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Anchor and chain damage to seafloor habitats in Antarctica: first observations

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The number of ships visiting Antarctic waters is increasing. However, the ecological consequences of this increase to Antarctic marine ecosystems remain unclear, including impacts to the seafloor. Benthic and mesopelagic exploratory surveys were conducted in Antarctica in 2022–2023 using deep-sea cameras tethered to a tourism vessel during routine tourism operations. The study area encompassed the Antarctic Peninsula, Weddell Sea, South Shetland Islands, Marguerite Bay, and South Georgia Island. A total of 36 surveys were completed resulting in 62 hours of 4K underwater video footage taken while at anchor or drifting. At Yankee Harbour, the researchers documented anchor and chain damage to sponge colonies, with clear scour marks delineating the disrupted substrate from undisturbed seafloor supporting marine life. Also observed was deposited mud, likely resulting from anchor or chain retrieval. This study presents the first published observation of anchor damage in Antarctica. Despite the observed damage, the Yankee Harbour survey also revealed rich biodiversity in proximity to the impacted areas. Most notably, three large (1–2 meters in height) giant volcano sponges (*Anoxycalyx joubini*) were observed. This paper shows observations of anchor and chain damage to vulnerable Antarctic seafloor marine life, discusses the potential ecological impacts of anchoring in polar habitats, and provides recommendations to better understand and mitigate further harm.

KEYWORDS

anchor damage, antarctica, seafloor, biodiversity, sponges, solutions

Introduction

Ship anchoring practices date back a few thousand years to the earliest days of seafaring (Thomson, 1902). However, the footprint of modern anchoring, as with many other human impacts to the seabed (e.g., trawling, mining; Halpern et al., 2019) has and will likely continue to intensify with increasing global shipping. Maritime passenger traffic, including cruise ships, is increasing (UNCTAD, 2023). Even during the COVID-19 pandemic in 2020, where cruise ship tourism was effectively suspended (Lin et al., 2022), the impact of cruise ship anchoring has been documented to have damaged thousands of square meters of reef in Barbados (Small and Oxenford, 2022). The demands of cruise-ship tourism have been expanding all the way to the polar regions, an increasing trend since the early 1990s with the 2022–23 season having the highest historic passenger numbers ever recorded (IAATO, 2023; Aronson et al., 2011). The consequences of cruise ship tourism, including the anchoring of vessels in Antarctica, has been a documented concern for decades (Erize, 1987; Lamers et al., 2015).

Anchoring is an overlooked ocean conservation issue (Davis et al., 2016), both around the world and in Antarctica specifically (Lamers et al., 2015). High-resolution mapping has produced the first ever global estimates of habitat damage caused by anchoring, showing “extensive and persistent” damage to the seabed and associated habitats (Watson et al., 2022) with potential consequences analogous to benthic trawling (Davis et al., 2016). Yet, the impacts of anchoring to marine ecosystems in Antarctica and the polar regions had not been previously examined (Broad et al., 2020). For the most part, studies documenting anchoring impacts have occurred in shallow waters (<10 m), temperate or tropical latitudes, and have focussed on recreational boat anchoring with diving assessments being the primary methodology (Broad et al., 2020). The impacts of vessel anchoring in these non-polar locations has shown to decrease the density of benthos (Francour et al., 1999; Deter et al., 2017), have short-term (days) and long-term (years) detrimental ecological impacts (Creed and Amado Filho, 1999; Milazzo et al., 2004; Rogers and Garrison, 2001), disturb all seabed habitat types (e.g., rock substrates and muddy soft bottom; Broad et al., 2020), and modify the behaviour of megafauna (Carome et al., 2022). Sessile seabed organisms, such as seagrass, corals and sponges, are particularly vulnerable to physical disturbance by anchoring (Broad et al., 2023). Tropical corals show decline in survival and growth and loss of coral density (Forrester, 2020), in some cases, up to ten years after a single anchoring event (Rogers and Garrison, 2001). Seagrass beds in a range of settings globally show reduced shoot density and coverage, diminished seagrass condition, and increased fragmentation in areas where anchoring occurs (Abadie et al., 2016; La Manna et al., 2015; Okudan et al., 2011; Creed and Amado Filho, 1999; Francour et al., 1999). Anchoring on rocky reefs has shown to cause declines in morphotype abundance and richness, including compositional shifts relative to non-anchored sites (Broad et al., 2023; Smith, 1988). The impact of anchoring in soft sediment ecosystems is less documented, however physical damage in muddy and fine-grained sediment habitats has shown persistent sediment disturbance in the upper ~30 cm, and in some cases up to 80 cm (Watson et al., 2022). However, the time of infaunal community recovery to physical disturbance in soft sediments was shown to substantially increase with depth of disturbance (Dernie et al., 2003). The impacts to marine life from anchoring in Antarctica are not widely understood, and therefore not well regulated. However, the region is home to unique and fragile ecosystems (Aronson et al., 2011) that may experience long-term environmental harm from anchoring, and are worthy of protection.

High-latitude polar regions may be some of the most vulnerable marine habitats to the impacts of anchoring. There are estimates of over 4,000 species of benthic marine life in Antarctica and many of these species are endemic and undocumented to science (Clarke and Johnston, 2003). These benthic organisms are vulnerable to anchor damage due to their sessile, slow-growing, and long-lived nature (Al-Habahbeh et al., 2020; Broad et al., 2020). Benthos in Antarctica play vital roles in filtering large amounts of water (Morganti et al., 2019), sequestering large amounts of carbon (Bax et al., 2021), providing food and shelter to many other species, and compounds from these animals are showing importance in biomedical research, such as an Antarctic sea squirt being analysed for skin cancer treatment (Murray et al., 2021). Seafloor habitats not impacted by ice scouring are protected from storms by seasonal ice cover, and historically have been left nearly pristine. The recovery time from anchor damage in Antarctica is expected to be slow, as other seafloor habitats have not recovered from mechanical disruption from debris after 77 years, and would likely not recover for at least 100 years (Jamieson et al., 2022).

The amount of ships and people visiting Antarctica is increasing. In the 2022–2023 season, over 70,000 people landed in Antarctica onboard 70 tourism vessels mainly operating in anchorable coastal waters (IAATO, 2024). There are 52 research vessels which conduct operations in Antarctica, and they are another likely source of recurring anchoring when they operate in nearshore environments or stop at research stations (McCarthy et al., 2019). In addition, an estimated 20 to 30 private yachts visit Antarctica each season, some with recurring trips (Antarctic Treaty Secretariat, n.d.). Additional anchorages may occur from 45 fishing vessels licensed for operations in the Southern Ocean in 2023-2024, and previous estimates are that 20–30 fishing vessels may conduct illegal fishing operations in the Southern Ocean (CCAMLR, 2016; AAP, 2003). The amount of anchorages by fishing vessels is unclear as their operations are mainly offshore in deeper waters.

There is no publicly available database for documenting the number of anchorages, nor the number of vessels anchoring in Antarctica annually, and this information is needed to understand the scope of the ecological impact. The number of ships primarily using dynamic positioning systems (DPS) instead of anchoring for short stays is unclear, but most newer vessels have these systems installed. Anchorable depths are usually confined to under 82.5 m depths, while deeper anchoring is possible, it is discouraged under guidelines (Intertanko, 2019). During November and December, many vessel activities do not operate at anchorable depths due to the presence of seasonal sea ice. But as sea ice cover hit near record lows in Antarctica in 2024, there is a possibility for increasing vessel access to shallower waters and subsequently more anchorable days and potentially a larger area available for anchoring (NASA Earth Observatory, 2024). Analogous observations in the Arctic have shown that declining sea ice cover has increased shipping traffic across previously ice-covered regions (Pizzolato et al., 2016; Ho, 2010). The consequences of sea ice loss in the arctic have highlighted changes to local and regional climate, oceanography, ecosystem function, marine biodiversity and animal behaviour (e.g., Meier et al., 2014). The increased stress on these sensitive environments due to sea ice loss (Serreze and Meier, 2019), will likely be further exacerbated by predicted increases in human activities in polar regions, including ship anchoring and vessel traffic. It is possible that some shallow water benthos in polar regions are more resilient to physical disturbance due to regular iceberg scouring promoting biodiversity and selecting for opportunistic species (Smale et al., 2008). However, adapting to multiple environmental pressures (e.g., climate change and sea ice loss) as well as increasing human presence is likely to be detrimental for slow-growing endemic species in Antarctica, with potential changes to ecosystem structure and reductions in marine biodiversity (Smale and Barnes, 2008).

The precise number of anchorages in Antarctica, the frequency of use and the cumulative impacts of anchor and chain disruption to Antarctic benthic habitats needs further investigation. In this study, we document for the first time the impacts of anchoring and chain damage at one harbour in Antarctica as well as providing estimates for the amount of anchoring activity for one month at this location. We also suggest further areas of anchor research in Antarctica and solutions to mitigate further harm which are informed by our experiences, and investigation of operational practices and regulations in the region.

Materials and methods

Over the course of the 2022–2023 Antarctic austral summer, four exploratory expeditions were conducted at 36 survey locations within Antarctic waters (Figure 1). Yankee Harbour, visited during Expedition 4 in March 2023, is the focus of this paper and additional sampling metadata for this expedition can be found in the Supplementary Materials. Deployment sites were chosen opportunistically alongside the vessel's tourism operations, when and where the sampling vessel could safely anchor or drift

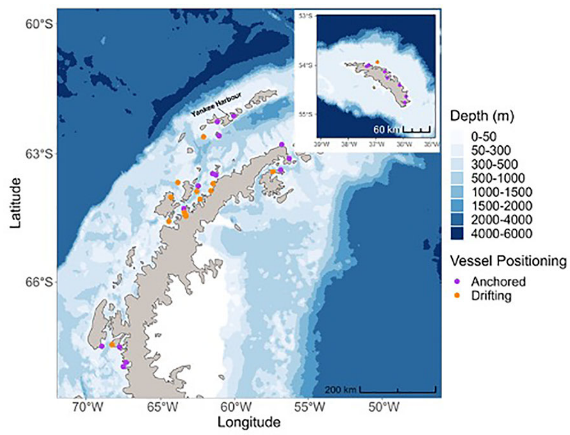

FIGURE 1
Sampling stations in the Antarctic Peninsula and South Georgia Island during the 2022–2023 Antarctic summer season showing anchored and drifting surveys.

(Graham et al., 2024). At these sites, a camera was lowered from a pilot door on the side of the ship using an electric winch and fibre optic tether, allowing the researchers to use a live feed onboard. Camera deployments were recorded from the surface, midwater, and one meter above the seafloor. Video was captured using a SubC Imaging 4K Deep Water Rayfin camera (1920 x 1080 pixels, 30 fps). The lighting system used were two Aquorea mk3 LED lights (15000 lumens) mounted on a SubC Imaging Towed Camera System. Lasers were not used during this survey, leading to a lack of precise scaling in our findings, but based on the distance from the seafloor the height of the image frame is estimated at less than $3m^2$ (Nakajima et al., 2014). Observations of disturbance to the seafloor and benthic organism sightings were noted on sampling sheets in the field, and extracted from the videos using a screen grab. Visual species identifications to the lowest taxonomic level we felt confident in were made using the "Underwater Field Guide to Ross Island & McMurdo Sound, Antarctica" (Brueggeman and Wu, 2023) and cross-checked taxonomic labels against the World Register of Marine Species (WoRMS, https://www.marinespecies.org/index.php), which provided the most recent authoritative classifications. No macrofaunal samples were collected, leading to some uncertainty at the species level, but fair reliability at the family level (Misiuk and Brown, 2024; Bowden et al., 2020). Although seafloor imaging reveals soft sediment, the lack of physical sediment sampling or sonar data makes validating the dominant seafloor type not possible at this time.

After the field season, Automatic Identification System (AIS) data were captured from Yankee Harbour to compare the spatial extent of anchoring and vessel traffic over one month in the 2023 summer season (1-31st March). AIS data were obtained from Starboard Maritime Intelligence (2023) at 12 minute intervals. Vessels operating at <1 knot speed and clustering within a 100 m radius were assumed to be anchored in accordance with previous literature (Deter et al., 2017; Watson et al., 2022).

Results

Seafloor observations

Multiple disturbances to the seafloor were observed during the survey conducted at Yankee Harbour. Clear striations and grooves were visible where the substrate was physically disturbed and a lack of marine life was evident compared to the surrounding non-anchored area (Figure 2). Of note was a crushed cactus sponge colony, likely *Dendrilla antarctica* (Brueggeman and Wu, 2023) (Figure 2f). Deposited substrate from the anchor or chain returning to the surface was also clearly defined (Figure 2d). Some mobile animals had reinhabited the area including brittle stars and snails, so the timing and source of the anchor damage is unclear, as it appears to have possibly occurred during a previous event.

The observed seafloor disruptions are presumed to be caused by anchor and chain damage and not iceberg scouring for the following reasons: the presence of nearby slow-growing species of sponge colonies unaffected by iceberg scouring (Figures 2g, f), the

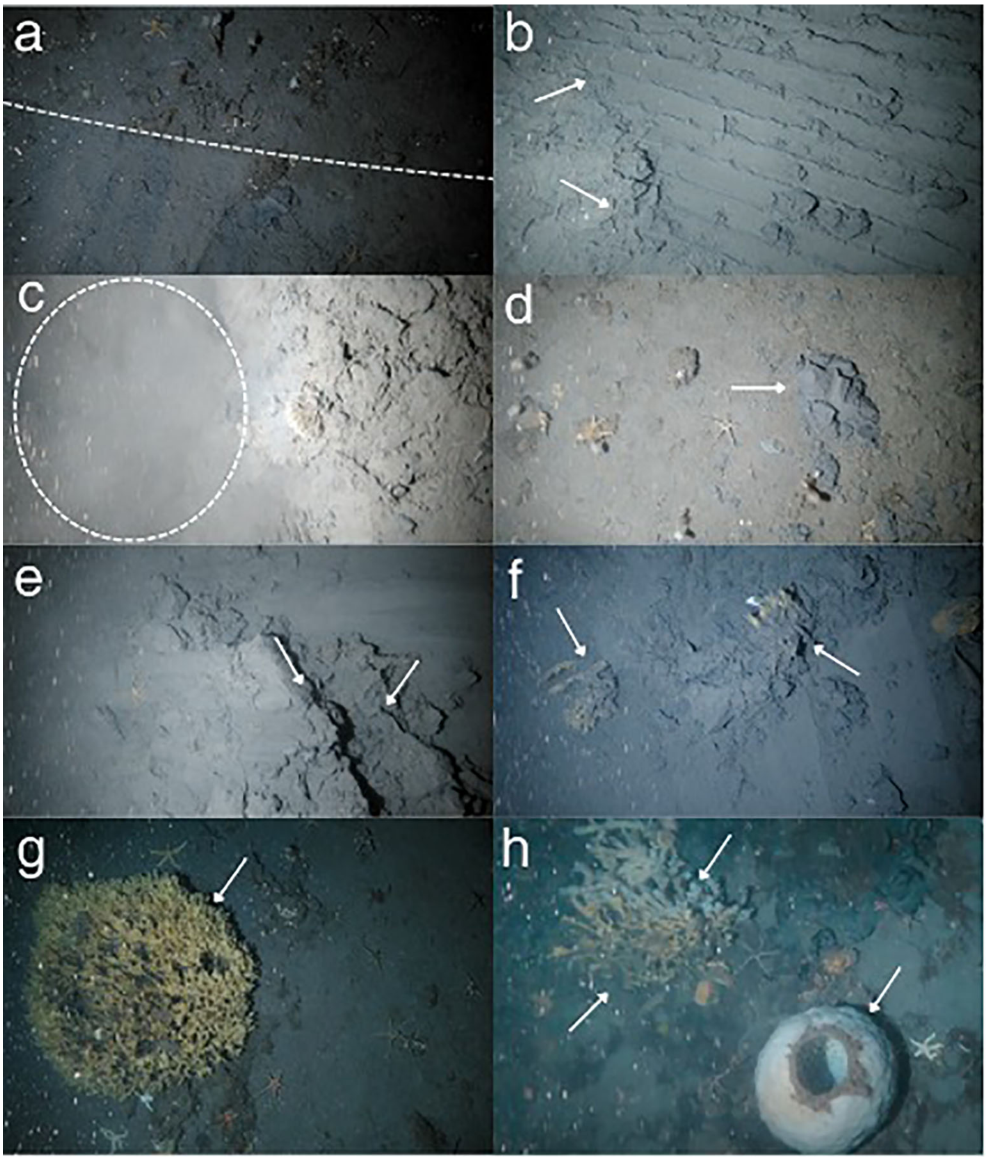

FIGURE 2
Anchor and chain damage at Yankee Harbour, Antarctica along with nearby healthy ecosystems. **(a)** Anchor chain disturbance (bottom half of image) next to undisturbed marine life (top half of image). **(b)** Arrows pointing to striations caused by lateral anchor chain movement showing a change in surface sediment structure, and removal of the upper sediment layer. **(c)** Resuspended sediment plume associated with recent anchoring shown in dashed outline. **(d)** Arrow pointing to muddy substrate redeposited onto the surrounding seabed from the anchor or chain return to the surface. **(e)** Arrows indicating disturbed soft sediment due to anchor and chain contact with the seabed. **(f)** Physically disturbed and smothered sponge colonies (likely cactus sponge *Dendrilla antarctica*) denoted by arrows. **(g)** Healthy sponge colony and marine life near damaged sites. **(h)** Giant volcano sponge *Anoxycalyx joubini* (1 of 3 sighted at this location) and other undisturbed sponge colonies discovered during the Yankee Harbour survey.

convex and uniform shape of the striations on the seafloor match the shape of a chain (Figures 2a, b, f), observations of deposited substrate suspected from the anchor or chain retrieval were found outside of the impact area and differs from surrounding seafloor terrain (Figure 2d), and the disturbance was observed at 70 m depth, with previous studies showing the majority of iceberg scouring under five meters depth and decreasing in frequency by 25 m depth (Barnes, 2017).

Nearby to the impacted area, marine life was present on the seafloor including three Giant volcano sponges *(Anoxycalyx joubini)*, which can reach 1–2 meters in height (Dayton et al., 2013). Giant volcano sponges are believed to be the oldest animals on the planet possibly reaching 15,000 years of age (Gatti, 2002). One such sponge had several crinoids on its rim filter feeding, and a notothenioid fish inside the sponge taking shelter (Supplementary Materials). Commonly observed species found on the seafloor during the 36 surveys around the Antarctic Peninsula and South Georgia Island while anchored or at anchorable depths included Antarctic sun stars (*Labidiaster annulatus)*, crinoids (*Heliometra glacialis)*, soft corals and sea fans *(Octocorallia)*, brittle stars *(Ophiuroidea)*, Giant Antarctic octopus (*Megaleledone Setebos)*, notothenioid fish *(Notothenioidei)*, dragonfish (*Bathydraconidae)*, icefish *(Channichthyidae)*, snails *(Margarella* *antarctica)*, sea squirts *(Ascidiacea)*, Antarctic scallops *(Adamussium colbecki)*, and sea spiders (*Pycnogonidae)* (Brueggeman and Wu, 2023). *In situ* observations of these species can be found in the Supplementary Materials.

AIS ship tracking data

AIS ship tracking data from the month of March 2023 within Yankee Harbour show extensive vessel traffic and potential anchoring activity in the late summer season (Figure 3). A total of eight passenger vessels were documented at low speeds for extended durations within Yankee Harbour during March 2023, manifesting as clusters of AIS points. AIS clusters are interpreted as vessels on anchor (Deter et al., 2017; Watson et al., 2022). A database recording anchoring activity from the ship operators is needed to verify the vessels on anchor, but the AIS results show the maximum amount of potential anchor activity in that month. Conversely, when vessels are at speed, the AIS data points are more sparsely spread out (e.g. as they are approaching or departing the anchorage; Figure 3). The eight vessels ranged from 73–164 m in length, and this analysis did not include zodiac or smaller support boats. If all eight vessels were anchored within the ~30–40 m water depth at Yankee Harbour, we would expect each vessel to deploy between 150–200 m of anchor chain onto the seabed (where chain is paid out at five times water depth; Davis et al., 2016). Within the month of March alone, the minimum impacted seabed due to eight anchoring events is 1,600 m, which does not account for any vessel swing or movement of the ship whilst on anchor.

Discussion

This study provides the first documented video imagery of anchor and chain damage on the seabed in Antarctica. Observed at Yankee Harbour in the Antarctic Peninsula were striations from a chain, scour marks from an anchor, resuspended sediment in the bottom waters, and deposited mud from the anchor or chains' return to the surface. There were crushed sponge colonies and a lack of benthic biomass observed in the disturbed areas. The damaged areas were contrasted by an abundance of marine life nearby including sponge colonies, sea squirts, worms, fish, sea stars, and other invertebrates.

During the 35 exploratory surveys conducted outside of Yankee Harbour in 2023, many species of benthos were documented in the Antarctic Peninsula and South Georgia Island while anchored or at anchorable depths which could be threatened by anchoring activity.

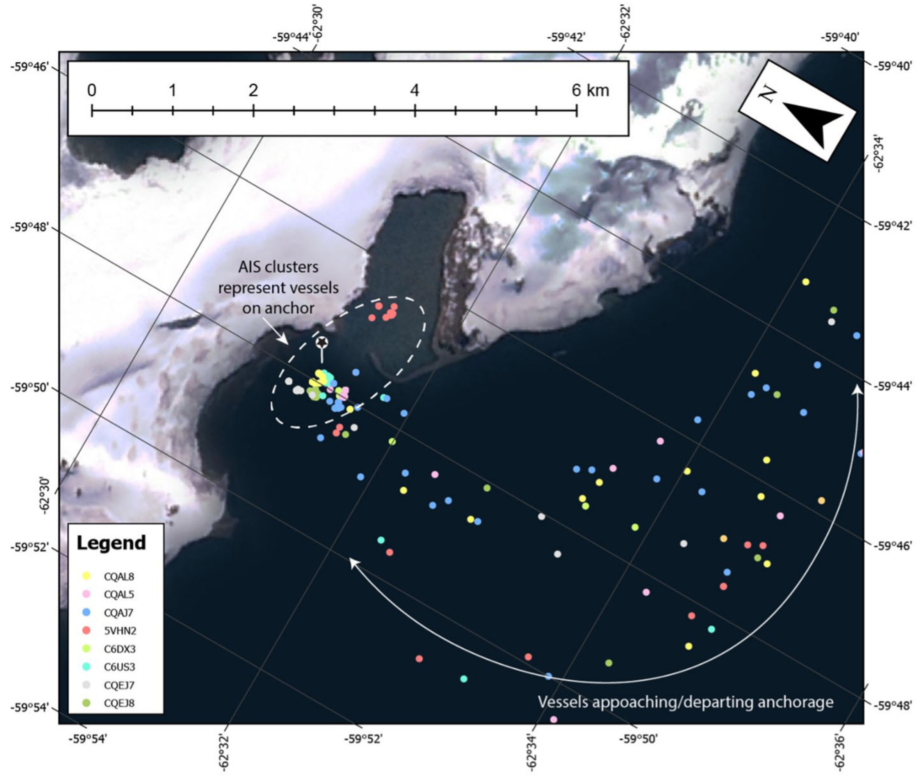

FIGURE 3
Vessels approaching and at anchor in Yankee Harbour, Antarctica. Coloured dots show AIS data for eight vessels over the month of March 2023, obtained from Starboard Maritime Intelligence. The call sign for each vessel is shown in the legend. Clustering AIS is interpreted to be vessels on anchor within the shallower harbour region, delineated by dashed circle. Vessels approaching and departing the anchorage area shown by more sparsely spaced AIS points. The black star represents the location of video footage shown in this study. Background imagery is from Esri, Maxar, Earthstar Geographics and the GIS user community.

These organisms are largely endemic, slow growing, and many are sessile, increasing their vulnerability to human disturbance. Given the estimated duration of recovery observed in sessile invertebrates in non-polar settings, some of these ecosystems may not recover for decades. Multiple species of volcano sponges and pockets of rich biodiversity were found throughout the Antarctica Peninsula at Yankee Harbour, Neko Harbour, Lapeyrere Bay, Bongrain Point, Damoy Point, Brialmont Cove, and near the Stromness Whaling Station in South Georgia Island. The authors recommend that these areas be considered for enhanced protection.

The extent of damage caused by anchoring in Antarctica is unknown, and many basic questions remain such as how many anchoring events are occurring each year and at what locations. AIS data presented in this study at one site over one month in 2023, provides insights into the volume of vessel traffic and anchoring events. If the number of anchoring events in March 2023 are representative of the Antarctic tourism season (November through March), the seabed in Yankee Harbour could be impacted by 40 anchoring events each season. Anchor damage should be better quantified, and regulations should be developed to avoid direct harm to Antarctic benthic species which are protected by the Antarctic Treaty. Anchor regulations for Antarctica can be established through groups like the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the International Association of Antarctic Tour Operators (IAATO), as well as by individual vessel operators and trip leaders involved in scientific research, commercial tourism, private yacht trips, or fishing. In November to December when sea ice is more prevalent, vessels in Antarctica anchor much less often because the presence of sea ice forces ships to operate in deeper waters beyond anchorable depths, demonstrating that operations can occur safely without anchoring. Most ships can now employ DPS to remain in a fixed location, a significant advancement over anchoring. Ships will still drift from the wind and currents while at anchor and must avoid larger icebergs. Anchored vessels still use fuel to run auxiliary engines to power electricity, and vessels in Antarctica may keep some engines running to power thrusters to avoid ice.

To understand the scope of anchoring impacts from Antarctic operations the authors recommend the following actions; (1) creating a database to record the total amount of anchorages each season per site, using AIS data and activity logs from ship operators when possible (2) estimating the spatial scope of the areas impacted by chains using positional data from ships that are anchored, (3) identifying additional sites with anchor and chain damage, (4) investigating the recovery of disturbed habitats over time, and (5) estimating the number of habitats and animals that are being disturbed. The authors also recommend the following actions to mitigate harm from anchoring in the region; (A) identifying nearshore vulnerable marine environments (VMEs) with high biodiversity and fragile species where anchoring would be off limits (Beeden et al., 2014; Davis et al., 2016; Broad et al., 2020), (B) establishing permanent or seasonal subsurface moorings at frequently used sites, or creating specific 'parking lot' areas where anchoring is permitted (Davis et al., 2016; Steele et al., 2017; Broad et al., 2020; Forrester, 2020), (C) replacing anchoring in favour of drifting or dynamic positioning (Broad et al., 2020; Davis et al., 2022), (D) restricting anchoring during short vessel stops (three hours or less) to limit the total amount of anchorages that occur (U.S. Coast Guard, 2008; Transport Canada, 2024).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

MM: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. MG: Data curation, Methodology, Visualization, Writing – original draft, Writing – review & editing. JH: Data curation, Methodology, Writing – original draft, Writing – review & editing. SW: Formal analysis, Funding acquisition, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcosc.2025.1500652/full#supplementary-material

SUPPLEMENTARY TABLE 1
Sites sampled in Antarctic waters during Expedition 4 in March 2023. Positioning here refers to the vessel's motion at time of sampling, either Anchored or Drifting (drifting using dynamic positioning).

SUPPLEMENTARY FIGURE 1
Examples of benthos observed during four Antarctic expeditions which may be at risk of direct harm or ecosystem changes due to anchor damage and chain scouring. **(a)** Tunicates, **(b)** Antarctic sunstar, **(c)** Dragonfish and hydroids, **(d)** Sea spider **(e)** Rock reef including bryozoa, anemone, sponges, sea stars, brittle stars, and notothenioid fish, **(f)** Giant volcano sponge and crinoids, with notothenioid fish inside.

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