Synthesis Report on the Environmental Impacts of Research and Logistics in the Polar Regions

by the Environmental Impacts Action Group of the European Polar Board

NWO, Laan van Nieuw Oost-Indië 300,
2593 CE The Hague,
The Netherlands

www.europeanpolarboard.org

@EuPolarBoard

Image credit: Max Koenig, Norwegian Polar Institute

Authors

Pjotr Elshout [1], Jérôme Chappellaz [2,3], Tania Gibéryen [4], Camilla Hansen, Jacek Jania [5], Kirstie Jones-Williams [6], Joseph Nolan [1,7], Baptiste Reverdy, Elmer Topp-Jørgensen [8], Atilla Yılmaz [9,1], Renuka Badhe [1]

How to cite

Elshout P., Chappellaz, J., Gibéryen, T., Hansen, C., Jania, J., Jones-Williams, K., Nolan, J., Reverdy, B., Topp-Jørgensen, E., Yılmaz, A., Badhe, R. 2023, Synthesis Report on the Environmental Impacts of Polar Research and Logistics in the Polar Regions. DOI: 10.5281/zenodo.7907235

[1] European Polar Board, The Hague, The Netherlands

2 Ecole Polytechnique Fédérale de Lausanne EPFL, Campus Valais Wallis, Sion, Switzerland

[3] Institut polaire français IPEV, Plouzané, France

[4] polar.lu - Luxembourg's Polar Programm, Luxembourg, Luxembourg

[5] Centre for Polar Studies, University of Silesia in Katowice, Poland

[6] British Antarctic Survey, Cambridge, The United Kingdom

[7] EuroGOOS, Brussels, Belgium

[8] Arctic Research Center, Department of Ecoscience, Aarhus University, Denmark

[9] The Scientific and Technological Research Council of Türkiye, Ankara, Turkey

Table of contents

Image credit: Renuka Badhe, European Polar Board

Table of contents (continued)

Image credit: Renuka Badhe, European Polar Board

Graphic design and layout by Blue Lobster (bluelobster.co.uk)

Foreword

Polar sciences are crucial to understand the effects of climate change. 6 out of 9 eco-tipping points identified by the IPCC are situated in the polar regions. Potential rising sea levels, altered weather patterns and changes in sea-currents are all connected to environmental change in the polar regions.

Although polar science is necessary to understand climate change, like any sector or industry, it is important to identify actions to reduce the impact of polar science on the environment.

The necessary polar research infrastructure to reach isolated research stations or remote regions has an impact on local ecosystems and the global environment. Research vessels emit (black carbon), research stations can impact local wildlife and research campaigns can accidentally introduce invasive species to the polar regions. Although remotely sensed data can in some instances accompany or even replace in-situ collected data, several processes that are key in understanding climate change can only be gathered by conducting in-person research in the polar regions, such as studying what is happening deep below the sea-surface or collecting data-samples.

This synthesis report aims to define best practices in limiting the environmental impacts of polar research. It synthesises best practices from both polar regions on how to conduct polar research while limiting its impact.

On behalf of the current members of the Action Group of Environmental Impacts and Logistics:

Jacek Jania
Atilla Yılmaz
Tania Giberyén
Elmer Top—Jørgensen
Pjotr Elshout
Renuka Badhe

Image credit: International Polar Foundation

EUROPEAN POLAR BOARD

1. Introduction

Image credit: International Polar Foundation

Background and motivation for the report

The EPB initiative on Environmental Impacts and Polar Research and Logistics was formed during a workshop in 2018, held in Davos during the POLAR2018 conference. The workshop was organised by the European Polar Board (EPB) and the EU Horizon 2020 project 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT), with the theme 'minimising plastic use and waste in polar research and logistics'. The session featured a range of international experts in polar research and logistics management and planning. Building on the Davos workshop, the breakout session discussed possible ways to minimise, or optimise, the impacts of Arctic research, including social impacts on Arctic communities. Panellists provided key recommendations on how to reduce the footprint of Arctic research. Whilst focused on Arctic research, the breakout session also included perspectives from Antarctica, and how existing tools and instruments used there may be transferable to the Arctic, to help protect the environment. The session included a discussion of both marine and terrestrial research activities in the Arctic.

Following these two sessions, the Action Group on Environmental Impacts of Polar Research and Logistics was formed at the EPB's Autumn 2018 Plenary Meeting, with a mandate to develop the initiative further. This development led to the expansion of the initial focus on plastics to other environmental impacts such as waste management, limiting carbon emissions, invasive species, and the disturbance of wildlife. The aim of this Action Group was to produce this synthesis report, thus bringing together knowledge and experiences from both poles on how to minimise environmental impacts whilst conducting research.

Research partners and collaborations

The EPB Action Group on Environmental Impacts of Polar Research worked together with other Action Groups focusing on minimising the environmental impacts of polar research. Other Action Groups included the Scientific Committee on Antarctic Research (SCAR)'s 'Plastics in Polar Environments' Action Group, the International Arctic Science Committee (IASC)'s 'Action Group on Carbon Footprint', the Association of Polar Early Career Scientists (APECS)' initiative to provide guidelines to limit carbon emissions whilst travelling, the British Antarctic Survey, and INTERACT.

Image credit: British Antarctic Survey

EUROPEAN POLAR BOARD

2. Scope and aims

Image credit: FINNARP

Scope and aims of the report

The Action Group explored how scientific research might impact the polar environment and how to limit these impacts by identifying best practices. The report is unique as it connects both polar regions through shared knowledge and best practices. Chapter 6 on legal frameworks underlines the differences and similarities between environmental impact practices and frameworks between the polar regions.

Target audience

This report was produced by an Action Group of the EPB and is intended for EPB member organisations. Nonetheless, any institution, operator, research station manager, or individual planning to conduct scientific research in the polar regions is encouraged to read the report and to consider actions to minimise the environmental impacts of their research.

Image credit: Renuka Badhe, European Polar Board

Future challenges regarding minimising environmental impacts of polar research

To sustain polar research, extensive infrastructure is required to supply remote activities with staff, food, and research tools. A future challenge is optimising existing polar research infrastructure through international collaboration to help reduce the environmental impacts of polar research. Another future challenge to limit the environmental impact of polar research is to attract funding to modernise existing polar research infrastructure and decrease its use of fossil fuels. This report contains examples of the latest developments in carbon neutral research stations, hybrid research vessels, and shared logistics.

A general challenge is sustaining high-quality polar research to understand climate change and its future impacts, both on the polar regions and globally. The Antarctic Treaty Consultative Meeting in 2022 underlined the importance of the 'Decadal Synopsis' in resolution 4 . The 'Decadal Synopsis' stresses the need for continued support from the international community to sustain Antarctic scientific research to better understand the effects of climate change on Antarctica in a local and global context .

Climate change itself may also cause issues for polar research, as weather patterns may change and become more extreme. As the Arctic warms, thawing permafrost may compromise the terrestrial infrastructure used for research. This could happen as soon as 2050 (Hjort et al., 2018).

Methodology

The report draws on existing guidelines provided by organisations coordinating and managing polar research, such as the Council of Managers of National Antarctic Programs (COMNAP), INTERACT III, SCAR, IASC, the Forum of Arctic Research Operators (FARO) and the Arctic Monitoring and Assessment Programme (AMAP). Additional input was provided by members of the EPB Action Group on Environmental Impacts of Polar Research and Logistics with polar research experience. Informal conversations with polar researchers and polar research managers also contributed to the contents of this report.

Image credit: Renuka Badhe, European Polar Board

EUROPEAN POLAR BOARD

3. Environmental impacts

Image credit: Renuka Badhe, European Polar Board

How does this report define environmental impacts?

This report defines environmental impacts as any effects that may be caused by polar research activity in the Arctic and Antarctic region. Such effects include the physical and chemical disturbance of soil, water, air, and the introduction of matter which alters the polar environment, such as invasive species of flora and fauna, and plastic pollutants.

This chapter contains one-page summaries of each of the identified environmental impacts associated with polar research.

These one-pagers assess each environmental impact using three variables to estimate the severity of the impact. These variables are: 1. the geographical scale of the impact (local, regional, or global), 2. the duration of the impact, and 3. the ability of an impact to spread (considering both its ability to multiply and the size of the area impacted). The following section gives more detailed definitions of these variables.

The geographical scale of the impact

Local environmental impacts (within a radius of less than 100 km)

Regional environmental impacts (within a radius of 100-1000 km)

Global/continental environmental impacts (within a radius of more than 1000 km)

The geographical scale of the impact is the ability of an environmental impact to directly affect a specific area. For example, dumping waste is considered a local environmental impact as it initially affects the direct environment, whereas carbon emissions have global environmental impact as they contribute to climate change.

The duration of the impact

Short: discrete impact without sequence

Repeated: sequenced, short impacts

Longer lasting: impacts that continue after research has been completed (including an estimation of how long the impact will remain)

Permanent: irreversible impact that alters the environment permanently

The duration of the impact is how long an impact lasts. For example, invasive species can have a permanent impact because with suitable conditions, invasive species can establish lasting presence. In contrast, wildlife disturbance can be a short-lived impact since wildlife may return to their normal behaviour after the disturbance has ended.

Image credit: Christo Pimpirev

Impact's spread ability

Non-spreading:
environmental impact cannot expand and/or multiply

Semi-spreading:
environmental impact has the potential to expand and/or multiply on a regional scale

Spreading impact:
environmental impact expands and/or multiplies (usually exponentially)

The spreading of an environmental impact refers to the ability of an impact to either multiply or spread throughout regions. Examples of spreading impacts are invasive species and oil spills. Non-spreading impacts include wildlife disturbances.

Examples of environmental impacts:

- Carbon emissions
- Black Carbon
- Invasive species
- Waste management
- Microplastics
- Wildlife disturbance
- Noise Pollution
- Water consumption
- Soil degradation

Image credit: Erwan AMICE – CNRS

Carbon dioxide and methane emissions

What are carbon emissions?
This report defines carbon emissions as carbon dioxide and methane produced by human activities such as the burning of fossil fuels by engines, food production and manufacturing of other goods. Human activities produce many types of emissions with different properties, which can accelerate climate change. Methane, for example, is a stronger greenhouse gas than carbon dioxide, but carbon dioxide remains in the atmosphere for up to 100 years longer.

How can polar research produce carbon emissions?

Scientific research campaigns and operations rely on research infrastructure and extensive logistics in remote regions. These logistics consist of airborne, marine, and terrestrial infrastructures (both mobile and fixed). These logistical networks often rely on fossil fuels to operate, and therefore emit carbon, black carbon, and heavy metals. the burning of fossil fuels.

Recently, many guides and initiatives have been developed on how to reduce individual and organisational carbon footprints for polar research.

Impact's geographical scale

Impact duration

Impact's spread ability (does not multiply)

- The INTERACT III pocket guide on how to reduce carbon footprints: D2.7.pdf (EU-interact.org)
- IASC's Carbon Footprint report: Report from the IASC Action Group on Carbon Footprint

What are the effects of carbon emissions on the polar regions

Carbon dioxide and methane emissions contribute to warming of the global climate. This effect is particularly potent in the Arctic, which is warming much faster than the rest of the world, causing its ice to melt (Yadav et al., 2020). The warming climate and melting ice affects Arctic and Antarctic ecosystems differently. The influx of freshwater from Greenland and Antarctica's glaciers can affect global ocean currents, change marine heat and cold transportation, and affect global weather events. The accelerated heat increase in the Arctic rapidly changes living conditions for Indigenous peoples and interferes with their livelihoods.

Image credit: Antony Dubber, British Antarctic Survey

Black carbon and heavy metal emissions

What are black carbon and heavy metal emissions?

Black carbon is produced by the incomplete burning of fossil fuels. Black carbon is fine, particulate matter, which biodegrades in temperate climates in several weeks. The cold climates of the polar regions slows (and sometimes nearly halt) biodegradation, causing the black carbon to accumulate over time.

How can polar research produce black carbon and heavy metal emissions?

Scientific research relies on extensive logistics to supply remote regions and research stations with provisions and staff. These logistics consist of airborne, marine, and terrestrial infrastructures. Operating logistical networks causes emissions of black carbon due to the burning of fossil fuels. As an example, generators providing energy to remote research stations can accumulate black carbon nearby (Cordero et al., 2022).

What are the effects of black carbon and heavy metal emissions on the polar regions

The impact of black carbon on the polar regions is twofold: it accelerates the melting of snow and ice locally, by reducing the ability of the snow and ice it lands on to reflect sunlight, and regionally, as it decreases overall surface reflectivity, warming the polar regions and thereby accelerating melt. Black carbon can also darken clouds, limiting their ability to reflect sunlight (Cordero et al., 2022).

Impact's geographical scale

Impact duration

Impact's spread ability

Image credit: Renuka Badhe, European Polar Board

Invasive species

What are invasive species?

Invasive species are species introduced to environments and ecosystems to which they are not native. They have the potential to establish a lasting presence and can alter the colonised ecosystem irreversibly.

How can polar research contribute to the spreading of invasive species?

Polar research can contribute to the spreading of invasive species in many ways. Research vessels can transport invasive species by discharging ballast water into polar oceans. Research aircraft can carry invasive small mammals and seeds. Individual researchers can carry seeds within their clothing and luggage (Hughes et al., 2020).

What are the effects of invasive species on the polar regions?

Invasive species can alter polar ecosystems. An example is rats and mice colonising the island of South Georgia and negatively affecting local bird populations. The rats and mice have now been completely eradicated from the island, but this was a costly operation both in terms of money and the impact on the ecosystem – as the method of poisoning the rats and mice also affected seven of the 30 native bird species, albeit temporarily. It took five years for the affected bird populations to recover (Martin and Richardson, 2017).

Impact's geographical scale

Impact duration

Impact's spread ability

In the Antarctic region, 200 invasive species have been reported, most of which originated from the European continent. Most of these invasive species are microbes, fungi, and plants, though some animals have also been introduced (Frenot et al., 2005). In the Arctic region, there are at least 60 invasive terrestrial plant species recorded (Tolvanen and Kangas, 2016). Invasive species can alter the local ecosystems on which Indigenous and local communities rely. Note: the examples of invasive species in this one-pager do not all directly relate to polar research and some can also be attributed to the transport industries and tourism.

For best practices on how to avoid introducing invasive species to the polar regions, see the overview of existing guidelines in chapter 8 and the two pagers of types of research associated with transporting invasive species.

Image credits: Sven Lidstrom, Norwegian Polar Institute

Waste (including wastewater and oil spills)

What is waste in the polar regions?

Waste is any human-produced material that is alien to the polar environment, such as beverage packaging, shipwrecks and discharged water which may be polluted with, for example, parabens and oil.

How can polar research produce waste?

Polar research produces waste in many ways. In-situ scientists produce waste in their day-to-day lives, for example from the food they use and their shower water. Scientists need many tools for scientific research and some of these tools produce waste by-products. Research equipment can also malfunction and become waste itself.

Not all remote research stations or operations have access to waste processing facilities. Waste can be stored and exported later to processing facilities outside of polar regions, processed locally where possible, or discarded in the surrounding environment (known as 'dumping'). Dumping can negatively affect local ecosystems and waste biodegrades extremely slowly in the cold polar regions (Prus et al., 2015).

What are the effects of waste on the polar regions?

Discarding waste in the local environment can have lasting impacts on ecosystems. The impact on the ecosystem depends on the type of pollution. Plastic bags may be regarded as food by wild animals, oil and other chemical substances can pollute ecosystems, and microplastics can enter the food chain (Reed et al., 2018). Oil spills can also negatively affect the environment and spills can derive from research station generators, supply vessels, aircraft, and vehicles. A study of an oil spill at Hornsund Station, Svalbard revealed how slowly oil spills biodegrade in the Arctic climate – in 2019, the area affected by an oil spill from 1985 had only decreased by 50% (Krzyszowska, 1985, Krzyszowska, 2019).

Hormones, chemicals, and metabolites from medicine usage can also contaminate wastewater. Depending on the ability of these chemicals to bind to water, they can become concentrated in individual marine flora and fauna (bioaccumulation) and increase in concentration higher in food chains (biomagnification).

Impact's geographical scale

Impact duration

Impact's spread ability

Image credit: FINNARP

Microplastics

What are microplastics?

Microplastics are small plastic particles, ranging from a few hundred nanometres to 5 mm, usually only visible using magnifying tools. They can end up in ecosystems when they erode from larger plastic objects, such as vessels, clothes, and food packaging.

How can polar research produce microplastics?

Researchers use research tools and personal products that are partially or wholly made from artificial materials and can shed microplastics into ecosystems. Examples include paint from the exterior of vessels, toiletries, small plastic particles, synthetic textiles, tyres, and tagging equipment. As both polar regions are sparsely inhabited, most marine microplastics found in polar ecosystems are not produced by polar research but have been transported to the polar regions by ocean currents (Waller et al., 2017; Bergmann et al., 2022). Research shows that microplastics in the eastern Arctic Ocean stem from the Atlantic Ocean (Ross et al., 2021). Nonetheless, there might be a connection between local microplastics and research stations, as in the Southern Ocean, microplastic concentrations in some cases appear to be slightly higher close to research stations (Waller et al., 2017; Reed et al., 2018).

Impact's geographical scale

Impact duration

Impact's spread ability

What are the effects of microplastics on the polar regions?

The severity of the impact of microplastics on ecosystems is not fully understood yet, however many studies suggest that microplastics have detrimental effects on marine ecosystems (MacLeod et al., 2021). Larger plastic waste particles can also provide shelter for invasive species; this has implications for biosecurity and may have other ecological impacts (Caruso et al., 2022).

Image credit: Daniel Nývlt, Czech Antarctic Research

Wildlife disturbance

What is wildlife disturbance?

In the context of this report, wildlife disturbance is defined as humans interrupting normal wildlife behaviours. This is an important consideration in remote regions where native species are not accustomed to humans.

How can polar research disturb wildlife?

There are various ways in which wildlife disturbance can occur, depending on the type of polar research. The use of large vessels, snowmobiles and aeroplanes can disturb both marine and terrestrial wildlife. Smaller campaigns or fieldwork carried out on foot can disturb bird populations. The infrastructure supplying permanent or semi-permanent facilities such as research stations can disturb local wildlife populations over extended timeframes. Research stations also have the potential to cause habitat fragmentation.

What are the effects of wildlife disturbance on the polar regions?

Anthropogenic activity can cause wildlife to migrate, increasing their energy consumption in an energy-scarce ecosystem (Coetzee and Chown, 2015; Barrueto, Ford and Clevenger, 2014). The stress of the disturbance (especially more frequent disturbances) can lead to increased heartrate and stress hormones in certain species (Coetzee and Chown, 2015) and can have negative effects on reproductive behaviour (Doyle et al., 2020). In extreme cases, wildlife can permanently migrate (Johnson et al., 2005). Roads and other access infrastructure for research facilities may cross traditional reindeer migration routes and complicate herding for Indigenous communities.

Impact's geographical scale

Impact duration

Impact's spread ability

Image credit: Daniel Nývlt, Czech Antarctic Research

Soil degradation

What is soil degradation?

Soil degradation is the trampling of vulnerable soil, vegetation, or human-made disturbances in the snow. The removal of vegetation may also cause soil degradation as it can enable erosion, depending on the terrain steepness, soil characteristics, precipitation, and hydrology.

How can polar research contribute to soil degradation?

Polar researchers can use transportation such as snow scooters and other vehicles, which can crush and degrade soil (Råheim, 1992). Disturbed soil can become susceptible to invasive plant species, such as the Poa annua, which is an invasive vascular plant found in destroyed soil structures around Polish Arctowski research station in Antarctica (Olech & Chwedorzewska, 2011). Taking plant samples can alter soil composition and this can cause irreversible changes to the species when they attempt to regrow.

Most scientists are aware of potentially inflicting damage to local soil and avoid this whenever possible. Depending on how frequently an area is visited by scientists, there are two known strategies scientists can use to minimise soil degradation. The dispersion strategy is used for areas that are infrequently visited. Dispersion is when scientists spread their impact in the area they are visiting by dispersing their movements. The other strategy for more frequently visited areas is to concentrate all activity into defined zones to keep the surrounding area untouched (Tejedo et al., 2009). In both polar regions, research stations can attract tourists who are less aware of the risks they pose for soil degradation. Most research stations have guidelines to instruct these tourists to avoid soil degradation. For more information and guidelines on reducing the effects of terrestrial research logistics on soil, see chapters 5 and 8.

Impact's geographical scale

Impact duration

Impact's spread ability

What are the effects of soil degradation on the polar regions?

In the Arctic, soil degradation by trampling can harm slow-growing, and sometimes endangered, flora and reduce the availability of certain plants on which other species may rely. In the Antarctic, human footsteps and tracks made by vehicles can obstruct local species. For example, penguin chicks can become trapped in snow depressions made by human footsteps, and snow vehicles can produce heaps of snow which obstruct penguin migration routes. In both regions, disruptions in the snow cover might change its insulation properties and could damage the local vegetation below.

Image credit: Henrik Spanggård Munch

Noise and light pollution

What is noise and light pollution?

Noise and light pollution are sounds and light produced by anthropogenic activities. Noise pollution is especially relevant for marine regions, as sound travels easily in water and more quickly in deeper water. Light pollution is amplified in ice and snow-covered regions due to their reflective properties.

How can polar research produce noise and light pollution?

Marine scientific activity and logistics produces echoes. Light pollution is an especially relevant concern for polar scientists during the polar night as the human-produced light starkly contrasts dark, remote regions. An example of light pollution is from research vessels in the Arctic Ocean during the Arctic night, where the artificial light source can influence the behaviour of fish (Berge et al., 2020).

What are the effects of noise and light pollution on the polar regions?

Noise pollution may have an impact on marine wildlife through for example echoes produced by (scientific) marine logistics (Erbe et al., 2019; Moore et al., 2012) or the use of snow scooters and helicopters. Light pollution can also impact wildlife during the polar night by disrupting sleeping patterns, potentially causing stress, and affecting breeding patterns (Bennie et al., 2015; Raap et al., 2015). In remote regions where anthropogenic activity is unusual to local wildlife, noise and light pollution can have magnified impacts (Markus and Sanchez, 2018).

Impact's geographical scale

Impact duration

Impact's spread ability

Image credit: DLR Rothera, British Antarctic Survey

Water consumption

What is water consumption in the polar regions?

Water consumption in the polar regions is the use of water by staff and scientists for activities such as drinking, showering, and cleaning.

How can polar research facilitate and manage water consumption?

Research stations can generate clean water using snow, ice, larger lakes (such as at the Polish Polar Station, Hornsund), or by using systems to desalinate seawater, though the latter option produces brine, which can be considered a waste product. Some research stations in the Arctic region are connected to regional water supply systems. In the past, some research stations imported drinking water in plastic bottles, however, this practice has already been replaced by water cleaning and snow and ice melting systems.

What are the effects of water consumption on the polar regions?

Producing clean water through cleaning, desalination and melting systems consumes energy. Usually, energy in research stations is produced by fossil fuel-burning generators, which produce carbon emissions and potentially black carbon, and can affect polar ecosystems.

Impact's geographical scale

Impact duration

Impact's spread ability

In regions where snow, ice and water are abundant, taking water from the surroundings does not seem to have a noticeable negative impact on the environment (Topp-Jørgensen et al., 2014).

Image credit: FINNARP

EUROPEAN POLAR BOARD

4. Types of research and their impacts on the polar regions

Image credit: Sari Matilainen, FINNARP

Research in the polar regions

The polar regions are made up of cryosphere, marine, and terrestrial components, consisting of oceans, seas, ice sheets, glaciers, land, and mountains. The combination of diverse climates in different seasons and the terrain where research is conducted results in a wide variety of types of research taking place in the polar regions.

In this chapter, different types of polar research are linked to the potential environmental impacts they could cause. The chapter consists of two-page summaries describing these types of research, their environmental impacts and the best practices associated with each type of research. In this report, the polar infrastructure necessary to sustain polar research (discussed in chapter 5) is treated as a separate activity with associated best practices.

Image credit: Witek Kaszkin, FINNARP

Research vessels

Environmental impacts:

- Emissions
- Risk of introducing invasive species
- Wildlife disturbance
- Noise pollution
- Managing waste and wastewater.

What are research vessels?

Research vessels are ships used for scientific research. Research vessels are generally equipped with tools for scientific research and larger vessels often carry a laboratory on board. The advantage of using a research vessel is their ability to move into remote maritime regions with advanced scientific equipment. This enables scientists to gather data, for example from the deep sea, which is not accessible by remote sensing. Research vessels vary in size: the Polarstern (operated by the Alfred Wegener Institute, Germany) can house a crew of 43 staff members and 55 scientists. In contrast, the M/S Clione operated by the University of South Bohemia, Czechia (not an EPB-Member) can house two staff members and eight scientists.

What are the environmental impacts of research vessels on the polar regions?

Most vessels operate on fossil fuels and emit carbon, black carbon, and other pollutants such as chipped paint in both their immediate and wider environment. Technology has improved to utilise resources such as fossil fuels more efficiently. Newer vessels use less fossil fuels compared to older vessels. Hybrid vessels are also emerging. Longer operating vessels can be refurbished and equipped with more environmentally friendly technology. As building a new research vessel uses many raw resources, in some cases it can be more environmentally friendly to update and refurbish an old ship than replace it with a new one.

Vessels can transport and introduce invasive species to the polar regions, such as small mammals, marine species (algae, shellfish and small fish caught in ballast water) and seeds. Some of these invasive species have the potential to permanently alter polar ecosystems. In some cases, research vessels can disturb wildlife by producing noise pollution in remote regions where there is usually no or limited anthropogenic presence. Marine mammals are especially prone to anthropogenic noise because it can interfere with their echolocation.

Best practices per impact:

(Black) carbon emissions:

- Reducing speed – Reducing speed can exponentially decrease fuel usage. The Polarstern for example usually maintains 10.5 knots to minimise fuel consumption, despite being able to travel at 16 knots.
- Refurbishing older vessels – It can be more sustainable to renovate old vessels with more environmentally friendly materials than build new vessels, due to the impact of the extensive supply chain for the new parts. When replacing old but still viable vessels, other organisations might be willing to buy, refurbish and operate the older vessels.
- Limiting distances – Operating from the closest Arctic or Antarctic hub possible limits distances and therefore minimises carbon emissions.

Risks of introducing invasive species:

- Marine species – Research vessels can transport marine species in two manners. They can taxi using ballast water or by attaching to the bottom of vessels (clams are an example of an attaching species). Changing ballast water before entering the

Image credit: Øystein Mikelborg, Norwegian Polar Institute

Southern Ocean or Arctic Ocean can help avoid introducing certain invasive species. There are legal frameworks that aim to prevent invasive species from entering the Southern Ocean. See chapter 6 on legal frameworks to learn which measures and protocols are in place to minimise environmental impacts for research vessels.

- Terrestrial animals and plants – Research vessels can carry invasive terrestrial animals, such as rats, mice, and plants. It is important to clean the vessel and staff clothes thoroughly. There are many guides and guidelines on how to achieve this, for example:
    - INTERACT's 'Reducing the Environmental Impacts of Arctic Fieldwork'
    - International Association of Antarctica Tour Operators (IAATO)'s 'Don't Pack a Pest!'

  See chapter 8 for more guidelines.
- Invasive germs – Polar bird populations are vulnerable to diseases from poultry. Therefore, poultry-based food products are not recommended for those conducting research in the Southern Ocean (Annex II, Article 4, Environmental Protocol of the Antarctic Treaty).

Wildlife disturbance and noise pollution:

- Marine noise pollution – The presence and movement of research vessels can disturb wildlife and the underwater noise they produce can disrupt marine wildlife communication, especially echolocation for whales. During the process of refurbishing or acquiring new research vessels, consider the amount of sound they make.
- International cooperation – International cooperation can optimise the efficiency of marine in-situ data collection and avoids unnecessary use of additional resources. A good example of international cooperation is the EU Horizon 2020 project ARICE, in which several polar science operators combine their efforts to organise optimised research campaigns.

Image credit: Renuka Badhe, European Polar Board

Research aircraft

Environmental impacts:

- Carbon emissions
- Black carbon
- Noise pollution
- Wildlife disturbance

What are research aircraft?

Research aircraft are aeroplanes and helicopters used for mapping for example ice thickness, magnetic fields, biodiversity, and tectonics. They are also equipped to measure aerosols, radiation, and temperatures.

The Alfred Wegener Institute (AWI) and the British Antarctic Survey (BAS) are the two European Polar Board Members which operate research aircraft. The benefit of using aeroplanes is that they can gather very detailed data over broad distances.

Research aircraft can also be used for logistical support for scientific activities.

What are the environmental impacts of research aircraft on the polar regions?

Like any other aircraft, research aircraft rely on fossil fuels and therefore emit carbon. Additionally, noise pollution from research aircraft can impact local wildlife. Aeroplanes can also transport invasive species to remote regions and larger aeroplanes can even carry small rodents or seeds.

Best practices:

- Reducing carbon emissions – As the technology evolves and provides more detailed satellite imagery, in the future, researchers may be able to rely more on satellite data than data gathered with aircraft.
- Reducing carbon emissions – Atmospheric balloons can offer a less environmentally impactful alternative when measuring temperatures and atmospheric data on fixed sites. Rothera Station, operated by BAS, makes extensive use of atmospheric balloons for long-term measurements.
- Optimising usage – When research aircraft travels to and within the polar regions, it can be useful to ensure it also carries research supplies to avoid unnecessary additional journeys.
- Preventing the introduction of invasive species – When research aircraft fly from more temperate zones to the polar regions, they should be thoroughly cleaned and checked to avoid introducing invasive species.
- Optimising usage – When replacing aircraft with newer models, where possible, choose models with optimal fuel efficiency and noise reduction measures.
- Preventing wildlife disturbance – Research aircraft produce noise that can disturb wildlife. See chapter 8 for guidelines on appropriate distances to keep from wildlife in several regions.

Image credit: British Antarctic Survey

Terrestrial facilities hosting in-house and external scientists – e.g. large research stations

Environmental impacts:

- Invasive species
- Carbon footprints
- Black carbon
- Noise/light pollution
- Wildlife disturbance
- Waste management
- Soil degradation
- Microplastics

What are large research stations?

Large research stations are fixed infrastructures which can house scientists for long periods of time. Research stations usually also have staff to operate the station, such as kitchen staff, cleaning staff and concierges. Stations have sleeping quarters, communal spaces, dining rooms and laboratories. One of the largest polar research stations is the McMurdo Station in Antarctica, which can house over one thousand people.

Research stations can attract tourist activity and some Arctic research stations have designated sleeping quarters for tourists and facilitate informative tours in and around the station. In Antarctica, stations situated on the peninsula can host guided tours, though tourists generally stay overnight on cruise ships adjacent to the continent.

What are the environmental impacts of large research stations on the polar regions?

Large research stations can impact the polar environment in several ways. Most research stations rely on fossil-fuelled generators, these generators can emit carbon emissions, including black carbon. Although most stations have thorough waste management plans, scientists have found heightened biochemical markers of anthropogenic sources close to Antarctic research stations (Prus et al., 2015).

Noise and light pollution from research stations in remote regions can cause wildlife disturbances. Visitors may also disturb wildlife if they are not well informed. For example, visitors may unknowingly trample rare flora when walking off-track or disturb local wildlife accidentally.

Image credit: Stephan Ingemann Bernberg, Villum Research Station, Station Nord

Most research stations are not connected to sewage infrastructure, though some in more accessible regions are. Research stations can have wastewater treatment systems to avoid polluting the direct environment with wastewater. Currently, out of 67 Antarctic research stations, 46 have such a system (Information Paper ATCM 44). Of a survey conducted amongst Arctic research stations of the INTERACT network, 37.9% are connected to local municipality sewage infrastructure, 20.7% release water into local rivers, lakes, or the sea, and 31% use water seeping systems whereby water is released into the ground or soil. 79.3% do not filter water, however that is usually the case for municipal sewage systems (INTERACT Survey 2021).

Image credit: Renuka Badhe, European Polar Board

Best practices:

Knowledge networks:

- INTERACT III and the Station Managers Forum combine and share their knowledge of many Arctic research stations and how to reduce their environmental impacts. Their latest booklet is called 'Reducing the Environmental Impacts of Arctic Fieldwork', see chapter 8.
- COMNAP has an Expert Group which shares expertise between research stations about how to limit environmental impacts on Antarctica.

Reduce travelling:

- During the COVID-19 pandemic, stationed research staff took samples in the field for scientists, as scientists were unable to visit the stations. Research station knowledge networks have discussed continuing with these mechanisms to ensure scientists only travel when necessary.

Operating research stations:

- Research stations often explore non-fossil fuel options when replacing aged generators. An example is Kilpisjärvi Biological Research Station in Finland, which aims to switch to heat pumps using warmth from the lake adjacent to the station, instead of fossil-fuelled generators.
- The Princess Elisabeth Antarctica Research Station, operated by the International Polar Foundation in Antarctica, is fully powered by solar and wind energy. It has two diesel backup generators for emergencies. The Foundation is currently exploring the use of hydrogen as an additional source of energy. The station also has a water treatment system that purifies all wastewater and recycles treated water for non-drinking purposes. It is home to the first fully electric polar exploration vehicle used for scientific missions, the Venturi Antarctica.
- Many research stations that are not connected to regional sewage systems filter wastewater before discarding it into the environment. Research stations not connected to regional sewage systems should install filters.
- Incoming staff should only bring clothes and equipment that have been cleaned thoroughly to avoid introducing invasive species.

Avoiding soil degradation:

- There are two known strategies scientists can use to minimise soil degradation near research stations, the choice of technique depends on the intensity of the activity. The dispersion strategy is used for areas that are infrequently visited. Dispersion is when scientists spread their impact in the area they are visiting by dispersing their movements. The other strategy for more frequently visited areas is to concentrate all activity into defined zones to preserve the surrounding area (Tejedo et al., 2009).
- Informing tourists – Many stations educate tourists about the fragility of soil in the polar regions and emphasise the importance of using existing pathways around research stations.

Image credit: Renuka Badhe, European Polar Board

Large research campaigns

Environmental impacts:

- Invasive species
- Carbon footprints
- Black carbon
- Noise and light pollution
- Wildlife disturbance
- Waste management
- Microplastics

What are large research campaigns?

Large research campaigns are cruises or terrestrial campaigns organised by groups of researchers. One of the largest recent research campaigns was the MOSAiC expedition, during which the AWI-operated icebreaker, Polarstern was deliberately set adrift in the Arctic Ocean to be trapped in ice for a year. Campaigns can also be undertaken by foot, aircraft, or vehicle.

What are the environmental impacts of large research campaigns on the polar regions?

The environmental impacts of large research campaigns vary, depending on the type and size of the campaign. Case studies are helpful for estimating the environmental impacts of large campaigns. In the Antarctic region, preliminary assessments, known as Initial Environmental Evaluations, are mandatory to obtain for research which has potential to have more than a minor or transitory impact on the environment.. In the Arctic region, the process differs depending on the country in which the research is conducted.

Research campaigns risk introducing invasive species, emitting (black) carbon (the amount depending on the transport used), disturbing wildlife, and producing noise and light pollution. For longer expeditions, waste and wastewater management should be considered.

Best Practices:

- Optimising fuel usage – The MOSAiC expedition limited fuel consumption by restricting the speed of the Polarstern.
- Prepare estimates of impacts – It is important to assess the environmental impacts of the research campaign before and after and share learnings within polar research knowledge networks. Studies assessing the true environmental impact post-expedition can be intensive. The MOSAiC impact study is a good example of this and is due for publication in 2023.
- Different types of fuels – The Moon-Regan TransAntarctic Expedition experimented with using a biofuel-powered vehicle to drive back and forth over West Antarctica in 2010, without experiencing major problems.
- International collaboration – Those considering future large research campaigns should coordinate and collaborate with others to fully utilise opportunities and reduce the need for additional, individual campaigns.

Image credit: Antony Dubber, British Antarctic Survey

Drones

Environmental impacts:

- Waste management
- Wildlife disturbance

What are research drones?

Researchers may use drones as tools for research. Drones enable scientists to study remote, hard to reach locations and tend to have a smaller impact on their direct environment than large vehicles. Drones can be airborne or suited to marine or terrestrial environments. Drones can be powered by fossil fuels or batteries, though technology is developing and some newer models are powered by solar energy.

What are the environmental impacts of drones on the polar regions?

Although drones are quieter and use less electricity or fuel than larger human-operated vehicles, there is still a risk of disturbing terrestrial and avifauna.

One study suggests that large marine mammals are undisturbed by aerial drones, whilst previous research has concluded that large marine animals behave differently when being monitored by researchers operating from larger aerial vehicles such as helicopters and aeroplanes (Christiansen, 2016). Using drones to study large marine mammals might be an effective and environmentally friendly solution to this disruption.

Another study suggests that the effect of drones on bird colonies varies, as some species appear distressed by nearby drones, whereas other species respond less to drones in their surroundings. The presence of drones can cause stress responses in birds, including accelerated heartrates and exposure to drones when nesting can disturb breeding patterns (Weimerskirch, 2018).

Best practices:

- Waste management – Install tracking devices in drones to ensure that if they crash, they are traceable and can be collected, where possible.
- Waste management – When possible, recycle parts from broken drones.
- Limit wildlife disturbance – Even when replacing larger human-operated research vehicles such as vessels and aircraft with drones, limit their usage as far as possible to minimise the disruption to polar wildlife and ecosystems (as required in the Antarctic region by the Madrid Protocol Article 3).
- Limit wildlife disturbance – Drones are excellent tools for studying marine mammals as research has concluded that they are undisturbed by drones but can be disturbed by larger research aircraft.

Image credit: Liliana Keslinka, Diana Grytsku, Adobe Stock

Automated sampling stations

Environmental impacts:

- Waste management
- Wildlife disturbance

What are automated sampling stations?

Automated sampling stations are installations which can generate data automatically without direct human operation. An example is the 'penguin bridge', installed by the Australian Antarctic Program on Béchervaise Island, which automatically records the weight of Adélie penguins as they cross the bridge. An important benefit of such a station is that there is no need for continuous human presence, which limits wildlife disturbance. This also limits travel to research areas, thereby cutting carbon emissions and reducing the disturbance of wildlife during transit to and from the research destination. Other examples of automated sampling stations are automated weather stations and wildlife cameras.

What are the environmental impacts of automated sampling stations on the polar regions?

Automated sampling stations are alien structures in a wild environment. They must be designed to limit disruption to the local environment or ecosystem. Once they have fulfilled their purpose, they should be removed to avoid potential waste and minimise lasting impacts.

Best practices:

- The Australian 'penguin bridge' in Antarctica has a very small environmental impact but generates useful data.
- INTERACT's 'Tracking Biodiversity' uses automated cameras with artificial intelligence to collect data, which may reduce the need for researchers to collect data in person.
- Efficient use of existing infrastructure – Equip existing infrastructure, such as ferries and cargo vessels, with automatic measuring tools.

Image credit: Silvi Reynar, Henrik Spanggård Munch

Individual researchers and fieldwork

Environmental impacts:

- Soil degradation
- Wildlife disturbance
- Potential waste
- Carbon emissions

What are individual researchers?

Individual researchers are scientists who conduct research in polar regions for universities or research programmes. Although referred to as 'individual researchers', they often operate from research stations with other scientists, but might conduct fieldwork in pairs or small groups.

What are the environmental impacts of individual researchers on the polar regions?

If regulations are not followed, individual researchers may impact local environments by disturbing wildlife, trampling vegetation, degrading soil, and leaving waste behind.

The environmental impact of individual researchers is difficult to generalise, as it varies greatly depending on where the research takes place (and therefore the degree of travel involved) and the surrounding environment.

For more recommendations, protocols, and measures to limit the environmental impact of fieldwork, read SCAR's 'Environmental Code of Conduct for Terrestrial Scientific Field Research in Antarctica' and the INTERACT guide 'Reducing the Environmental Impacts of Arctic Fieldwork'.

Best practices:

- Comply with existing regulations – Any research conducted in the Antarctic region needs to comply with the Madrid Protocol, which underlines the importance of limiting environmental impacts. In the Arctic, national frameworks also identify measures to limit environmental impacts. Read chapter 6 for more information on local environmental frameworks.
- Knowledge sharing – Networks such as INTERACT and COMNAP can identify best practices and share them with their networks.
- The Interagency for Conducting Research in the Arctic lists basic principles to comply with when conducting research in the Arctic.
- Reduce travelling – In some cases, research station staff or citizens can take samples and avoid the need for individual researchers to travel to remote places.

Image credit: Jan Kavan

Citizen Science

Environmental impacts:

- Wildlife disturbance
- When involving tourists – risk of introducing invasive species
- When involving tourists – carbon emissions

What is citizen science?

Citizen science is the involvement of citizens without certified scientific backgrounds in scientific research. It is important to note that definitions of citizen science may vary. In the Arctic region, citizen science is often conducted by local communities knowledgeable about their Arctic surroundings. In the Antarctic region, citizen science is often regarded as a participatory activity to engage Antarctic tourists and improve their understanding of the complexities of the region. Arctic tourists may also participate in citizen science. For example, the 2017 study by Bergmann et al. used quantitative data gathered by tourists to Svalbard to understand more about microplastic accumulation in the Arctic (Bergmann et al., 2017).

What are the environmental impacts of citizen science on the polar regions?

Citizens can assist with the gathering of scientific data. Locally coordinated data gathering can reduce the need for travel, thereby also reducing the associated carbon footprint. This is specific to the Arctic region, as there are no citizens of Antarctica. A benefit of citizen science involving residents is that locals are often very knowledgeable about their surroundings and thus can provide long-term experience-based data which is otherwise difficult to access.

Citizen science programmes on expedition cruises can successfully collect scientific data and enhance the knowledge and stewardship capacity of passengers. Some argue that citizen science data from expedition cruises should be considered a critical part of international Arctic observing networks and systems (Taylor et al., 2020).

Best Practices:

- Including tourism in data gathering: the Polar Citizen Science Collective, managed by IAATO.
- Including residents and tourists in data gathering: Happywhale – a platform that gathers photos of mammals taken by citizens and tourists in the polar regions.
- Including residents in data gathering: Ice Watch ASSIST Data Network allows citizens to observe sea ice.

Image credit: Ninis Rosquist

EUROPEAN POLAR BOARD

5. Impacts of logistics and infrastructures

Image credit: Matt Okraszewski

Infrastructures and logistics for polar research transport, supply, and house polar researchers. Examples include ports, airports, supply vessels, roads, and cargo planes. The main difference between these infrastructures and the research infrastructures discussed in chapter 4, part d, is that their primary function is to supply remote regions, rather than conduct research. Minimising the environmental impacts of polar research also includes the optimisation of the infrastructure necessary to sustain polar research.

Impacts of terrestrial infrastructures and logistics

What are terrestrial infrastructures?

Terrestrial infrastructures are roads, buildings, airports, and land vehicles such as trucks which are used to supply remote regions. Smaller examples are water pipes, wires, and antennae. In the Arctic region, there is a developed terrestrial infrastructure of roads for transporting researchers. In the Antarctic region, there is less fixed terrestrial infrastructure than in the Arctic. One of the larger terrestrial infrastructures in the Antarctic is the 1500 km long South Pole Traverse – the road connecting McMurdo Station and Amundsen-Scott Station. In remote regions, a lively scientific community may incentivise the development of more local infrastructures.

What are the environmental impacts of terrestrial infrastructures on the polar regions?

- Wildlife disturbance – Newly built roads can cross wild animal migration routes and disturb migration patterns, especially in the sub-arctic. Roads and other terrestrial infrastructures like train tracks can also cross migration routes of reindeer herded by Indigenous communities. Wild animals crossing roads or tracks risk collisions with vehicles. Vehicles needing to go off-road to reach research stations might also cause soil degradation.
- Noise and light pollution – Traffic on roads creates noise pollution and at night, light pollution.
- Waste – The construction of roads produces 'road dust' which may affect adjacent ecosystems (Walker and Everett, 1987).
- Carbon emissions – Carbon is emitted during the construction of new fixed terrestrial infrastructure. Cars and trucks are used in the operation of fixed terrestrial infrastructures and these vehicles, unless powered by electricity, emit carbon.
- Terrestrial logistics might cause local oil spills when refuelling vehicles.

Best practices:

- Coordinating combined efforts – The Tractor Train Traverse system in Antarctica is an effective way to supply research stations with minimal disruption, as all vehicles drive together and thus only disturb their surroundings once, as opposed to creating multiple disturbances with individual trips.
- Understanding risks – For newly built terrestrial infrastructure, environmental assessments can help identify risks for local ecosystems.
- Monitor impacts long-term to better understand them over long-timescales (Råheim, 1992).

Image credit: Renuka Badhe, European Polar Board

Impacts of marine infrastructures and logistics

What are marine infrastructures and logistics?

Marine infrastructure refers to harbours and supply vessels. Marine infrastructures provide supplies to scientists working in polar marine environments. Many research stations in the polar regions are in coastal areas and depend on marine logistics for their supplies.

What are the environmental impacts of marine infrastructures and logistics on the polar regions?

- Noise pollution – Regular supply vessels produce noise at similar volumes to larger marine mammals (PAME, 2019).
- Wildlife disturbance – Supply vessels can clash with marine life and harbours can disrupt local coastal ecosystems.
- Black carbon – Black carbon can concentrate in and around harbours as vessels converge in these areas.
- Carbon emissions – Marine logistics produce carbon to supply research facilities.
- Oil spills – Oil spills can occur when marine vessels are involved in accidents and during complications when refuelling.
- Waste management and pollution – Vessels can accidentally produce waste by losing buoys or shedding microplastics.
- Invasive species – Supply vessels can transport invasive species to remote regions.

Best practices:

- Limiting carbon emissions – As with research vessels, finding the most fuel-efficient speeds could decrease the emissions of supply vessels. This is complicated by the fact that most supply vessels are not operated by scientific institutions, but by other suppliers such as commercial services or the military. These organisations have different priorities and busy schedules and may be reluctant to reduce vessel speeds.
- Limiting carbon emissions – Although ships emit carbon, per weight, cargo ships are often more fuel efficient than aeroplanes and are therefore the preferred means of cargo transportation.
- Limiting carbon emissions – Combining the transportation of staff and other supplies can avoid individuals travelling by aeroplane and therefore reduce carbon emissions.
- International cooperation – Collaboration and sharing information on the status, routes, and planning of supply vessels between polar programmes can improve cargo optimisation.

Image credit: Finse Alpine Reserch Center

Impacts of airborne infrastructures and logistics

What are airborne logistics?

Airborne logistics is the use of aeroplanes and helicopters to supply research stations and campaigns, or airborne services transporting scientists to their research destinations. This definition also includes airport infrastructure. An example of airborne logistics is in the research town of Ny-Ålesund on Svalbard, which partially relies on incoming flights for fresh supplies for scientists, such as vegetables and fruits.

What are the environmental impacts of airborne logistics on the polar regions?

- Carbon emissions – Airborne logistics produce carbon emissions and black carbon.
- Black carbon emissions – Aeroplanes emit black carbon, which can accumulate around airports.
- Wildlife disturbance – Airborne logistics can disturb wildlife. This can include marine wildlife where airports are located near coastlines.
- Airborne logistics can carry and introduce invasive species to the polar regions.
- Invasive species – Aeroplanes used for cargo might accidentally transport invasive species to the polar regions.

Best practices:

- Cargo ships are more carbon-efficient than cargo planes. Where possible, use ships rather than aeroplanes for transporting research supplies.
- Choose fuel-efficient cargo options where possible.
- Optimise existing cargo infrastructure by cooperating with research partners to fully utilise airborne logistics.

Image credit: Andre Erlich, British Antarctic Survey

EUROPEAN POLAR BOARD

6. Legal frameworks

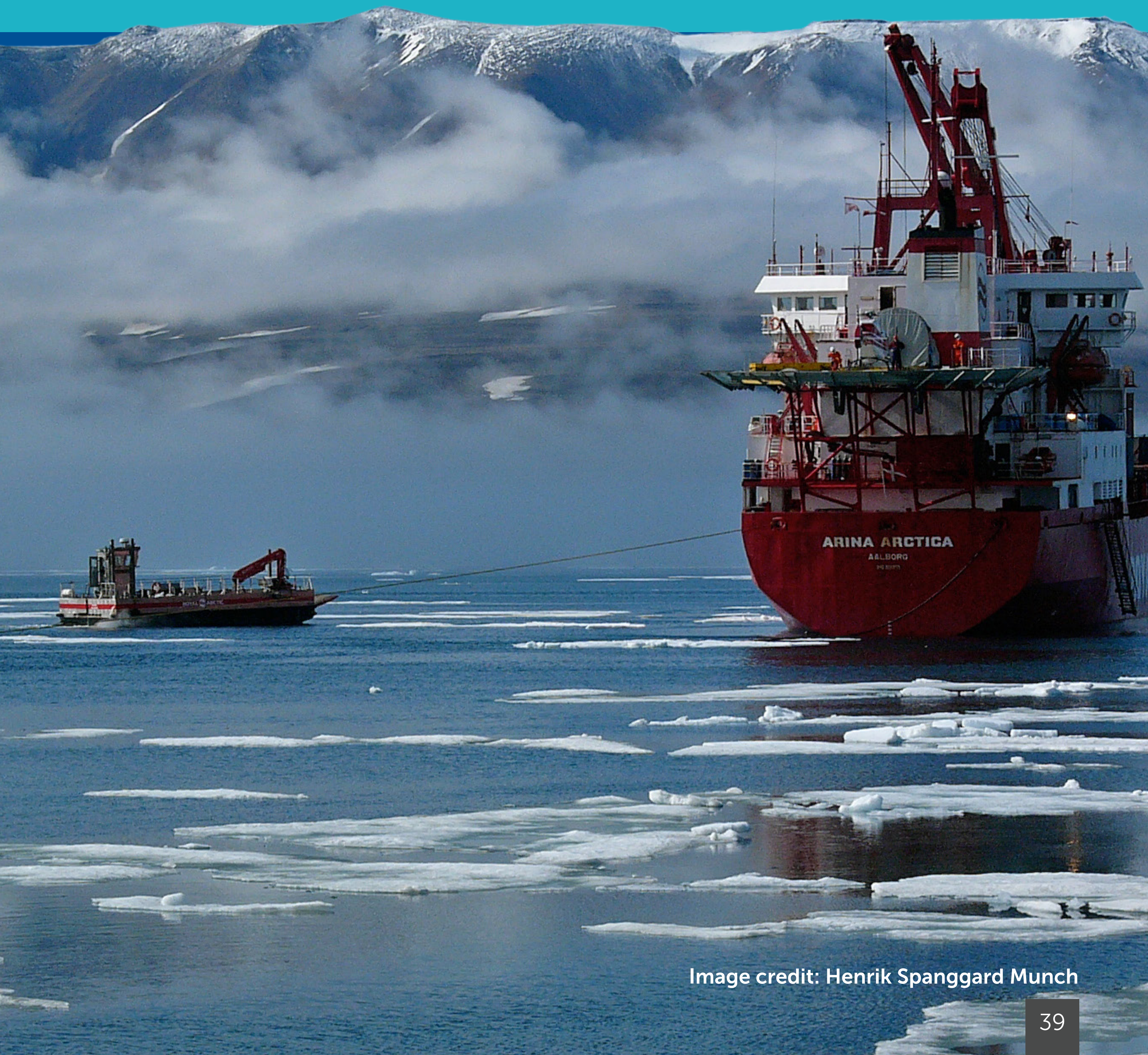

Image credit: Henrik Spanggard Munch

Introduction

The Arctic and Antarctic regions have different legal frameworks for environmental regulations. Whilst the Arctic region is subject to different legal frameworks for each Arctic country, the Antarctic region is governed by an international treaty. This chapter provides a brief overview and explanations of the legal frameworks on environmental regulations that apply to both regions.

The Antarctic region and permits for scientific research

A permit is required to conduct scientific research in Antarctica. The permit can be acquired via the country an organisation or individual is based in or operates from. This means the application process varies from country to country. Many countries or departments responsible for accrediting Antarctic research permits have specific criteria to limit negative environmental impacts. The Antarctic Treaty System provides a compliance baseline for all permit providers.

The Antarctic Treaty System

The Antarctic Treaty System (ATS) has been in force since 1961 and regulates international relations concerning Antarctica. It has 54 national signatories (as of 2022). There are several sub-agreements of the ATS which specifically address environmental management in the Antarctic region:

- **The Protocol on Environmental Protection to the Antarctic Treaty** (the Madrid Protocol) was signed in 1991 and designates Antarctica as a continent for science and peace (Madrid Protocol, Article 3) and effectively bans any economic activities based on exploiting raw resources (Madrid Protocol, Article 7). The Madrid Protocol mandates that an Initial Environmental Evaluation (IEE) is undertaken when planning scientific activity in the Antarctic region, to assess the activity's potential environmental impacts. Any country providing permits for scientific research in the Antarctic region needs to comply with the (environmental) requirements of the ATS.
- **The Convention for the Conservation of Antarctic Seals** (CCAS) was signed in 1972. CCAS aims to 'promote and achieve the protection, scientific study, and rational use of Antarctic seals, and to maintain a satisfactory balance within the ecological system of Antarctica' .
- **The Convention on the Conservation of Antarctic Marine Living Resources** was signed in 1982. The convention describes a commission and a scientific committee that cooperate to conserve Antarctic marine life.

Important sections of the Madrid Protocol regarding environmental impacts and scientific research

Taking or harmful interference with the native fauna and flora is prohibited except in accordance with a permit. Such permits shall specify the authorised activity, including when, where and by whom it is to be conducted.

To "take" or "taking" means to kill, injure, capture, handle or molest a native mammal or bird, or to remove or damage such quantities of native plants or invertebrates that their local distribution or abundance would be significantly affected.

Harmful interference means:

(i) flying or landing helicopters or other aircraft in a manner that disturbs concentrations of native birds or seals;

(ii) using vehicles or vessels, including hovercraft and small boats, in a manner that disturbs concentrations of native birds or seals;

(iii) using explosives or firearms in a manner that disturbs concentrations of native birds or seals;

(iv) wilfully disturbing breeding or moulting native birds or concentrations of native birds or seals by persons on foot;

(v) significantly damaging concentrations of native terrestrial plants by landing aircraft, driving vehicles, or walking on them, or by other means; and

(vi) any activity that results in the significant adverse modification of habitats of any species or population of native mammal, bird, plant or invertebrate.)

- No more native mammals, birds, plants or invertebrates are taken than are strictly necessary to meet the scientific purposes.

- The sampling shall be done in a manner that will not alter the diversity of species, as well as the habitats essential to their existence, and the balance of the ecological systems.
- The numbers or quantities of each species of native mammal, bird, plant or invertebrate taken in the Antarctic Treaty area should be recorded.

The protocol has six annexes on the following topics:

- Annex I (Environmental Impact Assessment)
- Annex II (Fauna and Flora)
- Annex III (Waste Disposal)
- Annex IV (Marine Pollution)
- Annex V (Protected Areas)
- Annex VI (Liability)

The provisions specified in these annexes shall not apply in cases of emergency relating to the safety of human life or of ships, aircraft, or equipment and facilities of high value, or the protection of the environment.

The Protocol states that the following wastes shall be removed from the Antarctic Treaty area by the producer of such waste:

- Radio-active materials;
- Electrical batteries;
- Fuel, both liquid and solid;
- Wastes containing harmful levels of heavy metals or acutely toxic or harmful persistent compounds;
- Poly-vinyl chloride (PVC), polyurethane foam, polystyrene foam, rubber and lubricating oils, treated timbers and other products which contain additives that could produce harmful emissions if incinerated;
- All other plastic wastes, except low density polyethylene containers (such as bags for storing wastes), provided that such containers shall be incinerated in accordance with Article 3 (1);
- Fuel drums;
- Other solid, non-combustible wastes.

The protocol also prohibits the introduction of the following materials onto land and ice shelves or into water in the Antarctic Treaty area:

- Polychlorinated biphenyls (PCBs);
- Non-sterile soil;
- Polystyrene beads, chips or similar forms of packaging;
- Pesticides (other than those required for scientific, medical or hygiene purposes).

Antarctic Specially Protected Areas

Antarctic Specially Protected Areas (ASPAs) are designated within the Madrid Protocol and include some coastal marine areas. These areas are given special status for protection of their outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or ongoing or planned scientific research.

Entry into an ASPA is prohibited except in accordance with a permit issued by the relevant authority. The authority may issue a permit for a compelling scientific purpose which cannot be served elsewhere and which will not jeopardise the natural ecological system in that area.

The activities within ASPAs are managed by the "Management Plans" which specify the description of the area and the values to be protected and management activities to protect the area (access to the area, prohibited activities etc.).

Within the Antarctic and sub-Antarctic region, there are several islands adjacent to the continent which are sovereign territory of national states. These regions fall under national jurisdiction and environmental frameworks.

Image credit: Xavier Balderas Cejudo

The Arctic region and permits for scientific research

The Arctic region is subject to national legal frameworks. Which national framework is applicable depends on the part of the Arctic you plan to visit, as the Arctic is subject to different legal frameworks with different environmental regulations for each Arctic country. In the Arctic region, researchers need a research permit granted by the country in which the research is conducted. INTERACT provides an overview of the different procedures for each country when applying for permits .

The Arctic Council is a soft governance organ which provides non-binding advice. The Arctic Council has produced three agreements:

- **The Agreement on Enhancing International Arctic Scientific Cooperation** is an agreement signed in 2017 by the eight Arctic countries. The agreement enables scientists in the Arctic to travel and work between countries. The agreement aims to ease cross-border challenges experienced by international scientists, such as acquiring visas, taking scientific equipment, and accessing remote regions.
- **The Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic** was signed in 2013 and aims to minimise the oil pollution in marine environments.
- **The Agreement on Cooperation on Aeronautical and Maritime Search and Rescue in the Arctic** aims to strengthen aeronautical and maritime search and rescue cooperation and coordination in the Arctic.

International waters in the polar regions

International waters in the polar regions are embedded in several legal frameworks executed by different organisations and governing bodies. These legal frameworks are not signed by all countries.

The most recognised convention regarding international waters which provides a legal framework is the United Nations Convention on the Law of the Sea (UNCLOS). States that have not signed this convention include the United States and Türkiye. It is an extensive convention, focusing on all anthropogenic activities in international waters. Whilst most of the convention addresses legal definitions of territorial and international waters, part XII of the convention focuses on 'Protection and Conservation of the Marine Environment'. Within the convention, there are clauses dedicated to environmental regulations and conducting scientific research.

The convention encourages signatories to use their full knowledge and capacities to protect the marine ecosystem by avoiding the release of harmful substances, limiting pollution from vessels and other marine installations (United Nations, 1982: 194.3), and avoiding the introduction of invasive species (United Nations, 1982: 196). The convention encourages international cooperation between signatories to develop detailed standards, protocols, and best practices to limit environmental impacts and conduct environmental assessments (United Nations, 1982: 204).

Articles of significance regarding environmental impacts and science in UNCLOS:

1: Use of terms and scope

40: Research and survey activities

61: Conservation of the living resources

116-120: Conservation and management of the living resources of the high seas

136-142: Section 2. Principles governing the area

143: Marine scientific research

145: Protection of the marine environment

146: Protection of human life

194-222: Measures to prevent, reduce and control pollution of the marine environment

234: Ice-covered areas

238-241: Marine scientific research

242-244: International cooperation

245-257: Conduct and promotion of marine scientific research

258 - 262: Scientific research installations or equipment in the marine environment

263: Responsibility and liability

264-265: Settlement of disputes and interim measures

266-278: Development of marine technology

EUROPEAN POLAR BOARD

7. Examples of best practices and experiences

Image credit: Renuka Badhe, European Polar Board

General best practices for polar research

- **Assess the environmental impacts of research campaigns and activities.** Assessing the actual environmental impact of a polar research campaign or activity can be time and resource intensive. As polar research operates in fragile environments, understanding the impact is a crucial part of research planning. Two preliminary actions can help to encourage environmental assessments of polar research:

  1. Make a plan for gathering environmental impact data ahead of the campaign or activity. The plan should include identified variables. This saves time by ensuring data is collected in the correct format for the assessment

  2. As environmental impact assessments take time and resource, when possible, negotiate with funders to allocate a portion of the overall project funds for conducting environmental assessments. Currently, scientists are conducting a retrospective assessment of the environmental impacts of the MOSAiC campaign.

- **Maintain and develop broad knowledge-sharing networks** to disseminate best practices. Examples are INTERACT III, an EU Horizon 2020 project, and the European Polar Board, which brings together many European research actors and COMNAP. Despite the many differences between the Arctic and the Antarctic region, communication of best practices between scientific actors in both regions could accelerate the use of less impactful research methods and practices.

- **Reduce the carbon footprints of (research) vessels** by finding the most efficient speed: fuel ratio (this differs per vessel). This can be challenging, especially when vessels are operated by external organisations such as private sector companies or the military, which often have busy schedules.

Image credit: Stefano Ventura, Renuka Badhe, European Polar Board

- **Avoid the introduction of invasive species.** Antarctica has strict rules to minimise the introduction of invasive species. Tourists and researchers are instructed on how to not introduce them, and the Antarctic Treaty System has instructions regarding vessels' ballast water. INTERACT's 'Reducing the Environmental Impacts of Arctic Fieldwork' and IAATO's 'Don't Pack a Pest' provide guidelines on how to avoid introducing invasive species in the polar regions.
- **Coordinate international cooperation for data collection** to optimise the number of marine research campaigns using the available resources. An example of this is the EU Horizon 2020 project ARICE.
- **Avoid using research aircraft which may disrupt the environment.** Where possible, consider collecting data using satellite images, drones, or atmospheric balloons, rather than research aircraft.
- **Consider options to reduce unnecessary travel.** During the COVID-19 pandemic, some stationed research staff took field samples for scientists, as scientists were unable to visit the stations. Knowledge networks have discussed continuing this to avoid unnecessary travelling for scientists.
- **Explore non-fossil-fuelled options** when replacing old generators for research stations. An example is Kilpisjärvi Biological Research Station in Finland, which aims to switch to heat pumps using warmth from the lake adjacent to the station, instead of fossil-fuelled generators.
- **Use existing infrastructure to collect data with automated sampling stations.**
- **Use existing infrastructure to collect data with citizen science.** Many polar tourists are interested in the environment and science and might be willing to help collect data.

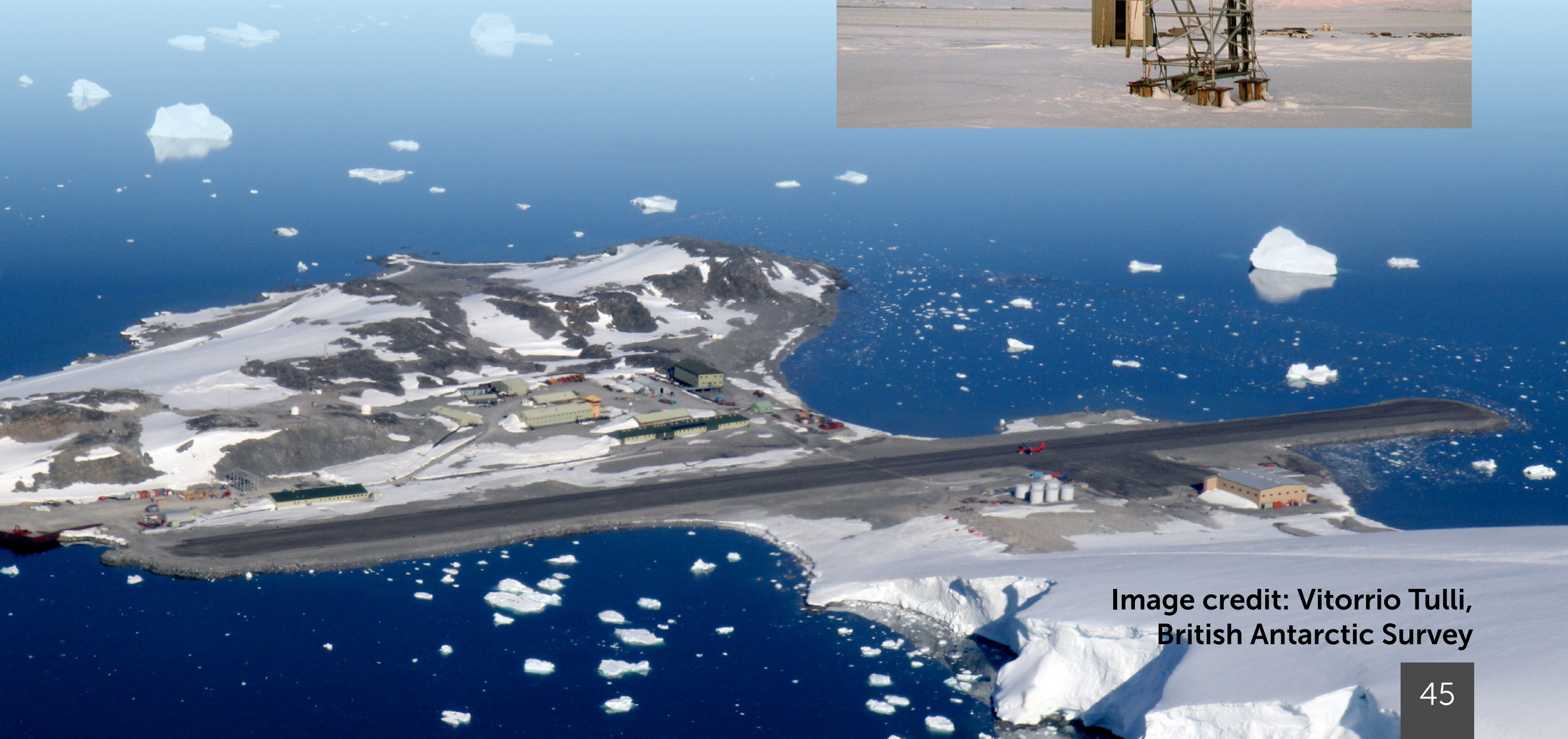

Image credit: Vitorrio Tulli, British Antarctic Survey

EUROPEAN POLAR BOARD

8. Existing guidelines

Image credit: Renuka Badhe, European Polar Board

Antarctic Treaty

- General Guidelines for Visitors to the Antarctic (2021)
- Non-native Species Manual (2019)
- Environmental Guidelines for Operation of RPAS in Antarctica (2018)
- Guidelines for the Operation of Aircraft near concentrations of birds (2004)
- Antarctic Clean-up Manual (2019)
- Practical Guidelines for Ballast Water Exchange in the Antarctic Treaty Area (2006)
- Guidelines for Environmental Impact Assessment in Antarctica (2016)
- Practical Guidelines for Developing and Designing Environmental Monitoring Programmes in Antarctica (2005)

Scientific Committee on Antarctic Research (SCAR)

- SCAR Environmental Code of Conduct for Geosciences Field Research Activities in Antarctica (2021)
- SCAR's Code of Conduct for the Use of Animals for Scientific Purposes in Antarctica (2019)
- SCAR's Environmental Code of Conduct for Terrestrial Scientific Field Research in Antarctica (2018)
- SCAR's Code of Conduct for the Exploration and Research of Subglacial Aquatic Environments (2017)
- SCAR's Code of Conduct for Activity within Terrestrial Geothermal Environments in Antarctica (2016)

Council of Managers of National Antarctic Programs (COMNAP)

- COMNAP RPAS Operator's Handbook (2022)
- COMNAP Fuel Manual (2008)
- Intercontinental Checklists for supply chain managers for the reduction in risk of transfer of non-native species (2019)
- COMNAP Best Practice for Energy Management (2007)
- COMNAP Practical Guidelines Environmental Monitoring (2005)
- COMNAP-SCAR Antarctic Environmental Monitoring Handbook (2000)
- COMNAP Visitors' Guide to the Antarctic (1993)

International Association of Antarctica Tour Operators (IAATO)

- IAATO Understanding Fur Seal Behaviour and Advice for interactions
- IAATO Seal Watching Guidelines
- IAATO Leopard Seal Watching Guidelines
- IAATO Cetacean Guidelines
- IAATO Birdwatching Guidelines
- IAATO Emperor Penguin Guidelines
- IAATO General Information for Wildlife Watching
- IAATO Don't Pack a Pest
- IAATO ATCM Visitor Guidelines
- IAATO Reducing waste – visitor guidelines
- IAATO Antarctic Treaty General Guidelines
- AATO Observer Checklist

Other

- INTERACT Reducing CO2 Emissions in Arctic Science
- Permits and Regulations For Arctic Fieldwork
- INTERACT Guide Reducing the Environmental Impacts of Arctic Fieldwork

Image credit: Vittorio Tulli

EUROPEAN POLAR BOARD

9. Literature

Image credit: Stefano Ventura

Barrueto, M., Ford, A. T., Clevenger, A. P.
2014 "Anthropogenic Effects on Activity Patterns of Wildlife at Crossing Structures." Ecosphere 5.

Bennie J., Duffy P. D., Davies T. W., Correa-Cano M. E., Gaston K. J.
2015 "Global Trends in Exposure to Light Pollution in Natural Terrestrial Ecosystems." Remote Sensing 7(3): 2715–2730.

Berge, J., Geoffroy, M., Daase, M.
2020 "Artificial light during the polar night disrupts Arctic fish and zooplankton behaviour down to 200m depth." Commun Biol 3, 102.

Bergmann, M., Collard, F., Fabres, J., Gabrielsen, G. W., Provencher, J. F., Rochman, C. M., van Sebille, E., Tekman, M. B.
2022 "Plastic pollution in the Arctic." Nature Reviews Earth & Environment, 3: 323-337.

Bergmann, M., Lutz, B., Tekman, M. B., Gutow, L.
2017 "Citizen Scientists Reveal: Marine Litter Pollutes Arctic Beaches and Affects Wild Life." Marine Pollution Bulletin 125(1): 535– 540.

Caruso, G., Bergami, E., Singh, N., Corsi, I.
2022 "Plastic occurrence, sources and impacts in Antarctic environment and biodata." Water Biology and Security. Vol . 1, May 2022, 100034.

Coetzee, B. W. T., Chown, S. L.
2015 "A meta-analysis of human disturbance impacts on Antarctic wildlife." Biological Reviews, Vol. 91/3, August 2016, P. 578-596.

Cordero, R. R., Sepulveda, E., Feron, S., Wang, C., Damiani, A., Fernandoy, F., Neshyba, S., Rowe, P. M., Asencio, V., Carrasco, J.
2022 "Black carbon in the Southern Andean snowpack." Environmental Research Letters, Vol. 17(4).

Doyle, S., Gray, A., McMahon, B. J.
2020. "Anthropogenic Impacts on the Demographics of Arctic-Breeding Birds." Polar Biology 43(12): 1903–1945.

Erbe, C., Dähne, M., Gordon, J., Herata, H.
2019 "Traffic, Seismic Surveying and Construction on Marine Mammals in Antarctica." Frontiers in Marine Science. November 2019.

Frenot, Y., Chown, S. L., Whinam, J., Selkirk, P. M., Convey, P., Skotnicki, M., Bergstrom, D. M.
2005 "Biological invasions in the Antarctic: extent, impacts and implications.". Biol Rev Camb Philos Soc. 80(1):45-72.

Hjort, J., Karjalainen, O., Aalto, J., Westermann, S., Romanovsky, V. E., Nelson, F. E., Etzelmüller, B., Luoto, M.
2018. "Degrading Permafrost Puts Arctic Infrastructure at Risk by Mid-Century." Nature Communications 9(1): 5147.

Hughes, K. A., Pescott, O. L., Peyton, J., Adriaens, T., Cottier-Cook, E. J., Key, G., Rabtisch, W., Tricarcio, E., et. al.
2020 "Invasive non-native species likely to threaten biodiversity and ecosystems in the Antarctic Peninsula region." Global Change Biology, Vol 26(4): 2702-2716.

Johnson, C. J., Boyce, M. S., Case, R. L., Cluff, H. D., Gau, R. J., Gunn, A., Mulders, R.
2005. "Cumulative Effects of Human Developments on Arctic Wildlife." Wildlife Monographs 160(1): 1–36.

Krzyszowska, A. J.
1985 “Tundra degradation in the vicinity of the Polish Polar Station, Hornsund, Svalbard.” Polar Research 3 n.s., 247-252.

Krzyszowska, A. J.
2019 “Effects of fuel spills on Arctic soil, 32 years later (Hornsund, Svalbard).” Polish Polar Research. vol. 40, no. 4, pp. 295–309, 2019

MacLeod, M., Arp, H. P. H., Tekman M. B., Jahnke A.
2021. “The Global Threat from Plastic Pollution.” Science 323(6550), p.61-65

Markus, T., Sánchez, P. P. S.
2018. “Managing and Regulating Underwater Noise Pollution.” In Handbook on Marine Environment Protection : Science, Impacts and Sustainable Management. Springer International Publishing, 971–95.

Martin, A. R., Richardson, M. G.
2017 “Rodent eradication scaled up: clearing rats and mice from South Georgia.” Cambridge University Press. Oryx 53(1): 27-35.

Moore, S. E., Reeves, R. R., Southall B. L., Ragen, T. J., Suydam, R. S., Clark, C. W.
2012. “A New Framework for Assessing the Effects of Anthropogenic Sound on Marine Mammals in a Rapidly Changing Arctic.” BioScience 62(3): 289–95.

Olech, M., Chwedorzewska, K.J.
2011 “The first appearance and establishment of an alien vascular plant in natural habitats on the forefield of a retreating glacier in Antarctica.” Antarctic Science 23(2), p. 153-154.

PAME
2019 “Underwater Noise in the Arctic: A State of Knowledge Report, Roveniemi, May 2019.” Protection of the Arctic Marine Environment (PAME) Secretariat, Akureyri (2019)

Prus, W.,, Fabiańska, M. J., Łabno R
2015. “Geochemical Markers of Soil Anthropogenic Contaminants in Polar Scientific Stations Nearby (Antarctica, King George Island).” Science of The Total Environment 518–519: 266–79.

Raap, T., Pinxten, R., Eens, M.
2015. “Light pollution disrupts sleep in free-living animals.” Sci Rep 5, 13557.

Råheim, E.
1992. “Registration of vehicular tracks on the Svalbard archipelago.” Norsk Polarinstitutts Meddelelser Nr. 122.

Reed, S., Clark, M., Thompson, R., Hughes, K. A.
2018 “Microplastics in marine sediments near Rothera Research Station, Antarctica. Marine Pollution Bulletin.” Vol. 133, August 2018, P. 460-463.

Ross, P .S., Chastain, S., Vassilenko, Etemadifar, A., Zimmermann, S., Quesnel, S. A., Eert, J., Solomon, E., Patankar, S., Williams B.
2021 “Pervasive distribution of polyester fibres in the Arctic Ocean is driven by Atlantic inputs.” Nature Communications 12, 106 (2021).

Taylor, A. R., Barðadóttir, Þ., Auffret, S., Bombosch, A., Cusick, A. L., Falk, E., Lynnes, A.,
2020. “Arctic Expedition Cruise Tourism and Citizen Science: A Vision for the Future of Polar Tourism.” Journal of Tourism Futures 6(1): 102–11.

Tejedo P., Justel A., Benayas J., Rico E., Convey P., Quesada A.
2009. “Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact.” Antarctic Science 21(3), p. 229-236. 21 (3), 229–236

Tolvanen, A., Kangas, K.
2016 “Tourism, biodiversity and protected areas – review from northern Fennoscandia.” Journal of Environmental Management. 169: 58-66.

Topp-Jørgensen, E., Rasch, M., Elger, K., Vincent, W., Bar, C.
2014. “INTERACT: Management Planning for Arctic and Northern Alpine Research Stations: Examples of Good Practices.” [S.l.] s.l: Aarhus University, DCE - Danish Centre for Environment and Energy.

Walker, D. A., Everett, K. R.
1987 “Road Dust and Its Environmental Impact on Alaskan Taiga and Tundra.” Arctic and Alpine Research 19(4): 479–89.

Waller, C. L., Griffiths, H. J., Waluda, C. M., Thorpe, S. E., Loaiza, I., Moreno, B., Pacherres, C.O, Hughes, K. A.
2017 “Microplastics in the Antarctic marine system: An emerging area of research. Science of the Total Environment.” Vol. 598, November 2017, P. 220-227.

Weimerskirch, H., Prudor, A., Schull, Q.
2018 “Flights of drones over sub-Antarctic seabirds show species- and status-specific behavioural and physiological responses.” Springer. Polar Biology 41(2).

Yadav, J., Kumar, A., Mohan, R.
2020 “Dramatic decline of Arctic sea ice linked to global warming.” Natural Hazards 103, 2617–2621.

EUROPEAN POLAR BOARD

Synthesis Report on the Environmental Impacts of Polar Research and Logistics in the Polar Regions

by the Environmental Impacts Action Group of the European Polar Board

NWO, Laan van Nieuw Oost-Indië 300,
2593 CE The Hague,
The Netherlands

www.europeanpolarboard.org

@EuPolarBoard

Image credit: Max Koenig, Norwegian Polar Institute