The effect of scientific research on Antarctica's natural environment

Are the regulations under the Antarctic Treaty sufficient to protect the environment?

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Abstract

This essay tries to assess the effectiveness of the regulations under the 1991 Madrid Protocol to prevent or limit environmental threats caused by research on the Antarctic continent. The surge in scientific research on the continent increases the chances of introduction of alien species from outside Antarctica, but also in the continent. Furthermore, research stations and scientific activities cause disturbance to wildlife, with adverse effects on individuals' fitness. Other factors such as soil damage and pollution also endanger the Antarctic environment. The Madrid Protocol contains regulations to reduce these threats , which are to be enforced by Environmental Impact Assessments evaluated by the Committee for Environmental Protection (CEP), and station inspections performed by signatory parties. These inspectors are often careful to accuse research stations of bad environmental practices, resulting in diminished compliance to the regulations. To ensure that the Antarctic environment is preserved, the current regulations should be enforced strictly, and rules limiting the expansion of science should also be implemented.

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Introduction

Antarctica is the most isolated continent on earth. Its natural barrier formed by the circumpolar current of the Southern Ocean and strong westerly winds have prevented species from entering and colonizing the region. If individuals do successfully come to Antarctica, they must deal with a harsh environment with extremely low temperatures, brief summers and infertile soil. Still, life has remained for 30 million years, since the break-up of Gondwana, making Antarctica a varied continent, with several endemic species [1]. The existing ecosystems are divided in one of Antarctica's 16 Antarctic Conservation Biogeographic Regions (ACBRs), which are based on biologically distinct ice-free areas (figure 1)[1], [2].

Human presence on the continent has been increasing over the past decades. Humans first came to Antarctica for historical whaling and sealing, but nowadays most human activity is related to research, tourism and other commercial activities [3]. In the 18th century, research and exploration of the continent started with voyages, and since the 20th century the interest in Antarctica has quickly expanded [4]. The International Geopolitical Year in 1957/58, and the 1959 Antarctic Treaty (hereafter also referred to as " the Treaty")[5] led to the construction of permanent research stations and an altogether increase in scientific research [4], [5].

The Treaty was initially signed by 12 countries (Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, The Soviet Union, the UK and USA), and was originally intended to settle the debate on sovereignty over the continent in the Cold War. However, the focus of the Treaty quickly shifted towards environmental protection. The Agreed Measures for the Conservation of Antarctic Fauna and Flora were accepted in 1964, followed by the 1972 Convention for the Conservation of Antarctic Seals (CCAS) and the 1980 Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) [6].

In the 1980s, several new Parties signed the Antarctic treaty. Interest in Antarctic science, and therefore also the number of research stations, increased [4]. This also led to growing concerns related to conservation of the environment, motivating the 1991 instalment of the Protocol on Environmental Protection to the Antarctic Treaty [5], which will be addressed in depth later in this essay. By 2019, 30 different countries controlled a total of 77 research stations. These stations vary in capacity, can be seasonal or year-round, and require visitations from ships at least once every season [4].

The Antarctic Treaty System (ATS), consisting of all related treaties and instalments, applies to the area south of 60°S, thereby

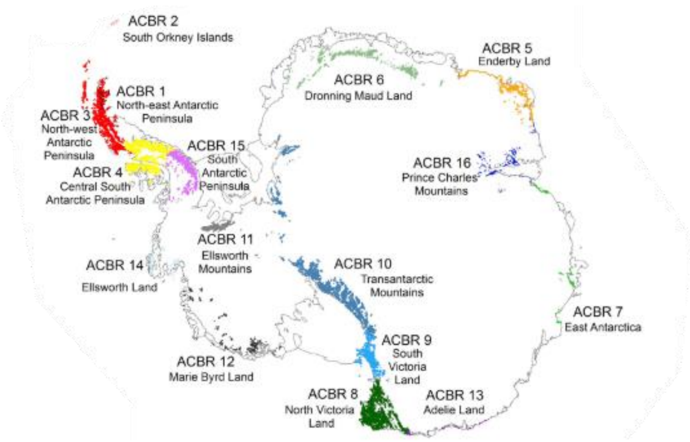

Figure 1. Antarctic Conservation Biogeographic Regions (ACBRs). The regions all have a unique flora & fauna, including species endemic to specific ACBRs [2].

exempting the sub-Antarctic islands [6], [7]. Governance is accomplished by the Antarctic Treaty Consultative Meeting, consisting of 29 of the 53 signatory states [2]. The Treaty advocates for 'freedom of scientific investigation', a continuation of the International Geopolitical year, so that international scientific cooperation can remain. This is achieved by, among others, dealing with the issue of sovereignty over Antarctica. Under the treaty, all previous and future claims are dismissed, making that no single country can appeal jurisdiction over the continent [6].

This essay focusses on the question: Are the current regulations concerning scientific research in Antarctica sufficient to protect and preserve the natural environment? At first, some of the key threats to the environment will be discussed, namely invasive species introductions, disturbance of wildlife, pollution and soil damage. Climate change will not be addresses specifically, as this is not an issue caused by human presence in Antarctica. Secondly, this essay focusses on the regulations under the Protocol on Environmental Protection to the Antarctic Treaty, as well as some other involved organisations. At last, an assessment will be made on the effectiveness of the current regulations to protect the environment.

1. Impact of research on Antarctica's environment.

§1.1 Invasive species

The geographic isolation, harsh climate and limited human activity makes Antarctica the least invaded continent in the world [7]. Still, the biodiversity of this region is under growing threat from invasive species [8]. The physical and physiological natural barriers these alien species previously faced have been weakened by climate change and increased human activity [4], [9]. As result, high numbers of individuals from a variety of species are introduced to Antarctica, to which they are not native [8]. This so-called propagule pressure is especially high in the Antarctic Peninsula, for multiple reasons. First of all, this part of the Antarctic continent is the closest to another continent, namely South America. The region also has a milder climate compared to the rest of the Antarctic mainland and is the focus of research, with by-far the highest density of established research stations, and consequently, the most visitors. And lastly, this region experiences the consequences of climate change the strongest [8].

Invasive species pose a significant threat to the Antarctic ecosystem, as they impact the biodiversity and ecosystem services in the environment [4], [10]. More specifically, the aliens can change community dynamics and competition, habitat structure and food webs [4]. This so-called "ecosystem engineering" causes, sometimes irreversible, changes to the environment, occasionally to collapse of the ecosystem [9], [10]. Consequently, the native, often endemic, flora and fauna becomes endangered, possibly even up to the point of extinction [9].

So far, the impact of exotic species on Antarctica has been minor [9], and none of the aliens have been vertebrates so-far [5]. However, the sub-Antarctic islands have shown that invasive species are indeed a considerable threat [9]. For example, the introduction of rodents and cats on islands in the sub-Antarctic, which can be traced back to humans visiting the sites, caused predation on native birds [5]. The limited impact of the invasive species is likely attributed to the lag time between the introduction and detection of a species. It takes time for individuals to get used to a new environment, or to alternate it for their benefit, and therefore it may take several years to decades before populations of invasive species explode [4]. This has already been observed in the Arctic, where it took the Red King Crab (*Paralithodes camtschaticus*) population 20-30 years to grow to a level it became a threat for the native ecosystem. Therefore, it is likely that there are significantly more invasive species already present in Antarctica, but they have stayed undetected [4].

There are many ways an invasive species could be brought to Antarctica, often through transportation along human activity routes [10]. Most terrestrial introductions have been close to or within research stations, coming from visitors' personal belongings and imported cargo, that bring plant propagules [5], [7], [8]. For example, the imported building material for the Halley VI Research station brought around 5000 seeds of 34 different taxa to the Antarctic Peninsula [8]. A study by Huiskes *et al.* showed that 33% of the visitors sampled brought seeds of a total of 530 different morphotypes, while 16% carried 535 bryophyte and/or lichen propagules [11]. Furthermore, vehicles and imported food can also be major contributors to the introduction of non-native species [8]. These products are all shipped or flown into the area. The usage of aircrafts instead of ships decreases the travel time significantly, but thereby increasing the chances of a species reaching Antarctica alive This further enhances the probability of alien introduction [8].

In the vicinity of research stations on the Antarctic Peninsula there are several reports of alien plants and invertebrates, and non-native invertebrates have also been found in multiple sampling locations. This once again suggests that the true number of invasions are likely greater than registered [8].

Another problem is the transport of species between Antarctic regions [8]. Species living in Antarctica are already adapted to survive in the extreme environment, so human movement between different ACBRs enable them to cross natural barriers [1]. Movement of cargo and researchers between these regions might cause redistribution of species that are endemic to a specific ACBR, or further spread the invasive species from outside of the Antarctic region [8]. The national Antarctic programmes of ten states (Argentina, Australia, Chile, France, New Zealand, Norway, South Africa, Spain, the UK and the USA) even visit several ACBRs on their standard shipping/air route [2]. Currently there are zero confirmed cases of transfer between ACBRs, but it is almost certain that microbial species have been relocated from one distinct region to another. Specific microbial taxa have been found around research stations, but not in the soil a bit further away, suggesting that they have been relocated by researchers [2].

Transfers between sub-Antarctic islands and mainland Antarctica have occurred [2]. For example, it has been reported that the movement of soil from the sub-Antarctic islands South Georgia to the Adelaide Island on the Antarctic Peninsula led to the transfer of multiple living organisms [12]. So far, the most persistent invader is the midge *Eretmoptera murphyi*, which was accidentally transferred from South Georgia to the sub-Antarctic Signy Island, in a transplant experiment in the 1960s. Research has shown that the larvae, which live in the soil, were most likely moved around by dirt sticking to the boots of researchers. Adult midges were first spotted in the beginning of the 1980s, and currently occupy an area of over 85,000 m^2. They are able to consume more organic matter than all native fauna combined, increasing the nitrate content of the soil, which negatively impacts local flora and fauna. The increased soil fertility also increases the chance of other non-native plants to successfully establish, showing that the repercussions of the introduction of such a small invertebrate can be enormous [1].

§1.2 Disturbance of local flora & fauna

The local flora and fauna are directly impacted by the scientific research on Antarctica. On the Antarctic mainland, research stations are mostly built on areas near the coast [9]. In total, the research stations cover at most 100 km^2 of land, which seems little on a continent of over 14.000.000 km^2 [13]. However, these stations are often clustered on ice-free areas with a strong base [9], [13]. Areas that are ice-free, have solid foundation, and are in proximity to the coast, only make-up 0.04% of the entire continent [13]. These areas are also the places with the most developed terrestrial ecosystems, and are important breeding- and moulting sites for marine vertebrates [5],[9], [13]. This creates a form of competition between the native species and the researchers, as extremely large proportions of the available land are already affected by human activity [9].

Wildlife living close to research stations can be disturbed by humans or the used machinery [5]. Predation and human disturbance trigger similar behavioural responses, leading to a trade-off between avoiding predation and fitness-inducing activities, such as feeding, breeding or parental care. The result is an alternation in the individuals' behaviour and physiology, possibly leading to a reduction in fitness, and consequently species abundance and persistence [14]. Species such as penguins and elephant seals have considerable impact on Antarctic terrestrial ecosystems. Changes in the abundance and persistence of these species can thus have significant impact on local terrestrial biodiversity patters [15]. Science activities often involve some sort of direct handling of animals, which causes severe stress in the individuals [5], [14]. Furthermore, disturbance caused by human activities under the sea surface, such as marine acoustic research and construction work, cause noise underwater. This potentially reduces the foraging efficiency for sea birds, by damaging their ears while diving, or by chasing their prey away [5]. An extreme example of disturbance because of research on Antarctica are the 7000 dead King Penguins (*Aptenodytes patagonicus*) that were found in the Lusitania Bay colony in 1990. The cause of dead could be traced back to an airdrop by a Royal Australian Air Force plane, which likely caused severe panic, triggering a fatal stampede [16].

The long-term effects of frequent inspections are still not entirely clear. There are studies that showed a clear negative relation between human disturbance and fauna's fitness-factors. For example, decreased breeding success in Adélie penguins (*Pygoscelis adeliae*), and reduced fledgeling weight in yellow-eyed penguin (*Megadyptes antipodes*), because of human disturbance have been observed. In contrast, other studies have not noticed any negative effects of human visitation. This includes breeding success in gentoo penguins (*Pygoscelis papua*), and even higher breeding success of Adélie penguins close to sites with major disturbance. This suggests that the impacts of local human disturbance can be neglectable compared to the impact of environmental changes. However, it is likely that habituation, whereby animals become less sensitive to a form of disturbance, has adjusted the response of the animals to disturbance [16].

§1.3 Other factors affecting local flora & fauna

Antarctic soils have, except for ornithogenic soils, poor organic content. The plant communities are thus restricted, consisting of majorly cryptograms, such as bryophytes, lichens, algae and cyanobacteria. This makes the Antarctic ecosystems fragile, and vulnerable to human disturbance [17]. The soil surface is one of the most vulnerable components of the Antarctic environment, and forms an essential habitat for terrestrial flora and (micro)fauna [17]. Something seemingly as little as a footstep can compress the soil, thereby alternating its structure, damaging the vegetation and changing the structure of invertebrate communities [9]. The low temperature, limited soil biota and the lack of vegetation make that soil processes generally operate for prolonged times, and therefore it would take decades for the soil to recover [6]. Thus, the footprints and vehicle tracks stay visible for an extended period [9]. Some research parties, that have established research stations near the coast, focus on research more inland. Temporary camps on site are frequently used in these cases, which centralizes the footprints of the researchers near wildlife populations, inducing the negative effect [13].

Pollution, in all sorts and forms, caused by the research stations is also a major concern for the preservation of the natural environment. The amount of fuel used per person during their relatively short time on the continent is exceptionally high. During the 2004/5 season, it was reckoned that each visitor was responsible for a CO_2 emission comparable to what an average person would emit in an entire year [18]. Birds are attracted by the lights of ships and stations, which cause low, but daily, mortalities [16]. These infrastructures also create chemical contamination, which causes local dispersal of dust, which affects the snow surface albedo. On land it can also damage the, already fragile, soil surface, vegetation and fresh-water ecosystems [9]. Near research stations, one of the most common sources of contamination are oil spills, of which the negative effects on wildlife are well-known [9]. Sewage emitted from research stations contains polybrominated diphenyl ether (PBDE). High levels of this organobromine compound have been found in marine organisms living close to an outlet. This, barely treated, sewage water and other releases can transmit diseases to the environment [5]. Lastly, decaying infrastructure might also release toxins, such as polychlorinated biphenyls (PCBs) and asbestos. However, the impact of these toxins on wildlife is still unknown [5].

In the future, it is expected that the number of research stations will increase, and thus also the number of researchers, staff, vessels, flights, traffic and fuel consumption. This will contribute to a larger spatial footprint, pollution and disturbance, unless further steps are taken to protect the environment. Furthermore, this increase will also lead to even more introductions of non-native species [5].

2. Regulations protecting Antarctica's environment.

§2.1 The Madrid protocol

In 1991, the Protocol on Environmental Protection to the Antarctic Treaty (from now on referred to as "the Madrid Protocol" or "the Protocol") was approved. This protocol contains all sorts of environmental regulations to ensure that the impact of humans on the Antarctic environment stays as limited as possible, and designates Antarctica as a nature reserve, which is devoted to peace and science [13], [19]. The Protocol commands all signatory parties to conduct an environmental assessment of the planned activities beforehand, for everyone they have jurisdiction over [13], [19]. Some key aspects of the protocol are:

1. All activities in the 60° areas are to be planned and carried out to restrict negative effects on the Antarctic environment and the connected ecosystems [6].
2. All activities in the ATS area must be planned in such manner that the air- and water quality, weather patterns, environment and flora & fauna populations, endangered populations and risk areas are not affected [6].
3. All activities shall be monitored and evaluated to ensure that possible unforeseen effects are detected early [6].

The Committee for Environmental Protection (CEP) was also established, to supervise the execution of the Protocol [6]. This committee examines the impact of an activity on the environment, and decides whether the activity is allowed to proceed [19]. Furthermore, Article

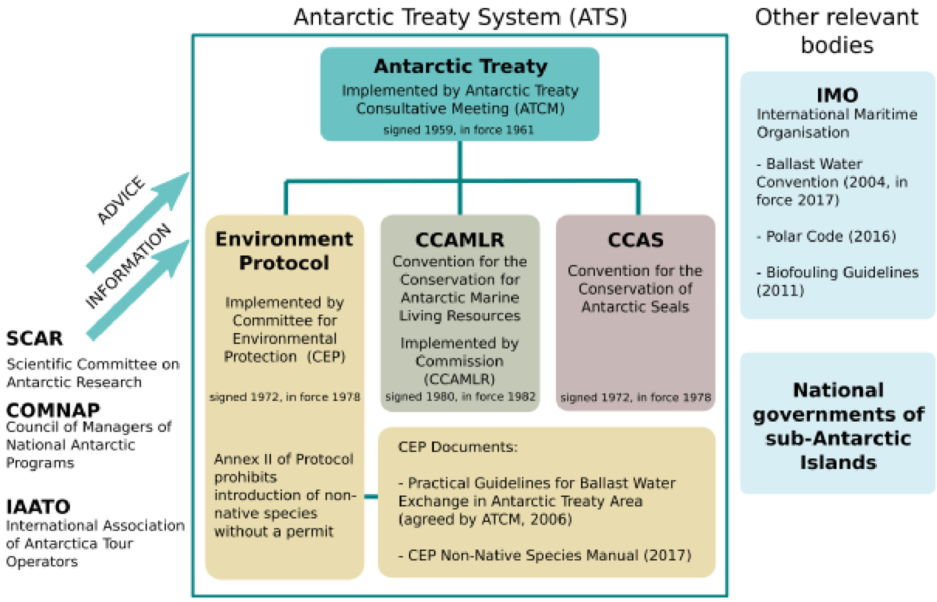

Figure 2. Overview of the most important bodies related to prevention of non-native species into Antarctica [4].

14 of the Protocol states that to advocate for the conservation of Antarctica's natural environment and its correlated ecosystems, all Parties are obliged to conduct inspections of research stations, to ensure that the guidelines of the Protocol are followed [20].

§2.2 Invasive species

There are several international organizations involved in the regulation and prevention of introductions of non-native species into, and within, Antarctica (figure 2). The Madrid Protocol and the International Maritime Organisation (IMO) together guarantee that common invasion pathways are no issue in the Antarctic [4].

Within the Madrid protocol, Article 4 of Annex II (Conservation of Fauna and Flora) bans intentional introduction of alien species into Antarctica, unless permitted, and that the deliberate importation of non-sterile soil is prohibited [2], [21]. The Protocol also addresses the transportation of native species between ABCRs, stating that the activities should be organised and regulated to stay clear of harmful changes in abundance, distribution or productivity of native species. All signatory states are compelled to reflect on the issues related to species dispersal while planning activities, which are then evaluated by the CEP, who have put the issues related to non-native species introductions as highest priority [2].

From 2017 onwards, the IMO Ballast Water Management Convention (BWM) regulates the dispersion of non-native marine species (NNMS) through ballast water. In order to reduce the likelihood of transporting alien species, ships are required to treat and oversee ballast water [4].

While the Madrid protocol oversees the formation of regulations, other organisations such as the Council of Managers of National Antarctic Programs (COMNAP), the Scientific Committee on Antarctic Research (SCAR) and the International Association of Antarctica Tour Operators (IAATO) provide information and advice. COMNAP and SCAR put together a "Checklist for supply chain managers of national Antarctic programs to reduce the risk of transfer of non-native species.". Additionally, SCAR has (co-)produced or reviewed several guidelines for parties, in order to reduce the probability of species transportation between ABCRs [2]. Examples of these recommendations are to rigorously clean equipment before going to a new location, or simply using different sets [2].

§2.3 Disturbance of local flora & fauna

Besides regulations concerning non-native species, Annex II of the Madrid Protocol also focusses on the potential effects of human activities on the Antarctic wildlife [14]. Article 3 states that "Taking or harmful interference shall be prohibited, except in accordance with a permit" [21], which has led to multiple guidelines concerning decreasing anthropogenic disturbance. These guidelines acknowledge that various species might be sensitive to disturbance and are inclusive of guidelines for aircraft operations and general pedestrian guidelines [14].

The International Association of Antarctica Tourism Operators also conducted guidelines, for both tourism- and national operators, compromising minimum distances to be kept from wildlife on foot and for a variety of vehicles [16].

§2.4 Other factors affecting local flora & fauna

To protect the soil from being trampled, the ATS has constructed three types of designated protected areas: Antarctic Specially Protected Areas (ASPA), Antarctic Specially Managed Area (ASMA), and Historic Sites and Monuments (HMS). ASPAs specifically are meant to protect the fragility of the Antarctic ecosystems. They are to be kept free from human activity, so pedestrian traffic should be kept as limited as possible. Possible approaches are to follow bedrock and already existing paths, which minimizes trampling effects on the vegetation. In the future, these areas are to be compared to places with large human interference, to get a clear understanding of the effects [17].

Antarctic waste disposal and management is regulated under Annex III of the Madrid protocol. It applies to all activities in the 60° degrees area related to scientific research, tourism and other (non-)governmental activities [6]. Article 1 states: "The amount of wastes produced or disposed of in the Antarctic Treaty area shall be reduced as far as practicable so as to minimise impact on the Antarctic environment and to minimise interference with the natural values of Antarctica, with scientific research and with other uses of Antarctica which are consistent with the Antarctic Treaty [22]." On top of that, all waste created in the ATS area is supposed to be cleaned on site, or brought back to the country under which the research activities take place [22].

Sewage disposal specifically is regulated under Article 2 of Annex III: "Liquid wastes, sewage and domestic liquid wastes, shall, to the maximum extent practicable, be removed from the Antarctic Treaty area by the generator of such wastes [22]." However, Article 5 states that it is allowed to discharge sewage and domestic water directly into the sea, as long as it is dispersed rapidly [22].

On the topic of toxins released into the environment, Article 7 of Annex II states: "No polychlorinated biphenyls (PCBs), non-sterile soil, polystyrene beads, chips or similar forms of packaging, or pesticides (other than those required for scientific, medical or hygiene purposes) shall be introduced onto land or ice shelves or into water in the Antarctic Treaty area [22]."

3. Assessment of the current regulations' effectiveness to protect Antarctica's environment.

It is unknown to which extent the researchers are informed on the composition of guidelines, as well as how well the rules are followed. The way national authorities have implemented the environmental impact assessment process, as required by the ATS, is also not clear [5]. To protect the natural environment of Antarctica from potential harmful scientific research, it is essential that all guidelines are followed strictly. Only then the EIA process will be effective [5].

There are only a few procedures to avoid accidental introduction of alien species, which are often not strictly followed [13]. The notion of preventing non-native species from entering and colonizing Antarctica is quite easily understood for different national parties, however, the same cannot be said for species transfer within Antarctica. Specific guidelines within the ATS for relocation of species between ABCRs are not formally in place yet, but the need for such instructions is recognized by the CEP in their Climate Change Response Work Programme [2]. One way to limit alien species introduction would be to increase the existing quarantine measures. This should apply not only for the scientists, but for all traffic in and out of Antarctica [5]. However, for effective management of prevention of species transfer, the knowledge on species' dispersal mechanisms, life history and physiology must expand [4], [7].

During inspections, the protection of flora and fauna was observed to be taken seriously in the majority of research stations, with sufficient knowledge concerning the guidelines [13]. Still, most stations have a high impact on their immediate environment. Since the implementation of the Madrid Protocol, the footprints of some stations have been steady, while others have enlarged theirs. Joint facilities are preferable, as they reduce the human footprint. Unfortunately, to date these stations are rare [5]. Still, the Netherlands has been consistent in its "shared facility" approach, and other countries such as France and Italy have built shared stations [23]. To address field work and temporary camps, little is known concerning the enforcement of environmental guidelines during these field activities [5]. Similar to the approach on invasive species introductions, in order to protect the flora & fauna of Antarctica, species-specific research, in specific regions, is required for improvement of the existing guidelines [14].

So far not one EIA seems to have blocked or adjusted any proposed activity. Focussing on pollution of the Antarctic environment, a scarcity of abandoned sites have been cleared, and even less have been fully decontaminated [5].

To check whether nations and research centres are complying with the Madrid Protocol, the Antarctic Treaty Consultative Parties organize site inspections. The significance of these inspections was found to be fundamentally flawed, as poor environmental conformity was not disciplined with sanctions. Diplomatically, this so-called 'no-blame policy' is ideal to preserve the peace between parties, but it does nothing to protect the environment [5]. For example, a report of inspections conducted by Germany & the UK in 1998 and 1999 contained a "best practice" list, which mentioned that certain research stations kept houseplants in soil, tropical fish, and grew vegetables [24]. However, the stations were not mentioned by name, and therefore it could not be determined whether the stations modified their practices [20].

The Chinese research station Great Wall has been inspected on several occasions, over a time-span of nearly 10 years. In the reports of these inspections, there were multiple probable and definite violations of the Madrid Protocol, as well as indications of bad practices, which enhanced the probability of harming the environment [20]. Still, the inspectors were discreet in blaming the station for its mediocre environmental practices. Furthermore, according to Annex III, Article 3 from the Madrid Protocol, all polystyrene should have been removed. However, in inspections carried out in 2006/07, polystyrene beads were found present in the Great Wall station [20].

Another station that has frequently been inspected was Rothera, from the UK. In general, this station has been praised for its excellent science and joint programs, but slight critique was given concerning the fuel drum storage in depots away from the station. In response, the British Antarctic Survey (BAS) stated that an environmental evaluation found that the activities, in this case the fuel depots, had limited impact, and were thereby deemed acceptable. However, other have stated that badly constructed fuel depots are a significant threat to the environment, as attempts of cleaning the environment comprehensively would be futile [20].

An example of a station that is praised for its environmental practices is SANAE IV, belonging to South Africa. The station is located inland, where wildlife might not be near the stations, which makes the regulations concerning disturbance less important. Per contra, these stations experience complications getting rid of their wastewater. One major environmental concern, as stated by the Norwegian inspection from 2000/01, is the disposal of wastewater onto the Vesleskarvet cliff, which is ice-free. This is forbidden by Article 4.1, Annex III of the Madrid Protocol, and is, similar to fuel, impossible to rinse completely [20].

Conclusion

So, are the current regulations concerning scientific research in Antarctica sufficient to protect and preserve the natural environment? The main problem concerning the regulations to protect the Antarctic environment, are not the regulations themselves, but rather the enforcement of them. As long as inspectors continue the "no-blame policy", negligence of the Madrid Protocol will not have any consequences, and minor violations will keep on occurring. Additionally, as climate change weakens the natural defence systems of Antarctica, it will become progressively easier for alien species to invade. Furthermore, global warming will affect the ecosystems, which makes them more fragile.

To ensure that Antarctica's natural environment is conserved, effective governance is necessary. A possibility to protect the environment would be to ban or limit building new research stations, so that the footprint stays stable. Joint facilities should be encouraged more, as the footprint of these stations is significantly lower compared to using two separate stations. To improve the guidelines, more species-specific research should be done.

This study does, due to limited time, not cover all threats to Antarctic wildlife, but just the most significant ones. It should also be mentioned that researchers are not the only humans present in Antarctica: tourism also plays a big role in bringing invasive species to the continent, disturbing wildlife and polluting the area.

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