, nor should measures to mitigate the consequences be.

Atlantic walrus *(Odobenus rosmarus)*, picture taken in Svalbard *(Photo: Ronald J. W. Visser)*

Societal relevance

The target group of the results from the proposed research programme include the European Commission and other European and national policy-makers, their advisors and funding agencies, academia and national research bodies.
The societal relevance of the proposed research programme includes (relevant European Sustainable Development Goals; SGDs are indicated):

- filling in gaps in the knowledge on ecosystem structure and function from both Polar Regions in order to provide scientific advice for managing the consequences of climate change and mitigating impacts on ecosystems and societies that depend on them. SDG 13.
- conservation, restoration and sustainable use of ecosystems and their services, which is a key for sustainable polar societies. SDG 14, SDG15.
- involving local communities in the generation of knowledge by participating in data collection and co-management, and in utilizing the toolbox for assessing ecosystem health. SDG 12
- promoting education and capacity building for innovative solutions in order to ensure the destiny of polar societies is in their own hands by broadening understanding on ecosystems and how they can be managed in a sustainable manner. SDG 4, SDG 9.
- healthy ecosystems that are the essential requirements for resilient and sustainable communities, and further for human health and wellbeing. Feeling part of the natural environment and being able to carry out traditional life with socio-cultural practices related to the native biodiversity is also essential for mental well-being in local and indigenous Arctic communities. SDG 3, SDG 6, SDG 11 (cf. also The One Health Initiative)

Research needs:

Subtopic 1: Filling the gaps

Recently, there have been several initiatives, e.g. the SCAR Horizon Scan for the Antarctic and ICARPIII for the Arctic, that identified pertinent knowledge gaps and urgent needs for research on polar ecosystems structure and function that should be addressed in the next decade. These major themes include the question of how threshold transitions will vary over different spatial and temporal scales and how they will impact ecosystem functioning, from genes to communities, under future environmental conditions. Other research themes involve the complexities of multiple stressors and their synergistic effects, as well the genomic and physiological basis of adaptation of polar organisms and communities. Further aspects of ecosystem structure and function that currently remain unexplored, are:

- Marine and terrestrial food webs, particularly in the coastal, deep sea and under-ice environments, possibility of co-evolution between species or disruption of key interactions
- Adaptation and resilience – or extinction and collapse – of species and ecosystems in response to global change
- Impacts of invasive species and range shifts of native species on polar ecosystems and human well-being

The EU has already made an effort by issuing an H2020 call addressing the aspect "Changes in Arctic Biodiversity" but there are still major gaps in knowledge on the diversity of polar ecosystems. A large-scale monitoring system of the Polar Regions should be able to deliver standardized, high-quality data on a range of essential biodiversity variables. Examples of these variables were proposed by the Group on Earth Observations Biodiversity Observation Network (GEO BON). Coordinated sampling and assessment has the potential to minimize the

Snow petrol *(Pagodroma nivea)* near Rothera research station, Antarctica *(Photo: Ronald J. W. Visser)*

Svalbard reindeer *(Rangifer tarandus platyrhynchus)* in June, Nordeskioldkysten Svalbar *(Photo: Ronald J. W. Visser)*

costs while increasing the usefulness of the obtained parameters. A harmonized monitoring system will make extensive use of remote-sensing technologies, in addition to local biodiversity assessments. The expected knowledge gain will contribute to a comprehensive understanding of biodiversity changes (taxonomy, life history, genetics) and modifications of ecosystems structures and functions (e.g. food web interactions, productivity, role in element cycles). This will contribute a crucial component to the One Health Assessment approach and also enable the stakeholders and right holders to make informed decisions about their future.

The involvement of local communities in sampling and monitoring, supported by modern technologies, has the potential to mobilize and involve traditional knowledge and raise awareness in the communities of the impacts of and potential responses to environmental changes.

Due to the large geographic and temporal scale of the data collection requirements, a well-designed data management plan is necessary and should be one of the first steps of any project. The collected data should be deposited to a public repository and open to all users (e.g. through the AMD). In addition, the biological material should also be deposited in public repositories or BRCs (Biological Resource Centres), some of which are available and supported by the European Research Infrastructures as part of the Horizon 2020 programme. For example, deposited microorganisms have the potential of being highly useful for research and in developing innovations for bioeconomy.

Subtopic 2: Assessing ecosystem health

Based on the improved knowledge of ecosystem structure and function, a toolbox should be developed that will allow stakeholders to reliably assess the state of ecosystems. To achieve this, there is a need to develop a set of genuine ecological indicators to identify and quantify thresholds and risks. These indicators are to be selected to synthetize a variety of relevant variables and enable researchers to explain the changes of the biodiversity and ecosystems. Examples of such indicators are physical-chemical parameters, indicators of the pressures on biodiversity, (e.g. concentration of particular contaminants such as plastics), species-based indicators of biodiversity changes (e.g. the status of key species such as Antarctic krill), and loss of genetic diversity of certain populations (e.g. large marine mammals, endangered seabirds, key microbial species, and commercially important species). In addition, reference sites covering key habitats need to be identified and integrated into a network of long-term observatories, together with existing monitoring sites.

Subtopic 3: Towards a sustainable future

Improved knowledge of polar ecosystems and a robust toolbox of ecological indicators and modelling approaches are needed for creating future scenarios and predictions, and for providing scientific advice for management and policy making. The models of biodiversity and ecosystem function will be complemented by models focusing on socio-economic aspects, generated by research dealing with 'Humans and Resources', as well as with coupled climate models that will be downscaled in 'Climate and cryosphere' research activities. In addition, the effects of planned management measures aiming at mitigating the negative impacts and maximising the resilience of natural and human communities in Polar Regions will be simulated.

There are existing polar platforms for collating and analysing data, and for synthesizing conclusions for sound, science-based advice for decision-making. In the Antarctic, mechanisms to nurture the interactions between scientists and decision-makers are organized through the ATS. For example, the network of Antarctic Specially Protected Areas (ASPA) is a science-based management tool to protect biodiversity and ecosystems. Another example is the ecosystem-based management approach that is applied by CCAMLR to ensure the conservation of the Antarctic marine ecosystem and avoid overexploitation of species. The Arctic Council with its working groups such as CAFF (Conservation of Arctic Flora and Fauna) and PAME (Protection of the Arctic Marine Environment) forms another example of a potential platform where comprehensive, holistic modelling would be capable of providing scenarios and advise for policy-makers. In addition, designing a network of protected areas with sustainable harvesting strategies for natural resources is underway for the Arctic.

Relevant cooperation partners and stakeholders

Ecosystem health of the Polar Regions is essential for all stakeholders, directly for the human populations in the Arctic and indirectly for everybody in Europe and elsewhere, since the Polar Regions have a more-than-regional, global significance, for example with regard to climate change and sea-level rise. In this respect, key stakeholders with a special interest are:

- Polar research and coordination organizations and other scientific communities (for example, IASC, SCAR, and EPB) that will gain a major boost for developing key polar science contributing to major developments in understanding polar biology while promoting international cooperation among polar countries and communities
- Intergovernmental organizations, such as the Antarctic Treaty System (ATS) and Arctic Council (AC), as well as their subsidiary bodies, whose policies and recommendations rely on the research carried out in the Polar Regions, particularly linked to protection of the environment and minimization of human impact (for example, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) or the AC working groups on the Conservation of Arctic Flora and Fauna (CAFF) and Protection of the Arctic Marine Environment (PAME)) The obtained data can be placed in a more global context by the activities of organizations like the Convention on Biological Diversity (CBD) and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).

Emperor Penguins *(Aptenodytes forsteri)* in Antarctica *(Photo: Alfred Wegener Institute / Stefan Hendricks)*

- Non-governmental organizations and agencies interested in the conservation and sustainable management of polar ecosystems (for example, the Antarctic and Southern Ocean Coalition (ASOC), the World Wide Fund For Nature (WWF))
- Agencies and organizations with global interests in climate, oceans, shipping and biodiversity, as the expected findings from Polar Regions are relevant to model scenarios on how the global climate and oceans may change in the future in relation to biological and physical processes (particularly for the Arctic) and affect human safety in the Polar Regions (e.g. relevant to FARO and COMNAP). Such work is also relevant for the development

Polar bear *(Ursus maritimus)* feeding on narwhal *(Monodon monoceros)* North of Svalbard *(Photo: Ronald J. W. Visser)*

of the Polar Code by the International Maritime Organization (IMO).
- Arctic countries and various other countries with polar interests, organizations of Arctic indigenous peoples as well as local Arctic communities
- Private and public corporations interested in exploiting polar biological resources, such as fisheries, biotechnological, food and pharmaceutical companies
- Education and outreach organizations, such as the Association of Polar Early Career Researchers (APECS), and Polar Educators International (PEI), that will benefit from an international effort to understand polar biology and how it can be protected. Scientific efforts to understand the life history of polar animals, such as polar bears and penguins, will provide the basics to introduce educational concepts of a wide range of disciplines to all generations.

Enabling capacities and resources

Capacity building

In general, significant efforts and resources need to be devoted to capacity building, as well as to public education and outreach. Capacity building is crucial for safeguarding the major role of European research in polar biology. Therefore, it is essential to create and maintain an effective infrastructure and/or network to nurture, develop and help establishing world leading polar scientists at European institutions. There are already various international initiatives that can contribute to this objective, such as the International Master in Applied Ecology, the UArctic network and International Antarctic Institute. Strengthening public education and outreach is also a pertinent action, since for most Europeans, the Polar Regions still seem to be "far away" and, hence, not necessarily of the highest importance. To remedy this misconception, researchers need to clearly communicate that the processes occurring in polar areas have a significant impact on the rest of the world, including Europe. The EU project Edu-Arctic is a good example of initiatives in this direction (although confined to the Arctic).

Svalbard reindeer *(Rangifer tarandus platyrhynchus)* in September *(Photo: Ronald J. W. Visser)*

Resources and logistical support needs

A new research programme on polar biology will require new facilities, technologies and efforts in coordination:

- **Improved polar research infrastructure:** vessels, stations, aircraft, satellites and in-situ and remote observations, monitoring and telecommunication
- **Better coordination:** The current network of field stations on land, and moorings and research vessels at sea needs to be coordinated in a complementary manner with compatible instruments and communication protocols. The FAIR principles for data management are the basis for long-term and efficient knowledge integration and (re)use of results.
- **New modelling techniques** e.g., coupling of ecological models with climate and socio-economical models
- **New technological requirements:**
  - Automatization for facilitating long-term, year-round observations in remote areas
  - Miniaturization for boosting in situ- and rapid analysis (e.g. high-throughput genetics, physico-chemical probes)
  - Use of remotely operated devices to explore inaccessible areas or to minimize environmental impacts (e.g. aerial vehicles, gliders, rovers) and ad-hoc communication systems to guide these devices and ensure data collection.

The EU has the capacity to help build such programme by:

- coordinating the polar infrastructures of European research institutions
- facilitating trans-national access to existing infrastructures and data sources
- establishing and funding of new long-term observatories
- encouraging international cooperation and exchange of scientists among European countries and beyond

There are already various European and other international projects, initiatives and organisations that contribute to such efforts to a certain extent - for example the EU Infrastructure project INTERACT (International Network for Terrestrial Research and Monitoring in the Arctic), the H2020 projects INTAROS (Integrated Arctic Observing System) and ARICE (Arctic Research Icebreaker Consortium: A strategy for meeting the needs for marine-based research in the Arctic), the FP7 project DEVOTES (DEVelopment Of innovative Tools for understanding marine biodiversity and assessing good Environmental Status), the IMBer project ICED (Integrating Climate and Ecosystem Dynamics of the Southern Ocean), the German cluster FUTURE OCEAN, the Arctic Science Partnership and the SCAR programme SOOS (Southern Ocean Observing System) as well as international organizations like EU-PolarNet and the European Polar Board. Technologies developed for the European Space Agency's missions, like the ExoMars rover, can be inspirational for observation, sensing and sampling purposes in the Polar Regions.

Way forward and key action areas

To fully address the polar biology needs outlined above, it is essential to have actions at different levels that are supported by the EU:

- Publish coordinated calls for seed money to implement new polar research programmes and long-term observation sites, especially at remote places in Polar Regions. Furthermore, coordination and standardization of monitoring protocols need to be developed and resources need to be allocated to the design and implementation of standardized data management, to ensure interoperability and making the best use of existing and accumulating data sets. In addition to programmes focusing on either the Arctic or the Antarctic, explicitly bi-polar approaches should also be encouraged and funded.
- Lead concerted international actions (involving EU countries and countries worldwide) to establish coordinated research and subsequent science-based and scenario-based advice for fast action in management and international policies. In the Arctic, cooperation between the EU, its Arctic member states (Sweden, Finland, Kingdom of Denmark) and other Arctic Council member states (Norway, Russia, Canada, Iceland and the US) and implementation of the Trans-Atlantic Research Alliance between EU, US and Canada, are necessary for ensuring coordinated activities (research, monitoring, management) at a pan-Arctic scale. In addition, fostering the involvement of indigenous Arctic peoples and local communities across national borders is crucial for sharing all useful information and experience with them, and for ensuring their broad involvement in ecosystem assessments.
- Support capacity building, promoting excellence at the level of universities and research institutes, to create and establish world leading scientists (and their teams) in polar biology.
- Nurture public education and outreach initiatives to demonstrate the relevance of polar biology in the Worlds ecosystems. Such initiatives may use the earlier work as background and starting point, e.g. the work done in connection with the International Polar Year.

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