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Breeding bird species richness and sensitivity to disturbance at Antarctic visitor sites

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SUMMARY

Tourism in Antarctica is increasing rapidly and is concentrated predominantly in ice-free areas in the Antarctic Peninsula region, an area that holds globally important colonies of breeding birds. Since 2005, the Antarctic Treaty Consultative Meeting (ATCM), which provides governance for the continent, has developed Visitor Site Guidelines that detail practical information for visitor management. In parallel, the ATCM has worked to develop methods to assess site sensitivity to inform visitor site management, but none have been formally agreed. With the expansion of tourism operations, there is an urgent need for site-specific information to enable policymakers to minimize disturbance at visitor sites, particularly to breeding seabirds. Responding to this need, we assessed the sensitivity of bird species known to breed at each landing site with ATCM Visitor Site Guidelines. We collated available data on breeding cycles for each site, identifying the most sensitive periods for individual bird species. The information was combined to determine species richness and the periods of heightened sensitivity to disturbance overall and for each visitor site. Our data showed that the most sensitive bird breeding stages overlapped with the summer peak in tourist landings at visitor sites. We recommend that these site-specific data be used to refine tourism management by the ATCM, including revision of existing and development of new Visitor Site Guidelines. Future studies could help improve sensitivity assessment by collecting data on distribution and numbers of breeding birds and hauled-out seals within visited areas, and carrying out cross-species comparisons of effects of disturbance.

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Research article

Breeding bird species richness and sensitivity to disturbance at Antarctic visitor sites

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ABSTRACT

Tourism in Antarctica is increasing rapidly and is concentrated predominantly in ice-free areas in the Antarctic Peninsula region, an area that holds globally important colonies of breeding birds. Since 2005, the Antarctic Treaty Consultative Meeting (ATCM), which provides governance for the continent, has developed Visitor Site Guidelines that detail practical information for visitor management. In parallel, the ATCM has worked to develop methods to assess site sensitivity to inform visitor site management, but none have been formally agreed. With the expansion of tourism operations, there is an urgent need for site-specific information to enable policymakers to minimize disturbance at visitor sites, particularly to breeding seabirds. Responding to this need, we assessed the sensitivity of bird species known to breed at each landing site with ATCM Visitor Site Guidelines. We collated available data on breeding cycles for each site, identifying the most sensitive periods for individual bird species. The information was combined to determine species richness and the periods of heightened sensitivity to disturbance overall and for each visitor site. Our data showed that the most sensitive bird breeding stages overlapped with the summer peak in tourist landings at visitor sites. We recommend that these site-specific data be used to refine tourism management by the ATCM, including revision of existing and development of new Visitor Site Guidelines. Future studies could help improve sensitivity assessment by collecting data on distribution and numbers of breeding birds and hauled-out seals within visited areas, and carrying out cross-species comparisons of effects of disturbance.

1. Introduction

Tourism within the Antarctic Treaty area is increasing and diversifying (Liggett et al., 2023). According to Headland (1994), the earliest Antarctic tourism expeditions date back to the 1930s, with later tourist trips organised by Argentina and Chile in the 1950s. However, it was only from 1966 that commercial tourism became increasingly popular (Bauer, 2001). Tourism has experienced a ten-fold increase over the past two decades, with around 75 tourist vessels and over 122,000 tourists visiting the Antarctic Treaty area during the 2023/24 summer season (IAATO, 2024a). The number of visitor sites has continued to increase, as has the length of the tourism season and the diversity of modalities and activities on offer (Bastmeijer et al., 2023; Makanse, 2024). Currently, there are six Antarctic tourism modalities: (1) cruise ship with landings on the Antarctic Peninsula, (2) cruise-ship-only, (3) cruise ship with landings in the Ross Sea and Antarctic continent, (4) air-cruise (either one way or two ways by air) with landings on the Antarctic Peninsula, (5) deep-field expeditions, and (6) yacht tourism (IAATO, 2024a). Except for cruise ship-only modality and scenic flight-only operations, all modalities involve the landing of tourists at visitor sites for activities including, but not limited to, the observation of wildlife (including birds and marine mammals), extended walks, photography, and visits to historic buildings and monuments. In the case of deep-field expeditions, activities could also include ski traverses to the South Pole, camping, ice climbing, and visits to remote emperor penguin, *Aptenodytes forsteri,* colonies, among others (Makanse, 2024).

Spatially, tourism is concentrated mainly around the northern and western Antarctic Peninsula and the South Shetland Islands (Fig. 1), although there are also visits to other areas, including the South Orkney Islands and the Ross Sea region (ATS, 2025a; IAATO, 2024a). According to data provided by the International Association of Antarctica Tour

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Acronyms

AT	Antarctic Treaty
ATCM	Antarctic Treaty Consultative Meeting
ATCPs	Antarctic Treaty Consultative Parties
ATS	Antarctic Treaty System
CEP	Committee for Environmental Protection
IAATO	International Association of Antarctica Tour Operators
NAPs	National Antarctic Programmes
SCAR	Scientific Committee on Antarctic Research
VSGs	Visitor Site Guidelines

Operators (IAATO), which advocates and promotes safe and environmentally responsible travel to Antarctica, 80 % of the landings and activities occurred at just 27 sites (13.6 %) out of the total of 199 sites that were visited at least once during the most recent 2023/24 season (IAATO, 2024a) (Fig. 1). This pattern of high visitation at relatively few sites has been consistent over at least the past decade. During the 2012/13 season, 76.6 % of all landings were at 25 sites, covering a total land area of just ~2 km^2 in the northwest Antarctic Peninsula and South Shetland Islands (Bender et al., 2016). Nevertheless, there are now far more landings at locations that used to be visited rarely, and there is increasing pressure from tour operators to visit new sites that may deliver extra opportunities for exploration or novel adventure and other activities (Senigaglia et al., 2025). Climate change is providing

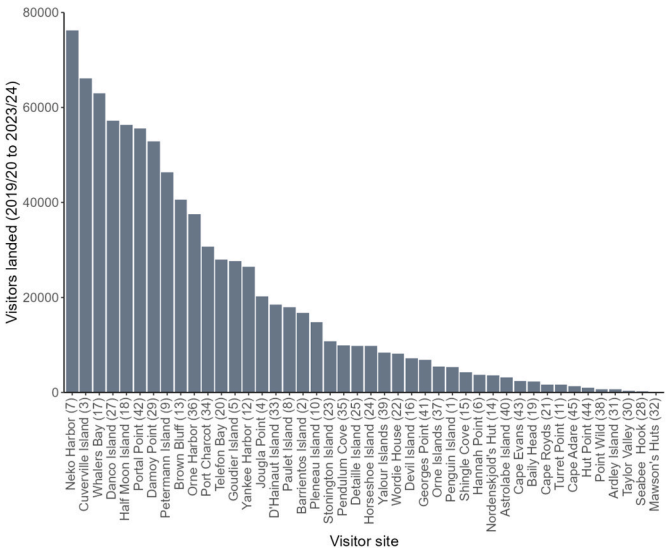

Fig. 2. Overview of Antarctic visitor numbers at sites with ATCM adopted visitor site guidelines from seasons 2019/20 to 2023/24. Total number of visitors landed for the most recent five tourism seasons (2019/20 to 2023/24) at each of the 44 sites with Antarctic Treaty Consultative Meeting (ATCM) site guidelines. The visitor site numbers, shown on the x-axis, match those provided in Fig. 1.

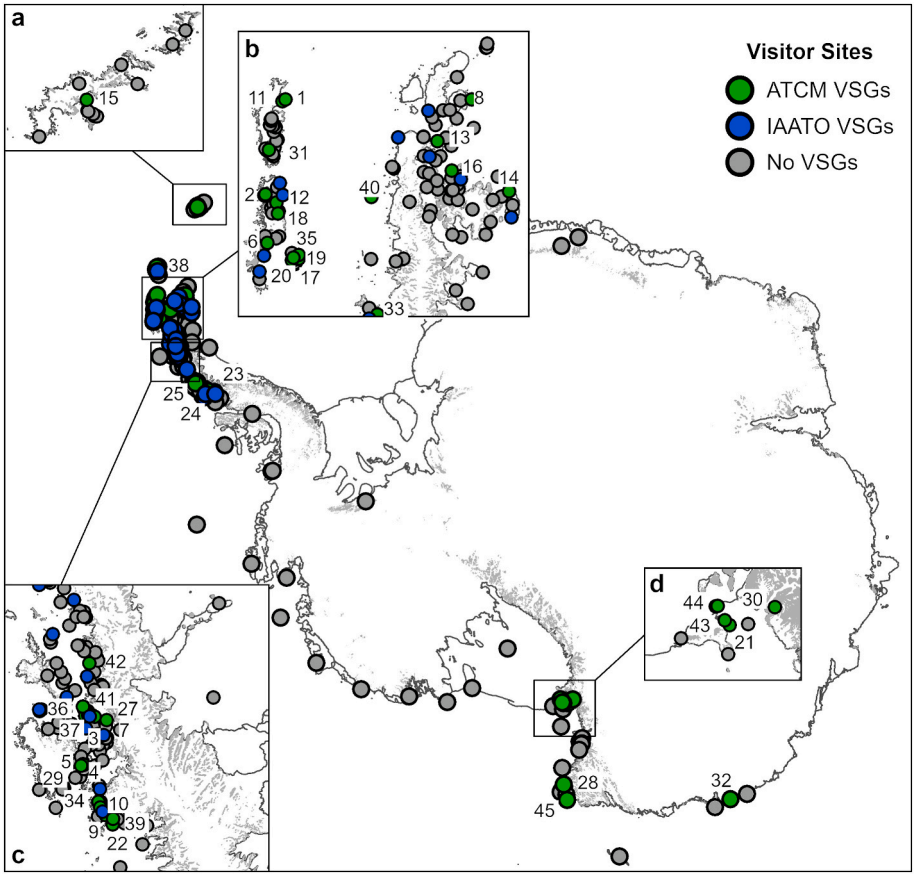

Fig. 1. Overview of Antarctic visitor sites from seasons 2019/20 to 2023/24. Map of visitor sites in Antarctica highlighting sites that have Visitor Site Guidelines adopted by the Antarctic Treaty Consultative Meeting (ATCM); sites with Visitor Site Guidelines adopted only by the International Association of Antarctica Tour Operators (IAATO); and sites that have no currently adopted Visitor Site Guidelines. Site identification numbers assigned by the ATCM are provided for sites with Visitor Site Guidelines adopted by the ATCM (see Fig. 2 for more details). Insets are provided for a) the South Orkney Islands, b) the northern Antarctic Peninsula and South Shetland Islands, c) the Danco Coast, and d) the southern Ross Sea region.

opportunities to visit previously inaccessible areas by accelerating glacier loss, reducing sea-ice extent, and advancing the timing of ice break-up (Chown and Brooks, 2019; Lee, 2019; Norway, and the United Kingdom, 2024). This has potentially major consequences for the environment as, with the increase in tourist landings and the amelioration of climatic conditions on the Antarctic Peninsula, there are higher risks of transfer and subsequent establishment of non-native species, pollutants and pathogens, and of disturbance to native wildlife and isolated terrestrial communities that have evolved thus far without any human contact (Tin et al., 2009; Chown et al., 2022; Hughes et al., 2025).

Antarctica is managed under the regime established by the Antarctic Treaty which has expanded into the Antarctic Treaty System (ATS) (Convey et al., 2012; Hughes et al., 2023). Due to the emergence of tourism activities, IAATO, established in 1991, has served as the principal member organization responsible for the self-regulation of the Antarctic tourism industry (IAATO, 2025). Hence, tourism operations have been managed primarily through self-regulatory mechanisms based on the principles and bylaws established by IAATO, a key participant within ATCMs as an Invited Expert (Bastmeijer and Lamers, 2013; Hughes et al., 2023).

Over time, IAATO has developed a series of protocols, Visitor Sites Guidelines, and codes of conduct, some of which have been formally adopted by the Antarctic Treaty Consultative Parties (ATCPs). Currently, the formal ATS management instruments applicable to Antarctic tourism activities include environmental impact assessments, post-visit reports, general guidelines for visitors (e.g., restricting the number of people onshore at any one time), and some Visitor Site Guidelines, which were co-developed with IAATO (Bastmeijer and Roura, 2008).

Visitor Site Guidelines provide tour operators, national Antarctic programmes and tourists with general guidance on how to conduct visits at specific sites. Most Visitor Site Guidelines contain guidance concerning permitted activities, walking areas, closed areas, landing zones, and viewing distances to wildlife, while accounting for site conditions, safety considerations, and underscoring the environmental values associated with the site (ATS, 2025b; Cajiao et al., 2021). Currently, a total of 44 Visitor Site Guidelines have been formally adopted through Resolutions at ATCMs. A further 27 Visitor Site Guidelines have been developed by IAATO, which encourages its members to adhere to them, and where they serve as standards for site management at locations where ATCM Visitor Site Guidelines are not yet in place (IAATO, 2024b). Despite this, there have been calls from policymakers and the scientific community for site-specific and species-specific assessments to be undertaken at all current and prospective visitor sites; these should consider local environmental conditions and the sensitivity of different species throughout the year (New Zealand, 2012; Coetzee and Chown, 2016; Cajiao et al., 2022).

The need to assess sensitivity at visitor landing sites was apparent long before the recent expansion in tourism. Following detailed fieldwork, Crosbie (1999) proposed the development of mechanisms to manage site visits that take into consideration local sensitivities and also highlighted the need for individual site monitoring plans. Coetzee and Chown (2016) recommended the implementation of site-specific management measures that follow the precautionary principle to avoid disturbances to wildlife. Within the policy-making domain, the ATCPs have discussed the need to assess the sensitivity of visitor sites in light of the increase in the number of tourists and the tourism footprint. Starting in the early 2000s, there have been several attempts by ATCPs to develop sensitivity assessments through the Committee for Environmental Protection (CEP) and to include perceived sensitivity ratings in Visitor Site Guidelines for informing additional management measures, but these initiatives have since stalled (United Kingdom, 2004a; IAATO, 2005a, 2005b; Australia, New Zealand, Norway, the United Kingdom, and the United States, 2015; IAATO, 2019). Although a Resolution was adopted in 2021 to update information contained in Visitor Site Guidelines, to date, no formal sensitivity assessment methods for visitor sites have been fully developed or used by the CEP to inform policy.

As most visitor landings occur between mid-October and late March (IAATO, 2024a), there are clearly concerns around potential overlap with the breeding seasons of birds and marine mammals present at visitor sites. Our study aims to fill this knowledge gap by conducting a sensitivity assessment for many of the most popular visitor sites based on the timing of breeding of the local bird species. We focused this assessment on sites with ATCM Visitor Site Guidelines as they are the sites that host the most visitors. Our objectives were to: (1) collate data on the breeding cycles of all bird species known to breed at each visitor site; (2) identify the most sensitive periods for individual bird species at each site and produce a site-level and aggregated sensitivity scale; and (3) integrate the available data to produce an overall bird diversity index for each visitor site. The results have important implications for policy and decision-making when managing visitor sites. This is particularly timely as the ATCM recently initiated a dedicated process to develop a comprehensive framework for Antarctic tourism and other non-governmental activities (ATS, 2023).

2. Methods

We developed a database that included 41 popular sites for which the ATCM has agreed upon Visitor Site Guidelines and where birds have been recorded as breeding, suspected breeding, or present/observed only. Our database was based on the online Visitor Site Guidelines repository available on the Antarctic Treaty Secretariat website (ATS, 2025). The database did not include three sites as no bird species were recorded as breeding, suspected breeding, or present only (nos. 23 - Stonington Island, 25 - Detaille Island, and 30 - Taylor Valley). We used the IUCN Red List of Threatened Species as an indication of global conservation status of each species. We did not include marine mammals in our assessment because they were only recorded as confirmed or suspected breeders at two sites. We also included Signy Island and Anvers Island in this database, even though there are no ATCM Visitor Site Guidelines for these sites, because they were the source of comprehensive data on the timing of breeding of most bird species and are subject to increasing tourist visitation.

This made a total of 43 sites included in the database. Information on bird species present at each site was systematically extracted from the Visitor Site Guidelines. Additionally, species records within a 1 km radius of each site were retrieved from the SCAR biodiversity of ice-free Antarctica database (Terauds et al., 2025) as a means of verifying the accuracy of our initial data. All sites were categorized by subregion, i.e., South Shetland Islands, northwest Antarctic Peninsula, southwest Antarctic Peninsula, Ross Sea, and South Orkney Islands.

We determined the timing of key stages in the breeding cycle of each bird species present at each of the locations using information from species accounts in Marchant and Higgins (1990), Borboroglu and Boersma (2015), Billerman et al. (2024), peer-reviewed literature, doctoral theses and peer-reviewed reports by the British Antarctic Survey (see Supplementary Material Table 1 for details on bibliography used for each species). Timing of breeding may vary with colony location and is generally later at higher latitudes, reflecting the later timing of sea-ice retreat (which may affect access to prey or the timing of the spring phytoplankton bloom), or melting of snow or ice at nest sites (Keogan et al., 2022; Burr et al., 2016). Consequently, we collated the available information on the mean and range dates of arrival, laying, hatching, end brood-guard, and fledging. If multiple date ranges were available for a species at a given location, we reported the range encompassing most observed dates. If the data were insufficient for a given species and location, missing mean dates or ranges for laying, hatching, end brood-guard, and fledging were estimated from close sites that had data available, based on the mean durations of incubation, brood-guard, crèche (penguins only) or post-guard chick rearing (all other species). Color codes were used in the breeding cycle figures to denote different stages in the breeding cycle (pre-laying, incubation, brood-guard, and crèche/post-guard chick rearing) of each species

present at each visitor site. The timing of breeding cycles for a particular species was compared among sites and regions to determine if there were consistent differences. As this was not the case (see Results), a generalized breeding cycle was then determined for each species and assumed to apply at all sites where local data on timing were unavailable.

We calculated species richness, reflecting the number of species reported as breeding or suspected to be breeding at each site. We also scored the sensitivity of each species according to the breeding stage. High sensitivity [red] was assigned to the incubation and brood-guard stages, as eggs or young chicks can be taken by a predator or chilled if the attendant parent moves away as a result of disturbance, or trampled by visitors or other birds. Medium sensitivity [orange] was assigned to the crèche/post-guard chick-rearing stages, as chicks are mobile and relatively safe from predators even if unattended. However, there remains the risk of increased energy expenditure or regurgitation of stomach contents in response to disturbance or trampling for those well camouflaged. Low sensitivity [pale yellow] was assigned to the pre-laying period, as adults will move or otherwise tolerate short-term disturbance, and to the winter period when birds are absent from the site. For each site, we tallied the number of species in the sensitive periods each week based on their breeding schedules as a measure of their weekly sensitivity throughout the breeding season. A three-tier (star) system was used to express site-specific data availability of the information on breeding cycles for each site: one star (up to one-third of the data were site-specific), two stars (between one-third and two-thirds were site-specific), and three stars (site-specific data were available for all breeding bird species). See Supplementary Material Table 2 for details of every site assessed.

3. Results

From our initial database of 43 sites, we excluded five sites (no. 35 Pendulum Cove, no. 20 Telefon Bay, no. 44 Hut Point, no. 42 Portal Point, and no. 22 Wordie House) where bird species were reported as present/observed, but not breeding. The timing of the breeding cycle was determined for 19 bird species recorded as breeding or suspected breeding for the remaining 36 sites with Visitor Site Guidelines, and Signy Island and Anvers Island (Fig. 3). According to the IUCN Red List, with the exceptions of the emperor penguin, which is listed as Near Threatened, and the maraconi penguin, listed as Vulnerable, all species assessed in our study are categorized as Least Concern. This category does contribute to determining species priority in terms of sensitivity. Although Fig. 3 does not include sites with birds only present/observed, we acknowledge that prolonged disturbance could still be a concern for species that are present but not breeding, particularly moulting penguins which rely on stored energy reserves. This information, sensitivity periods, and availability of data on the timing of breeding are provided by site and for all species assessed in Supplementary Material Table 2.

Most of the sites, and associated breeding birds, are concentrated in

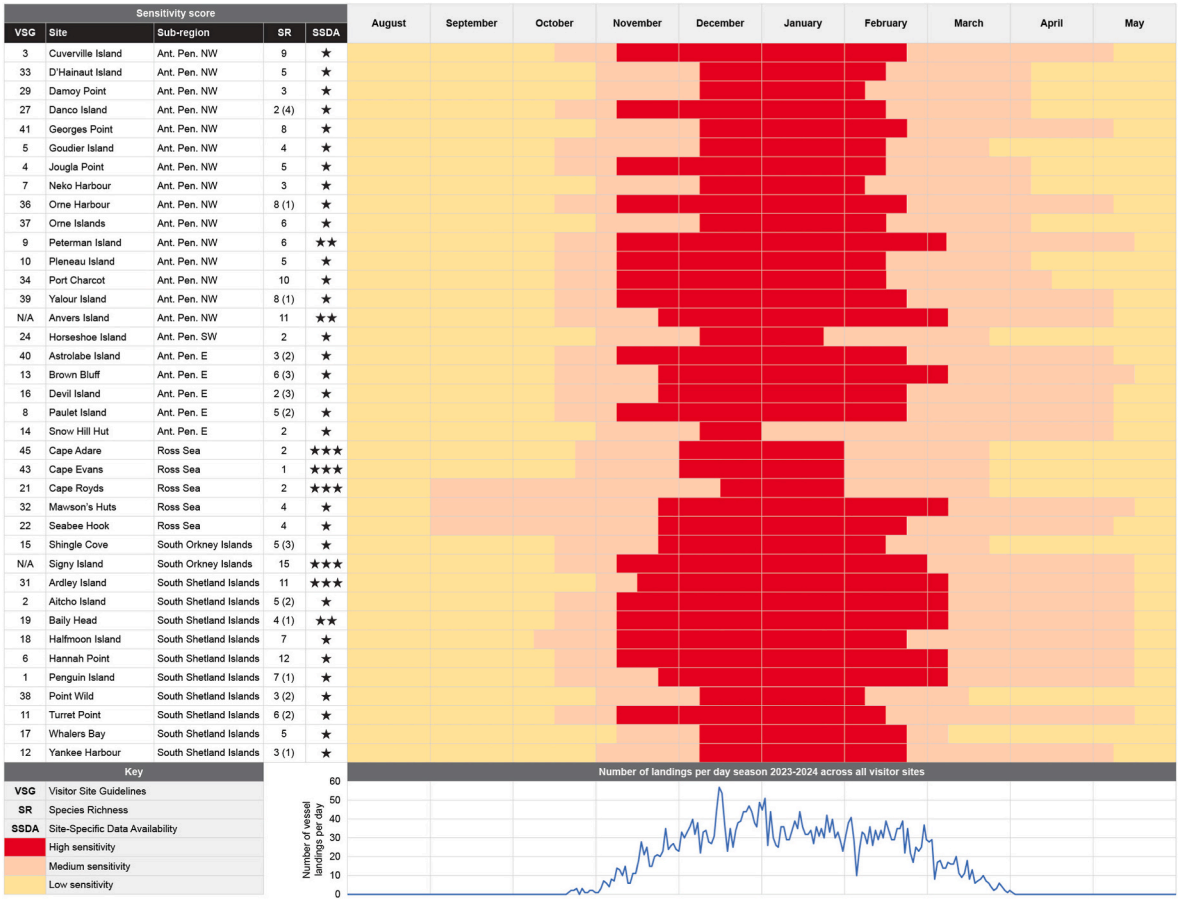

Fig. 3. Summary of the sensitivity assessment for all sites with Visitor Site Guidelines, Signy and Anvers Islands, and distribution of tourists across the season. The sensitivity score for each week reflects the most sensitive breeding stage of any breeding bird species at that site. High sensitivity [red] was assigned to the incubation and brood-guard stages; medium sensitivity [orange] was assigned to the crèche/post-guard chick-rearing stages; and low sensitivity [pale yellow] was assigned to the pre-laying period and to the winter period when birds are absent. Values in parentheses are the number of species for which breeding is suspected but not confirmed. Five sites (Pendulum Cove, Telefon Bay, Hut Point, Portal Point, and Wordie House), where the only bird species were reported as present/observed, were excluded from this figure. The linear graph shows the number of vessels landing across the Antarctic Peninsula for each day during the tourist season of 2023–2024. The vessel landing number data were available from IAATO (2024a).

the northwest Antarctic Peninsula (15 sites) and the South Shetland Islands (10 sites; Figs. 1 and 2). Together, these two regions represent 66 % of the total sites assessed (38 sites). Species richness ranged from one to 15 species (median 6), with the highest value (15) corresponding to Signy Island in the South Orkney Islands and the lowest value (1) found at Cape Evans (in the Ross Sea). A total of ten species were recorded as suspected breeders, distributed across 14 sites. The median number of visitor sites where each species was recorded as suspected breeders was two (range one to four).

The most widespread species were the kelp gull *Larus dominicanus*, brown skua *Stercorarius antarcticus* and Wilson's storm petrel *Oceanites oceanicus*, which were recorded as breeding or suspected breeders at 28, 27 and 22 sites, respectively. The least widespread were the Antarctic prion *Pachyptila desolata*, South Georgia shag *Leucocarbo georgianus* and macaroni penguin *Eudyptes chrysolophus*, which were each found at only 1–2 sites.

Timing of breeding varied considerably among species. The Antarctic tern *Sterna vittata,* kelp gull *Larus dominicanus*, and Adélie penguin *Pygoscelis adeliae* arrive early, although they do not necessarily lay eggs early. Cape petrel *Daption capense*, snow petrel *Pagodroma nivea,* black-bellied storm petrel *Fregetta tropica,* and southern fulmar *Fulmarus glacialoides* arrive and lay the latest. The breeding cycles of many bird species broadly overlapped; incubation is often in mid-November to the end of December, brood-guard in January, and crèche/post-guard chick-rearing in February to mid-March. The clear exception was the emperor penguin, whose incubation and brood guard are from May to mid-August. However, the emperor penguin was only recorded as present/observed at four sites. Regional differences in breeding schedules within species were minor (<2 weeks), with the greatest variability seen in the gentoo penguin *Pygoscelis papua*. Fig. 4 presents an example of the breeding cycle of brown skuas and gentoo penguins across sites.

Data on the timing of breeding were often unavailable for specific visitor sites. Site-specific data for all breeding species were available for just four visitor sites and Signy Island, and for two-thirds of breeding species at only two further visitor sites and Anvers Island. There were no site-specific data for the remaining 30 visitor sites; hence, the generalized breeding cycles applicable to different sub-regions were assumed to apply. Examples that illustrate the varying levels of data availability are Signy Island, where bird research has been undertaken for several decades. However, tourist visits are rare compared to other visitor sites. Cuverville Island, which is the second most visited site, has no site-specific data on bird breeding schedules (Fig. 5).

Fig. 4. Breeding cycles of the gentoo penguin *Pygoscelis papua* and brown skua *Stercorarius antarcticus* across different visitor sites. The gentoo penguin exhibits the greatest variability in breeding schedule, and the brown skua is one of the most widespread species across the visitor sites. The timings are based on site-specific data for gentoo penguins at Ardley Island, Goudier Island, Peterman Island, Port Charcot, and Signy Island, and brown skuas at Ardley Island, Baily Head, Signy Island, and Whalers Bay, and on the generalized cycle for all other sites.

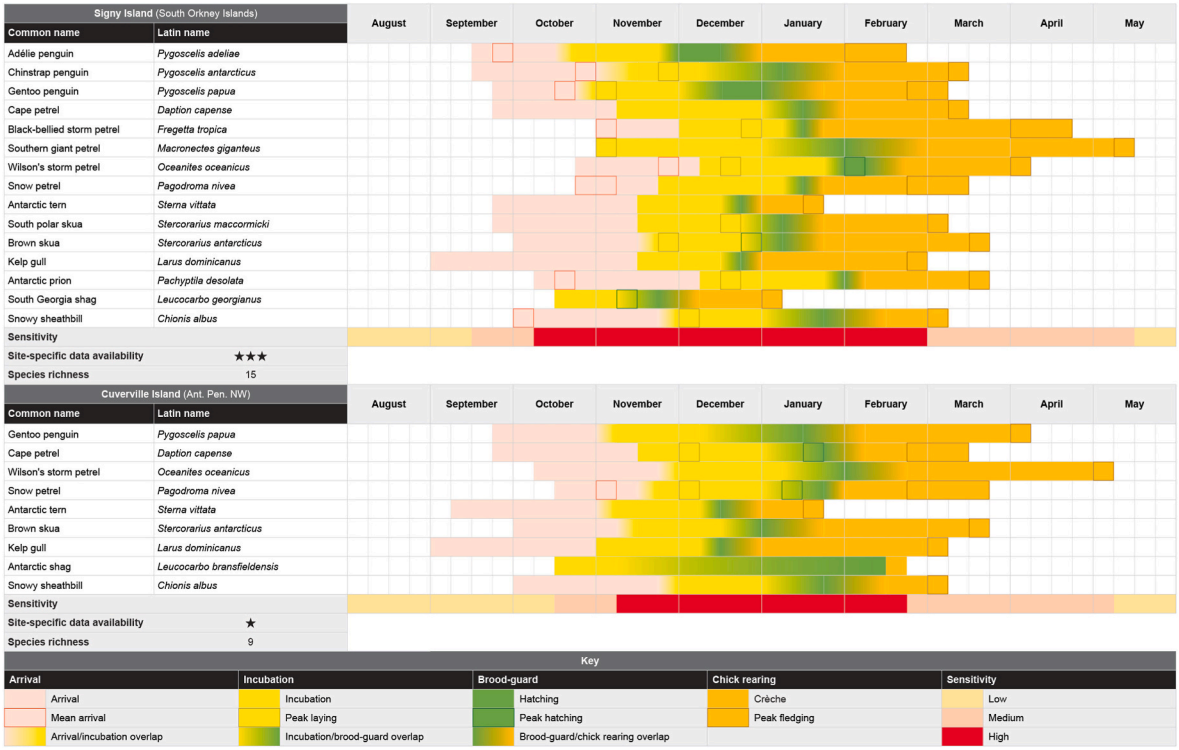

Fig. 5. Example bird sensitivity assessments for Signy Island and Cuverville Island, with differing levels of data available on the timing of breeding. The sensitivity score for each week reflects the most sensitive breeding stage of any breeding bird species at that site where high sensitivity [red] was assigned to the incubation and brood-guard stages; medium sensitivity [orange] was assigned to the crèche/post-guard chick-rearing stages; and low sensitivity [pale yellow] was assigned to the pre-laying period and to the winter period when birds are absent. Species richness reflects the number of species reported breeding or suspected breeding at each site. A three-tier (star) system was used to express the level of availability of site-specific information on breeding cycles for each site: one star (up to one-third of the data were site-specific), two stars (between one-third and two-thirds were site-specific), and three stars (site-specific data were available for all breeding bird species).

4. Discussion

We aimed to assess the sensitivity of breeding birds at some of the most-visited tourist sites in the Antarctic to inform current discussions and the development of a more robust framework for managing and regulating Antarctic tourism. Even though Visitor Site Guidelines have been recognized as a valuable tool among ATCPs and practitioners (New Zealand, 2012), there is a clear need for tailored guidance for specific sites that takes into consideration the variation in sensitivity and vulnerability of wildlife throughout the season, local topography and the distribution of breeding birds at each site as this can affect assessments and guidelines (Crosbie, 1999; Coetzee and Chown, 2016).

4.1. Visitor site guidelines and sensitivity assessments

The adoption of new Visitor Site Guidelines by the ATCM and the tourism industry has been a slow process despite concerns about the rapid pace with which tourism has grown, its diversification, and its expansion to more localities that may also be assisted by the effects of climate change (Lee, 2019; Makanse, 2024). The need for formal visitor guidance was first proposed to the ATCM in a paper tabled by the United States in 1991, which included the first *Guidelines for Tour Operators and Tourists* (United States, 1991). Despite the formal adoption of the general *Guidance for Visitors to the Antarctic* in 1994, it was not until 2003 that IAATO presented to the ATCM the first Visitor Site Guidelines that they developed for the 33 most visited sites (IAATO, 2003), and only in 2005 were the first set of Visitor Site Guidelines formally adopted by the ATCM. Notably, the adoption of the first ATCM Visitor Site Guidelines in 2005 (see Fig. 6) coincided with a period of rapid growth in Antarctic tourist numbers. In a proactive effort, in 2008, IAATO introduced its first

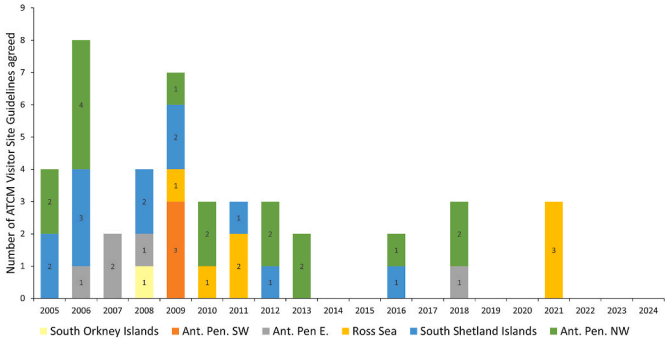

Fig. 6. Visitor Site Guidelines adopted by the ATCM by year and region. Information extracted from the final reports of ATCM meetings from 2005 to 2024.

version of Visitor Site Guidelines to include visitor sites that did not yet have Visitor Site Guidelines approved by the ATCM. Despite the 44 ATCM Visitor Site Guidelines and the further 27 IAATO Visitor Site Guidelines in use, the pace of adoption of new ATCM Visitor Site Guidelines has slowed (36 in 2005–2013, cf. eight in 2014–2024). Furthermore, despite tourist numbers continuing to grow, exceeding 100,000 for the first time during the 2022/23 season, no new ATCM Visitor Site Guidelines have been adopted as of 2021. It is unclear what factors may have stymied progress in recent years, although repercussions from the COVID-19 pandemic may have played a part (Liggett et al., 2024).

The 33 draft Visitor Site Guidelines originally proposed by IAATO in 2003 (Fig. 7) included a site sensitivity rating that was based on

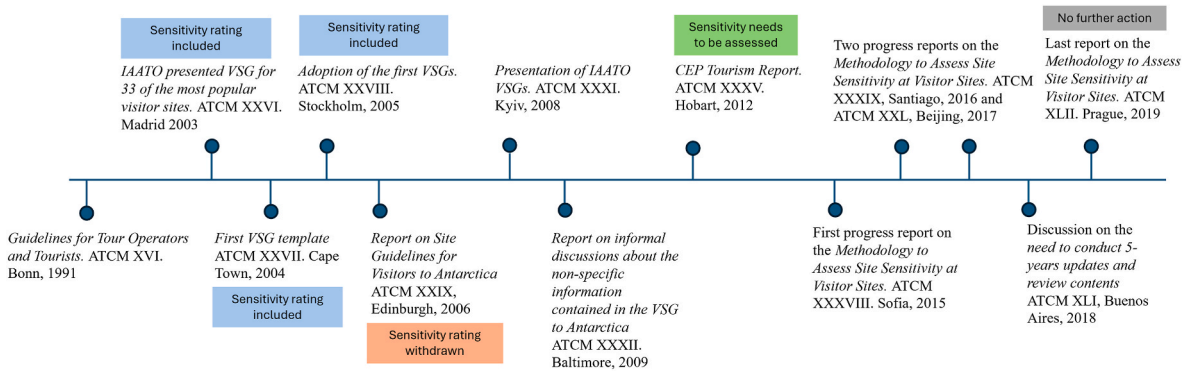

Fig. 7. Timeline of adoption of Visitor Site Guidelines (VSGs) and discussions on site sensitivity assessments. Information extracted from the final reports of ATCM meetings from 1991 to 2024.

biodiversity values, potential impacts, and availability of space to walk. Each site was assigned an environmental sensitivity rating (low, medium, or high). The criteria for ranking sites focused on species diversity, potential impacts of visitors to flora and fauna, and the amount of available space in which visitors could walk (IAATO, 2003). A perceived sensitivity rating (low, medium, or high) was formally proposed in 2004 by ATCPs and was adopted along with the first ATCM Visitor Site Guidelines in 2005; however, it was not clear if a systematic method was used to arrive at this rating system (IAATO, 2005a). In 2006, following the convening of a CEP Intersessional Contact Group on *Site Guidelines for Visitors to Antarctica*, the CEP introduced a new format for Visitor Site Guidelines with shorter descriptions that eliminated the sensitivity rating that had been applied previously (United Kingdom, 2004b).

The topic of sensitivity and Visitor Site Guidelines resurfaced at ATCM XXXV (2012) with the report on *Tourism and Non-governmental Activities in the Antarctic: Environmental Aspects and Impacts* (New Zealand, 2012) The report recommended the development of a method for assessing the relative sensitivity of each visitor site in order to assess appropriate management needs. In response, at ATCM XXXVIII (2015), several ATCPs presented the first progress report on a *Methodology to Assess Site Sensitivity at Visitor Sites* that included the results of an expert survey on a sensitivity assessment for sites with Visitor Site Guidelines (Australia et al., 2015). Of all risks assessed (e.g., vegetation trampling, fuel leaks, litter, noise pollution, and ground compaction), disturbance of seabirds was identified as contributing the most to site sensitivity for a number of visitor sites (e.g., Hannah Point, Aitcho Island, Paulet Island). At ATCM XXXIX (2016) and ATCM XL (2017), two reports introduced a methodology for sensitivity assessment based on expert judgment. The most recent report on this topic was tabled to the ATCM in 2019, and it proposed a methodology that encouraged the use of expert judgment to assess variation in site characteristics through the season and the sensitivity of species at different life cycle stages. No further progress has been made, and the proposed methodology has yet to be adopted as a formal means of assessment. In 2021, Resolution 4 was adopted, including an annex containing a "Site Guidelines for Visitors Checklist" to update information about Visitor Site Guidelines. Apart from this, discussions have shifted toward creating interactive site maps, layouts, and an online application aimed at communicating the details of Visitor Site Guidelines to a broader audience (Germany, 2021).

In contrast to earlier attempts, the site-specific breeding-bird sensitivity assessment described in our study is based on a thorough literature review. We focused on breeding bird species because there is more information available on these taxa in comparison to others, such as marine mammals of which only two species were recorded as breeding or suspected breeding at two visitor sites, according to the Visitor Site Guidelines. Although we were able to locate some data for all the bird species assessed, these were rarely site-specific; indeed, site-specific breeding cycles for all breeding bird species were only available for 5 out of 38 sites assessed (including Signy Island and Anvers Island). As indicated by our results, 30 sites for which ATCM Visitor Site Guidelines had been agreed had no site-specific breeding bird data, and three sites had data for two-thirds of the breeding bird species present. Together, these 33 sites account for 64 % of total landings, with the highest number of landings occurring at Neko Harbor (76,214 landings from 2019/20 to 2023/24; Fig. 1, Panel B; Fig. 2).

4.2. Visitor site guidelines and data limitations

Information contained within the Visitor Site Guidelines on marine mammals, vegetation, and even geological features at visitor sites was very general in nature and of limited value for management. Comprehensive assessments that consider seasonal variability and species sensitivity are largely lacking. This underscores the need for a comprehensive assessment of the full range of site features for both existing sites and those where tourist visitation might occur in the future. Very few studies have compiled exhaustive assessments of biodiversity at visitor sites that could contribute to ATCM Visitor Site Guidelines assessments. However, some useful research has been undertaken. Braun et al. (2012) conducted comprehensive baseline surveys and monitoring on Fildes Peninsula, including Ardley Island (Visitor Site Guideline No. 31). Cajiao et al. (2020) found 19 additional flora species at Aitcho Island compared with those reported by the corresponding Visitor Site Guideline (No. 2). Lee et al. (2024) used expert knowledge to identify values at landing sites, ranging from the native flowering plants (*Deschampsia antarctica* and *Colobanthus quitensis*) to sites containing fossil-bearing rocks. Whilst not a replacement for comprehensive field surveys, expert knowledge can still help to fill data gaps. Despite visitor sites being generally highly accessible (in terms of location and the practicalities of landings), there are still significant gaps in knowledge that hinder thorough assessments of their sensitivity.

4.3. Science and monitoring, and its contribution to site management

Our study underscores the importance of science-based assessments for informing policy and decision-making. For most of the assessed bird species at the visitor sites examined, the incubation and brood-guarding stages, which represent the periods of highest sensitivity, coincided with the peak of tourist visitation and landings (Fig. 3). Despite variation in the timing of the most sensitive periods for birds, depending on species richness, the general pattern of highest sensitivity from December to mid-February was consistent across sites. Given the ongoing interest in developing a tourism regulatory framework, there may now be opportunities for ATCPs to incorporate these types of assessments and tools as a mechanism to ground future legislation and management of the Antarctic tourism industry.

From a management perspective, there may be benefits in

reconsidering the inclusion of science-based sensitivity assessments when developing Visitor Site Guidelines to minimize disturbance to breeding wildlife populations or other wilderness and historical values at the site (Braun et al., 2012; Francis et al., 2025). Baseline surveys and sensitivity assessments followed by the development of associated Visitor Site Guidelines at existing and emerging visitor sites are urgently needed to help manage the rapid expansion of tourism across the Antarctic Peninsula region, in particular. Monitoring site activities and impacts is also necessary, particularly in light of the potential synergistic impact of human presence and climate change on terrestrial sites (Lee et al., 2017, 2022). Furthermore, sensitivity should be assessed not only in terms of disturbance but also in terms of the risk of potential human-mediated wildlife pathogen and non-native species introductions and establishment, and vulnerability of soils and vegetation to trampling (Tejedo et al., 2012; Hughes et al., 2019, 2025; Bennison et al., 2024). It should be recognized that site impacts may also result from visitation by national Antarctic programme personnel and by crew and observers on fishing vessels. Hence, site management guidelines need to be adequately communicated to all potential visitors.

Our intention is also to prompt discussion and further involvement of the tourism industry, which should be encouraged to contribute to additional assessments and monitoring of birds and mammals, terrestrial communities, and potential human impacts at visitor sites. Given the desire within the industry to deliver citizen science projects for their guests, and the expertise within the expedition leader and guide community, collecting environmental data at visitor sites could prove to a be a 'win-win-win' for tour operators, environmental managers, and policymakers. The environmental stewardship program initiated by IAATO could be seen as an example of long-term data collection and monitoring.

5. Limitations and future research

This study is not without limitations. Our assessment focused exclusively on the number of bird species breeding at visitor sites, as there was insufficient data to account for breeding numbers, density or distribution at the scale of individual visitor sites. The lack of data also prevented us from evaluating sensitivity of other taxa—such as vegetation and marine mammals—present at different sites, which are potentially subject to disturbance and exhibit varying levels of sensitivity throughout the season.

Future studies could help improve sensitivity assessment by collecting data on distribution and numbers of breeding birds and hauled-out seals within visited areas, and carrying out cross-species comparisons of effects of disturbance. It would also be useful to incorporate information on geological features, patterns of tourist use, and presence of non-native species. Although almost all of the bird species considered here were Least Concern, future changes in IUCN Red List status should be considered in further assessments of species sensitivity and vulnerability. Climate change is facilitating access to remote areas and also increasing temperatures, particularly on the Antarctic Peninsula (Doddridge et al., 2025). However, effects on wildlife at both local and regional levels remain unknown. Improving knowledge of ecological and climate change effects on regional and local scales will contribute to a more comprehensive understanding of the sensitivity and vulnerability of Antarctic ecosystems.

6. Conclusion and recommendations

We have provided information on the sensitivity of breeding bird species at sites with ATCM Visitor Site Guidelines. It is clear that the period of greatest bird sensitivity to disturbance coincides with the period of high tourist visitation. These data should be used, alongside knowledge of local topography, distribution of breeding birds, and visited areas to inform the management of visitors to the sites. We suggest that breeding bird sensitivity assessments, undertaken here for sites with ATCM Visitor Site Guidelines, should also be undertaken for other popular visitor sites and sites new to tourist visitation. Acknowledging the local knowledge and expertise of IAATO members, we recommend that the tourism industry persists in their work to create new Visitor Site Guidelines and, following appropriate review, that they should be formally endorsed by the ATCM. IAATO is also uniquely placed to further contribute to regular coordinated monitoring activities at visitor sites, including as citizen science projects. Collection of basic monitoring information, such as wildlife presence, trail state, extent of snow cover throughout the season, etc., could help to inform the revision of existing Visitor Site Guidelines and the creation of new guidelines.

CRediT authorship contribution statement

Daniela Cajiao: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Richard A. Phillips:** Writing – review & editing, Validation, Methodology, Investigation, Conceptualization. **Jasmine R. Lee:** Writing – review & editing, Visualization, Validation, Conceptualization. **Kevin A. Hughes:** Writing – review & editing, Validation, Methodology, Investigation, Conceptualization.

Declaration of interest statement

The authors report that there are no competing interests to declare.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.127971.

Data availability

Sources to the data used in this manuscript and detailed results of this analysis are available in Suplementary Material 1 and 2

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