Potential ecosystem impacts of cargo and building activities associated with the new Troll station, Dronning Maud Land, Antarctica

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1. Introduction

Despite its geographic isolation, the continent of Antarctica has been subject to widespread and long-term human activity since the 1950s when the establishment of permanent research stations became common (Hughes et al., 2023). Research and associated support and logistic activities in the Antarctic can have negative impacts on the natural environment, including through the emission of greenhouse gasses (Pertierra et al., 2013; Crossin et al., 2020), disturbance and/or displacement of wildlife (Coetzee and Chown, 2015), destruction of habitat (Pertierra et al., 2018; Brooks et al., 2019; Cannone et al., 2021), the introduction of non-native species (e.g., McCarthy et al., 2019), and the release of pollutants into the atmosphere and marine and terrestrial environments (e.g., Waller et al., 2017). The majority of these human impacts in Antarctica have been associated with research station construction, operation, and resupply (Tin et al., 2009; Crossin et al., 2020). Yet, Antarctic research has delivered globally significant scientific advances across numerous research disciplines and such research is key to responsible policy making and environmental management.

A prerequisite for the right to participate in governance in the region is 'substantial scientific research activity,' as stated in the Antarctic Treaty (Gray and Hughes, 2016; Pertierra et al., 2017; Leihy et al., 2020). The Antarctic Treaty System is an international agreement acceded by 56 nations which designates all land, ice, and sea south of 60° S as a 'natural reserve devoted to peace and science' (see: https://www.ats.aq/index_e.html#). All parties to the treaty have freedom of scientific research south of 60° S and recognize the need to minimize human impacts on the Antarctic environment. There are a total of 70 permanent research stations on Antarctica which represent 29 of the 56 parties to the Treaty. Of these, seven parties maintain territorial claims in Antarctica, including Argentina, Australia, Chile, France, New Zealand, the United Kingdom, and Norway.

In the Norwegian claim of Dronning Maud Land (between 20° W and 45° E), the permanent research station, Troll, is maintained and operated year-round. Troll is located at Jutulsessen, 235 km from the coast, and was first established in 1990. The most recent large-scale structural updates were built in 2005, and the station is now nearing the end of its 20-year lifetime. In 2023, the first steps were taken to replace Troll with a smaller building fit to house 65 people and with laboratory space for up to 20 researchers. The updated Troll station is set to be finished in 2030. Until now, activities for maintaining Troll station have been dominated by annual resupplies where land-based operation and logistic staff from the Norwegian Polar Institute (NPI) rendezvous with a contracted container ship at the coast on Fimbulisen every January. Operations at Fimbulisen are expected to increase with the building of a new Troll station, with the first major building activities set to begin in 2025.

In response, this report has been commissioned by the Antarctic Program of the NPI to document and assess the state of the ecosystem along Fimbulisen and potential impacts associated with building activities of the new Troll station. Fimbulisen is an ice shelf between 160–550 m thick which floats over the Kong Håkon VII Hav in the Atlantic sector of the Southern Ocean off the coast of Dronning Maud Land (Nøst et al., 2004). In some areas along the coast (e.g., Rektangelbukta), Fimbulisen is fringed by landfast sea ice, and in most areas, it is buttressed by a band of freely drifting pack ice which protect it from weathering and erosion by waves and storms. Several species of seabirds and marine mammals have been observed along the coast during recent resupply cruises, and different types of potential ecosystem impacts have been identified. This report presents observations of the number of species, their respective behaviors, and potential impacts to marine wildlife associated with resupply activities at Fimbulisen. As the administrative authority for the Antarctic Regulations, NPI is bound to enforce and maintain the obligations that Norway has assumed under the Environmental Protocol, including to both maintain Troll station and minimize potential environmental impacts (see: https://www.regjeringen.no/en/dokumenter/meld.-st.-32-20142015/id2415997/?ch=3). This report thus provides empirical data which can be used in decision making and policy creation around future activities at Fimbulisen associated with the rebuilding of Troll station. However, we note that this report is not an environmental impact assessment and does not follow the procedures of an environmental impact assessment as outlined by the Norwegian Ministry of the Environment (see: https://www.regjeringen.no/globalassets/upload/kilde/md/bro/2003/0001/ddd/pdfv/182783-t-1428_e.pdf).

2. Materials and methods

The species present, number of individuals per species, and their behaviors were observed on four cruises to the Kong Håkon VII Hav in the austral summer between 2020–2024 (**Table 1**). The primary purpose of these cruises was to resupply Troll station, and research activities were conducted around resupply operations. Leaving from Cape Town, South Africa, the container ship sailed southwest towards the designated unloading location over an approximately ten-day transit period. Weather permitting, the vessel would moor to the ice shelf upon arrival and proceed to unload containers onto the shelf using two large cranes. Most of the cargo was fuel (jet fuel and polar grade diesel), and the other supplies included food, snow-going vehicles, tools, personal equipment, etc. Resupply of fuel included both unloading new containers of fuel and re-filling containers already onshore using a ship-based pump system. Empty containers and supplies needing repair were loaded onto the boat for transport back to Tromsø once unloading operations were finished. Unloading operations typically lasted four to seven days, and about 50 containers were delivered at peak capacity. Ecosystem observations occurred throughout transit periods and unloading operations. During observation shifts, two scientists would observe environmental conditions (i.e., weather, sea ice concentration, iceberg drift) and animal behaviors from the bridge of the vessel. Animals were counted when they passed outside the forward port side of the vessel. Observation shifts were one hour in duration and photos were taken during observations to further aid in species identification. Outside of

observation shifts, sightings were noted by the ship's crew. Time, position, and weather data were noted alongside species, number of individuals per species, and behavior. Observations were focused on seabirds and marine mammals (pinnipeds and cetaceans). Although observations occurred throughout the entire duration of each cruise, this report will focus on those organisms observed immediately at Fimbulisen, where the potential impacts from future operations associated with the new Troll station are expected to be the most significant.

3. Results

A list of all species observed during unloading operations at Fimbulisen and their conservation status according to the IUCN (2023) is presented in **Table 2**. In total, fourteen unique species of seabirds, pinnipeds, and cetaceans are observed, with seabirds the most abundant and cetaceans the least common of the four groups.

Of the flightless seabirds, Adélie penguins are more abundant than emperor penguins. Adélie penguins are frequently observed in groups ranging between six or seven up to twenty or more individuals (**Figure 1b** and **1d**). They are infrequently observed alone and are often with at least one other bird. Adélie penguins are typically observed on ice floes and swimming between floes. They can move quickly while standing or by laying on their abdomens and sliding forward by pushing with their feet. Adélie penguins have also been observed on the ice shelf itself. They are very curious and often get close to the ship and infrequently walk through the container camp on the ice shelf. Emperor penguins are mostly observed as solitary and are seemingly less active than Adélies. They stand on ice floes or on the ice shelf and show more shy or skittish behavior, turning their backs towards the ship or swimming away when the boat gets close. However, in 2023 one emperor penguin walked back and forth through the container camp and along the shelf during the unloading operations (**Figure 1a**). Notably, juvenile emperor penguins have been observed around Fimbulisen each year (**Figure 1c**). Less commonly, Adélie and emperor penguins have been observed standing on the same ice floe. Both penguin species are observed mostly during the day and not during the night. Generally, when sea ice is not present penguins are not observed.

Of the flying seabirds, Antarctic petrels and snow petrels are the most abundant. These two species fly together in large flocks along the edge of the ice shelf (**Figure 2a** and **2b**). We estimate that hundreds of these two petrels are observed daily at the unloading location on Fimbulisen. They have also been observed diving and landing on the water, exhbiting foraging or feeding behavior around Fimbulisen (**Figure 2c**). Neither Antarctic or snow petrels are attracted to the ship and their activity seems mostly undisturbed by the ship activity. Wilson's storm petrels are observed in the evening and throughout the night. They are very attracted to the ship, flying closely in and around the cranes and even landing on deck (**Figure 2d**). Antarctic terns are infrequently observed at Fimbulisen but have been documented in 2021. Southern giant petrels are observed in low abundance daily, approximately five to ten a day (**Figure 2e**). They fly alone in large sweeping patterns. Northern giant petrels have also been observed at Fimbulisen but are generally less common than Southern giant petrels, as the coastal region of Antarctica is outside the common range of the Northern giant petrel.

Marine mammals are overall less common than seabirds at Fimbulisen. Like penguins, seals are observed almost exclusively in correlation with sea ice. Both crabeater and Weddell

seals are observed daily when sea ice is present. Crabeater seals are observed lying solitary on ice floes and are typically relatively inactive (**Figure 3a**). In comparison, Weddell seals are frequently observed in groups of four to fifteen individuals. They are more active and are often seen swimming in between floes, and in addition to lying on floes in groups (**Figure 3b** and **3c**). Leopard seals are observed infrequently at Fimbulisen, and the one individual that was observed in 2024 was lying solitary on an ice floe and mostly inactive. Whale sightings are uncommon at Fimbulisen during unloading activities, and most of the whale observations during these cruises have occurred in open ocean environments where drifting icebergs are present. The humpback and fin whales that were observed at the coast were swimming in small groups, less than four individuals, and quickly moving through the unloading area (**Figure 4a, 4c, 4d,** and **4e**). Orcas have been observed along the shelf, and in both 2021 and 2022 family groups with calves were observed (**Figure 4b**). Orcas are typically observed in pods, ranging from 50 individuals observed in 2021 to four individuals in 2023. The orcas observed around the shelf region have likely been the Type B (Pitman and Ensor, 2003). This ecotype is known to hunt seals in the pack ice surrounding the Antarctic continent, which is in alignment with the actively hunting pod observed in 2023.

4. Discussion

Although most species observed at Fimbulisen are considered non-threatened by the IUCN, observations of juvenile animals and foraging, feeding, and hunting behaviors suggest a high potential for environmental impacts at Fimbulisen. What is more, operations associated with construction, maintenance, and resupply of research stations are known to have relatively high environmental impacts in the Antarctic (Tin et al., 2009; Crossin et al., 2020). To maintain compliance with the Antarctic Treaty and mitigate potential environmental impacts, we suggest that a formal environmental impact assessment should be done, and based on this assessment, an environmental impact reduction strategy be adopted for the rebuilding of Troll station. In this discussion we outline several potential environmental risks and provide suggestions for mitigation actions which can serve as a starting point for this impact reduction strategy and highlight the need for a more formal assessment. Specific strategic suggestions are listed here in short and expanded upon below. Within these suggestions, we wish to highlight that large individual changes can offer significant benefits, but the success of all practical improvements will likely depend on the active engagement and support of involved staff and personnel.

- Plan out activities at Fimbulisen to be as low impact as reasonably possible
- Develop and enforce protocols on biosecurity and marine pollution prevention
- Develop and maintain emergency response plans to acute environmental risks
- Allocate adequate resources for monitoring during resupply and building activities
- Commitment to continuous improvement in all operations associated with Troll station

In expanded detail that is:

- Plan out all activities at Fimbulisen, including ship operations and overland transport to and from Troll, to be as low impact as reasonably possible.

From our observations, the major environmental risks associated with resupply operations at Fimbulisen are disturbance and/or displacement of wildlife, destruction of habitat, and greenhouse gas emissions. A potential action to mitigate these risks is to establish an unloading location where mooring is possible and sea ice and icebergs freely drift. During the 2024 resupply cruise, it was challenging to determine a safe unloading zone due to calving activity along the ice margin. Extremely low sea ice concentrations this season exposed the ice shelf to waves and storms, increasing the risk of calving of the ice shelf. The ship was forced to search for new unloading sites which resulted in environmental disruption over an extended area along the shelf. To avoid an impromptu search for an alternate mooring location, leading to increased greenhouse gas emissions from marine and terrestrial logistics, ice conditions should be closely monitored prior to the scheduled resupply. We acknowledge that sea ice and iceberg drift are a less predictable natural factor and therefore suggest that distinct back up locations be determined in addition to the primary unloading location. If unloading occurs at only one location and the ship can moor, the greenhouse gas emissions from both ship- and land-based operations will be decreased, noise from the ship and land-based vehicles will be reduced, and sea ice that is broken due to ship movement will be lessened.

Behavioral (vigilance) and physiological changes (heart rate, hormones, blood chemistry) have been documented in Antarctic wildlife in response to snowmobiles and boats (Culik et al., 1991; Boren et al., 2002). Additionally, population scale changes in wildlife such as abundance and morphometric changes have been observed in regions under longer-term and high disturbance regimes from human activities as compared to disturbance free regions (McClung et al., 2004; Villanueva et al., 2012). Because we observed that some seabirds avoid the ship during unloading, we suggest that these animals are disturbed by activities at the ice shelf and actions such as turning off the main engines during mooring and reducing the area that the ship impacts may help to relieve this disturbance. Additionally, orcas use echolocation to locate prey in their environment and there may be a risk of disturbance in terms of increased noise associated with increased traffic. However, research indicates that if ship speed is kept at a reasonable level (i.e., engine activity decreased or turned off), noise received by orcas is kept at a minimum (Houghton et al., 2015). Emperor penguins and their newly fledged offspring are also vulnerable to disturbances by increased traffic. Therefore, we suggest that further investigation be made in terms of how increased ship traffic might impact the ecosystem around Fimbulisen. Specifically, we encourage the creation of a formalized environmental risk assessment and corresponding impact mitigation strategy to mitigate impacts to the best extent possible.

- Develop and enforce responsible protocols on biosecurity and marine pollution prevention, specifically on ballast and wastewater, non-native species, and microplastics.

The introduction of invasive non-native species is increasing in Antarctica and may present one of the greatest threats to Antarctic biodiversity (Frenot et al., 2005; Hughes et al., 2015). The largest threat we observed for the introduction of non-native species is through ballast water from the ship and unclean clothing and personal equipment. To maintain compliance with policy on the introduction of non-native species to Antarctica (Annex II to the Protocol on Environmental Protection to the Antarctic Treaty; see:

https://documents.ats.aq/recatt/Att432_e.pdf), we suggest specific protocols be put in place to mitigate these risks. Cargo ships doing operations at Fimbulisen should be required to exchange ballast at least 200 nautical miles offshore and have an on-board ballast water treatment system. Lagrangian drift results from experimental ballast water release in the Western Antarctic Peninsula show that exchanging ballast water 200 nautical miles offshore considerably reduces the arrival of propagules to marine protected areas along the coast (Duliere et al., 2022), and the 200 nautical mile standard is also in compliance with point 5 of the Antarctic Treaty Consultative Meeting. Following the Ballast Water Management Convention, all vessels must be fitted with D-2-compliant ballast water treatment systems by September 2024, which would remove and destroy biological organisms from ballast water using UV treatment, filters, and chemical injections (International Maritime Organization, 2024). Proper compliance with regulations around ballast water release and treatment have the potential to effectively mitigate most risks associated with non-native species introduction via ballast water release along Fimbulisen. From conversations with the captain aboard M/V Silver Arctic, we believe these types of measures are already being taken on this vessel, and we encourage that this be considered when contracting with other vessels in the future. Practical guidelines for ballast water exchange in the Antarctic Treaty Area can be found here: https://documents.ats.aq/recatt/Att345_e.pdf.

It is estimated that visitors to Antarctica carry an average of 9.5 non-native seeds per person and that scientists carry greater propagule loads than tourists (Chown et al., 2012). Although we acknowledge that general risk for invasive species establishment at Fimbulisen is relatively low due to low temperatures and permanently covered soils, equipment used by NPI employees has often been in high-latitude environments, and non-native species introduced by their equipment may be adapted to such extreme environments such as those found at Fimbulisen and Troll Station. Upgrading Troll station will increase ship-borne and air-borne traffic, as well as the amount of personnel and equipment, thus increasing the risk of transferring non-native species. Steps required to mitigate this potential risk have been accorded within the Antarctic Treaty System and include comprehensive inspections of equipment, clothing, and cargo, thoroughly cleaning and disinfecting equipment, clothing, and boots before arriving in Antarctica, training and education around the risks associated with non-native species introduction, and research on and monitoring of the establishment and spread of invasive species (see: https://documents.ats.aq/ATCM42/WW/ATCM42_WW008_e.pdf). Additionally, protocols to clean and sterilize equipment have already been developed by several organizations, such as the Australian Antarctic Program https://www.antarctica.gov.au/antarctic-operations/travel-and-logistics/cargo-and-freight/biosecurity/) and the British Antarctic Survey (https://www.bas.ac.uk/wp-content/uploads/2021/08/BAS-Biosecurity-Regulations.pdf). Therefore, we suggest a review of the legal obligations on biosecurity in Antarctica (Annex II to the Protocol on Environmental Protection the Antarctic Treaty) and mapping of the pathways to which non-native species may be transferred.

Microplastics (<5 mm) have now been documented in Antarctic sediments (Waller et al., 2017), seawater (Isobe et al., 2016), snow (Aves et al., 2022), and sea ice (Kelly et al., 2020). The narrow niches evolved by endemic Antarctic biota make them especially vulnerable to toxicological effects from microplastics, including neurotoxicity, reproductive toxicity, and

oxidative stress (Chen et al., 2021; Jewett et al., 2022). While microplastics can affect all Antarctic environments through long-range transport, human presence is documented as increasing local-scale plastic pollution (Rota et al., 2022). Primary sources of microplastics are from personal care products (e.g., some toothpastes and face scrubs) and from gray water produced by laundry machines, with an estimated 728,000 microplastic fibers potentially released from a single 6 kg wash of acrylic fabric (Napper and Thompson, 2016). In fact, Waller et al. (2017) estimated a release of 7.5–27.5 mg microplastics person^{-1} day^{-1} in the Southern Ocean. Although complete removal of microplastics is difficult, these results suggest that vessels and research stations be equipped with suitable wastewater treatment plants where possible. Annexes III and IV of the Protocol on Environmental Protection to the Antarctic Treaty prohibit the release of wastewater from vessels within 12 nautical miles of the coast, but Parties to the Treaty are not compelled to treat wastewater released from scientific research stations. From conversations with the captain aboard M/V Silver Arctic, we believe that wastewater release follows the Protocol, and we encourage that this be considered when contracting future vessels for work at Fimbulisen. We maintain that it is the obligation of the NPI to ensure that proper ballast water and wastewater systems are in place on the vessels contracted for work around Fimbulisen and Troll station. We also suggest that the new Troll station be outfitted with a wastewater treatment system which includes filters for the removal of microplastics to reduce the local impact of plastic pollution around Troll. Complete legal obligations on the prevention of marine pollution are found in Annex IV to the Protocol on Environmental Protection to the Antarctic Treaty (see: https://documents.ats.aq/recatt/Att011_e.pdf). Thus, to fulfill these legal obligations, we suggest that biosecurity and pollution risks be considered in full during the formal environmental risk assessment and that proper steps be taken to mitigate these risks during all building activities associated with the new Troll station.

- Develop and maintain emergency response plans for acute environmental risks, such as oil spills, specifically.

During unloading operations, we observed that a substantial portion of cargo is fuel. In addition to the offloading of fuel containers, old fuel containers are refilled, which involves running hoses and pumping from the ship to the container on land. We contend that during these operations there is a high risk for a spill. The potential impact of a spill depends mainly on the size of the spill, and it has been reported that minor spills (<1 liter) are common throughout the Antarctic during refueling operations (Hughes and Stallwood, 2006). Medium (100s of liters) and large spills (1,000s of liters) are less common in Antarctica, and may be caused by spills during bulk fuel tank refilling or leakage from ships (Wilkness, 1990; Kerry, 1993). Due to the extreme environment and geographic isolation of Antarctica, even a small pollution event can have greater significance than elsewhere in the world due to difficulties in clean-up responses (Clarke and Harris, 2003; Raymond et al., 2017).

Following an oil spill, lighter molecules quickly evaporate leaving behind high molecular weight molecules such as Aliphatic, aromatic, and polyaromatic hydrocarbons (Green et al., 1992; Aislabie et al., 1999). These heavy molecules demonstrate high ecotoxicity and impact marine life through inhalation, ingestion, and dermal pathways, each with its own suite of physiological response that can comprise both health and long-term survival and reproduction

(Helm et al., 2014). For seals, this can cause damage to the respiratory system, gastrointestinal system, and eye, skin, and mucus membranes, while for whales this can cause acute respiratory injury (Helm et al., 2014). Mass mortality of seabirds is common in the aftermath of oil spills (e.g., Castege, 2007). From conversations with the captain aboard M/V Silver Arctic, we believe an oil spill response plan is already in place alongside a risk assessment on the shipping of fuel containers, and we strongly recommend that this be considered when contracting with other vessels in the future. Due to the gravity of consequences of an oil spill at Fimbulisen, we further suggest that this plan be re-visited to add risk, impact, and mitigation measures specifically from the vantage point of risk to the environment.

- Allocate adequate resources for monitoring during resupply and building.

The creation of a formal environmental impact assessment and environmental impact reduction strategy, such as those presented by Crossin et al. (2020) and Lockrey et al. (2020), requires significant time and energy. This suggests that a dedicated management project focused on environmental monitoring and management associated with operations around the building of the new Troll station is needed. The creation of such a project, in turn, demands that adequate resources are allocated for monitoring, analysis, and strategy writing before, during, and after resupply and building operations. Such a project should also be tasked with ensuring proper alignment with both the Protocol on Environmental Protection to the Antarctic Treaty and Norwegian interests and policies in the Antarctic. Additionally, the creation of monitoring programs focused on environmental disturbance, i.e., ecotoxicology, around Fimbulisen and Troll station in support of strategic decision making on environmental impact reduction and protection would require dedicated scientific and logistical staff. Outside of financial resources, adequate time should also be allocated to ensure both environmental and personal safety during unloading and building operations. Strict compliance with health and environment regulations would decrease safety risks for personnel working with heavy machinery and hazardous materials during building and unloading operations. Decrease of these safety risks also decreases environmental risks through, for example, cautious pumping of fuel between containers. The creation of such projects and changes in timelines associated with building and resupply inherently requires increased flexibility in the configuration and use of assets and personnel. However, we suggest that such action would greatly improve the success of any environmental impact reduction strategy created for the building and maintenance of the new Troll station.

- Commitment to continuous improvement in all operations associated with Troll station.

The suggestions presented here are contingent on the commitment of the Antarctic Program of NPI. Improved understanding and adaptation in the culture, behavior, and practices of all employees in the Antarctic Program is prerequisite to the need for improved monitoring and data collection. As such, genuine consultation and the inclusion of staff in a participatory design process should be an essential component of any strategies or protocols developed around environmental monitoring, impact assessments, and reduction and mitigation strategies. We suggest that all visitors to the Antarctic south of 60° S under the direction of NPI participate

in mandatory educational seminars informing on both national and international policies as outlined in the Antarctic Regulations and Environmental Protocol to the Antarctic Treaty prior to departure.

5. Conclusion

The new Troll station will integrate innovative energy strategies to greatly reduce the greenhouse gas emissions, and thus the global-scale environmental impacts, of the station. Yet, it is the building and resupply activities associated with maintaining Troll which pose an additional risk for environmental damage by habitat destruction and disturbance and the introduction of non-native species, in addition to exceptionally high greenhouse gas emission. With operations at Fimbulisen and Troll station expected to increase in the coming years, so too will these environmental impacts and the need for effective planning and management. This poses the risk that an ad hoc approach will be employed where existing practices are scaled up as demand increases, resulting in greater fuel use and proportionately larger environmental impacts at both the Antarctic and global scale. Further investigations of future resource requirements would allow for a more strategic approach and the development of mitigation solutions. This would ensure that a growth in operations at Fimbulisen minimizes environmental impacts and maximizes the efficiency of cargo and ship-based activities. Future research and operational improvement opportunities are beneficial, for both Norway and the greater Antarctic community, however any actions will be bound by treaties, plans, and policies. Future-proofing these changes thus requires an in-depth investigation of potential environmental impacts and risks alongside mitigation and adaptation strategies. It is hoped that the insights provided here will pave the way for a more formalized environmental risk assessment and impact reduction strategy associated with the resupply and maintenance of Troll station. We maintain that it is the duty and obligation of the NPI to see to it that such an assessment and impact reduction strategy is created, as NPI is the appointed authority for the Antarctic Regulations per section 7 of the Dependencies Act (see: https://www.regjeringen.no/en/dokumenter/meld.-st.-32-20142015/id2415997/?ch=3). We hope that this report can be a platform for further discussion and work on this topic.

Table 1. Overview of annual resupply cruises to the Kong Håkon VII Hav.

Dates	Vessel name	Scientific focus
31 Dec. 2020 – 14 Jan. 2021	M/V Malik Arctica	Pelagic sampling and mooring deployment
22 Dec. 2021 – 18 Jan. 2022	M/V Silver Arctic	Sea ice sampling
10 Jan. 2023 – 13 Feb. 2023	M/V Silver Arctic	Pelagic sampling and mooring deployment
5 Jan. 2024 – 7 Feb. 2024	M/V Silver Arctic	Sea ice sampling

Table 2. Overview of organisms observed during unloading operations at Fimbulisen. Presented conservation status is from the International Union for Conservation of Nature's Red List of Threatened Species (IUCN, 2023).

Common name	Scientific name	Year observed	Conservation status
Flightless seabirds			
Adélie penguin	*Pygoscelis adeliae*	2021, 2022, 2023, 2024	Least concern
Emperor penguin	*Aptenodytes forsteri*	2021, 2022, 2023, 2024	Near threatened
Flying seabirds			
Wilson's storm petrel	*Oceanites oceanicus*	2021, 2022, 2023, 2024	Least concern
Antarctic tern	*Sterna vittata*	2021	Least concern
Snow petrel	*Pagodroma nivea*	2021, 2022, 2023, 2024	Least concern
Antarctic petrel	*Thalassoica antarctica*	2021, 2022, 2023, 2024	Least concern
Southern giant petrel	*Macronectes giganteus*	2021, 2022, 2023, 2024	Least concern
Northern giant petrel	*Macronectes halli*	2023	Least concern
Pinnipeds			
Crabeater seal	*Lobodon carcinophagus*	2021, 2022, 2023, 2024	Least concern
Weddell seal	*Leptonychotes weddellii*	2021, 2022, 2023, 2024	Least concern
Leopard seal	*Hydrurga leptonyx*	2024	Least concern
Cetaceans			
Orca	*Orcinus orca*	2021, 2022, 2023	Data deficient
Humpback whale	*Megaptera novaeangliae*	2023	Least concern
Fin whale	*Balaenoptera physalus*	2023	Vulnerable

Figure 1. Flightless seabirds at Fimbulisen. Both emperor (**a** and **c**) and Adélie penguins (**b** and **d**) are observed at Fimbulisen on the ice shelf, surrounding sea ice, and swimming in the water. Juvenile emperor penguins are also frequently observed at Fimbulisen (**c**).

Figure 2. Flying seabirds at Fimbulisen. The most abundant species of flying seabirds observed around Fimbulisen are Antarctic petrels and snow petrels (**a** and **b**). These two species fly in large flocks at the edge of the ice shelf and are observed feeding and foraging in the water immediately adjacent to the shelf (**c**). Wilson's storm petrels (**d**) and Southern giant petrels (**e**) are also observed at Fimbulisen.

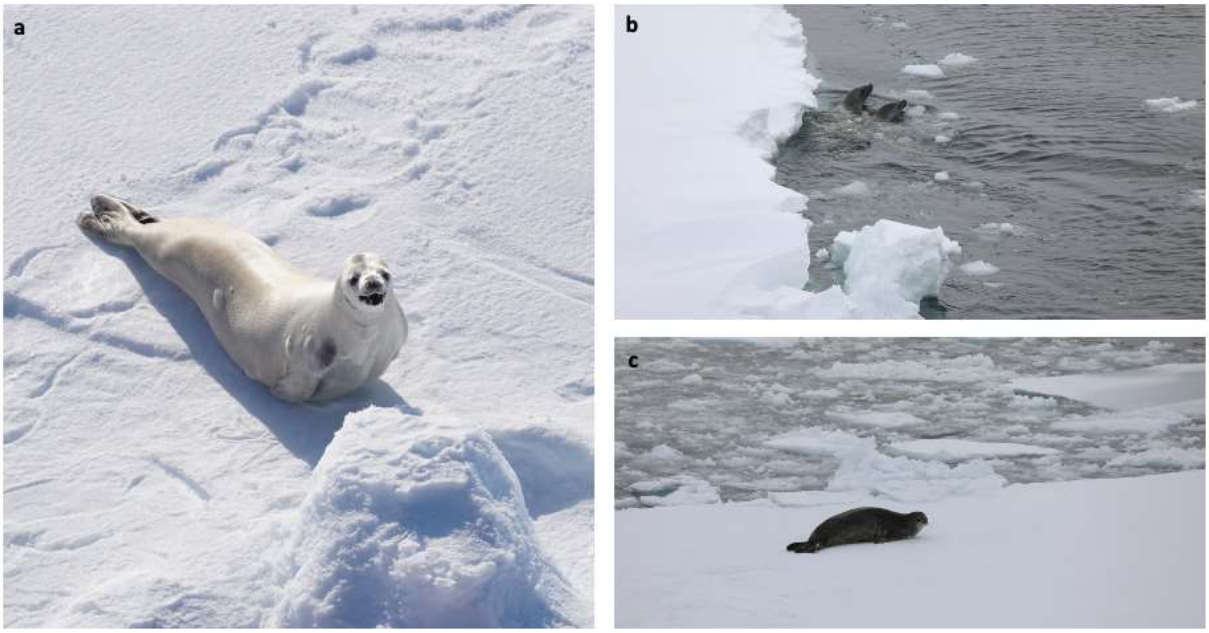

Figure 3. Pinnipeds near Fimbulisen. The two most prevalent species of pinnipeds at Fimbulisen are crabeater seals (**a**) and Weddell seals (**b** and **c**). Crabeater seals are frequently observed as individuals, while Weddell seals are more often in groups.

Figure 4. Cetaceans near Fimbulisen. Cetaceans are more often observed in open waters further away from the immediate vicinity of the ice shelf. Humpback whales are the most common (**a, c,** and **e**). Orcas (**b**) and fin whales (**d**) are less commonly observed. Orcas are often in groups or family pods and hunt within the sea ice, while fin whales swim very quickly and are the least abundant.

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