



Identifying priorities for systematic Antarctic vegetation protection at the continental scale

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ABSTRACT

Antarctica's vegetation underpins its terrestrial ecosystems yet it is threatened by climate change, human activity and the introduction and spread of non-native species. Protecting these vegetation communities is critical to conserving all Antarctic terrestrial life. However, current protection under the Antarctic Specially Protected Area (ASPA) system is spatially uneven, leaving some vegetation communities vulnerable. In this study, we used recently derived satellite vegetation cover data at the continental scale to quantify the proportion of protected and unprotected vegetation across each of the 16 recognised Antarctic Conservation Biogeographic Regions (ACBRs). Estimates suggest that only 21.4% of Antarctica's satellite-detected terrestrial vegetation cover is protected by the current ASPA system, though acknowledging that some sparse and patchy vegetation communities may not have been detected. Protection is regionally uneven, with most ACBRs having less than 10% of their vegetation cover protected, and only one ACBR (North-west Antarctic Peninsula) reaching 27.2%. Next, using satellite and modelled vegetation data, we applied a systematic conservation planning framework to identify key sites of unprotected vegetation within each ACBR. In total, we identified 92 candidate sites to inform future protection efforts, with notable examples including Fildes Peninsula (North-west Antarctic Peninsula), Taylor Valley (South Victoria Land) and the Vestfold Hills (East Antarctica). Overall, a slightly higher proportion of sites were identified in the continental Antarctic than the maritime Antarctic. This study provides a comprehensive, evidence-based framework to inform the protection of Antarctica's vegetation. Our findings highlight gaps in the protection of Antarctic vegetation and identify opportunities for enhanced future conservation.

1. Introduction

Antarctica's terrestrial vegetation is widely distributed, but covers

less than 1% of the continent's ice-free ground (Walshaw et al., 2024). It comprises a range of taxonomic groups, including cryptogamic communities (lichens, bryophytes, eukaryotic algae, cyanobacteria and

Abbreviations: ACBRs, Antarctic Conservation Biogeographic Regions; ASPAs, Antarctic Specially Protected Areas; ATCM, Antarctic Treaty Consultative Meeting; CEP, Committee for Environmental Protection; NDVI, Normalised Difference Vegetation Index; PUs, Planning Units.

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microbial soil crusts) and two flowering plant species (*Deschampsia antarctica* and *Colobanthus quitensis*). Vegetation is more abundant and diverse in the maritime Antarctic, which lies north of the Gressitt Line, the biological boundary that divides the Antarctic Peninsula from the rest of the continent (Chown and Convey, 2007). Antarctic Conservation Biogeographic Regions (ACBRs, numbered 1–16) further divide the continent into regions, with five of the 16 recognised ACBRs (1, 2, 3, 4 and the northern parts of 15) located within the maritime Antarctic (Terauds et al., 2012; Terauds and Lee, 2016).

Though limited in total area, vegetation communities play a vital role in Antarctic terrestrial ecosystem functioning. They provide essential habitat and resources for invertebrates and microorganisms, and contribute to key ecological processes such as carbon and nutrient cycling (Block et al., 2009; Colesie et al., 2013; Durán et al., 2021; Sancho et al., 2016). However, vegetation is vulnerable to multiple stressors, including physical disturbance and destruction from direct human activities (such as trampling and infrastructure construction), as well as the broader impacts of anthropogenic climate change (Amesbury et al., 2017; Lee et al., 2022a; Pertierra et al., 2013; Robinson et al., 2018; Tejedo and O'Neill, 2018). There is also evidence that introduced non-native species may impact native Antarctic vegetation via competition for space and resources (Cavieres et al., 2017; Frenot et al., 2005; Molina-Montenegro et al., 2019). With these pressures predicted to become more widespread across the continent (Hughes et al., 2019; Pertierra et al., 2017), there is a need for further development of systematic conservation efforts (Coetzee et al., 2017; Lee et al., 2022b).

The Kunming–Montreal Global Biodiversity Framework aims for at least 30% of terrestrial, inland water, marine and coastal ecosystems to be effectively conserved and managed by 2030, particularly those critical for biodiversity and ecosystem functions (Secretariat of the Convention on Biological Diversity, 2022). Though vegetation communities do not constitute all terrestrial areas in need of protection in Antarctica, they are important areas that contribute considerably to overall biodiversity and function. While Global Biodiversity Framework targets do not formally apply to Antarctica, they do serve as useful benchmarks for protection.

Currently, comprehensive spatial protection in Antarctica is primarily achieved through Antarctic Specially Protected Areas (ASPAs), implemented via the Antarctic Treaty System (Hughes and Grant, 2018; Lee et al., 2022b). While Antarctica is designated as a 'natural reserve, devoted to peace and science' under Article 2 to the 1991 Protocol on Environmental Protection to the Antarctic Treaty (which came into force in 1998 and is commonly referred to as the Environmental Protocol), it was recognised from the outset that some areas might need additional protection or management if they host unique or vulnerable communities, or if the area is subject to intensive human activities (Bastmeijer and Van Hengel, 2009). Annex V to the Environmental Protocol details the different primary reasons for which ASPAs can be designated, including the protection of 'outstanding environmental, scientific, historic, aesthetic or wilderness values...', such as areas kept inviolate from human interference, or those containing representative or exceptional ecosystems (Antarctic Treaty Secretariat, 2025). In terms of terrestrial vegetation protection, an estimated 59% of Antarctic plant and cryptogam species do not occur in any ASPA (Wauchope et al., 2019), although these estimates do not indicate how much vegetation cover is protected.

The under-representation of vegetation species may partly reflect the spatial bias in ASPA designation, as many ASPAs are located close to research stations and within ACBRs that have strong intercontinental logistical connections, such as the North-west Antarctic Peninsula (ACBR 3) and South Victoria Land (ACBR 9) (Hughes et al., 2013; Hughes and Grant, 2017). This, along with the fact that some ASPAs were originally designated as Sites of Special Scientific Interest (SSSI), highlights the intention to protect active research sites. These patterns suggest that ASPA designations are influenced by geopolitics, ease of implementation, and site accessibility, particularly given that environmental knowledge is generally greater and management costs are lower

near research stations (Hughes and Grant, 2017).

To work towards a more representative ASPA network for vegetation, we must first understand where it is and how much cover is currently protected. Previous work has mapped terrestrial vegetation cover within specific ASPAs (e.g. Cannone et al., 2018; Bollard et al., 2022; Lucieer et al., 2015; Sandino et al., 2025) and across the ASPA system as a whole (Hughes et al., 2015). These studies mapped vegetation to varying levels of detail: with higher-resolution techniques like ground or drone surveys providing more accurate and fine-scale estimates, and satellite imagery providing much broader coverage (Hughes et al., 2015; Fretwell et al., 2011; Walshaw et al., 2024), but often underestimating total vegetation extent. Using high-resolution satellite imagery and the Normalised Difference Vegetation Index (NDVI), Hughes et al. (2015) assessed vegetation cover within 33 ASPAs that list macroscopic vegetation as an explicit protection objective in their management plans. In total, they reported 16.1 km² of protected vegetation across Antarctica, with over 96% located in ACBRs 2 and 3 (South Orkney Islands and North-west Antarctic Peninsula, respectively), and over 50% located in a single ASPA (Byers Peninsula, ASPA 126).

While Hughes et al. (2015) provide valuable insights, they did not assess the relative extent of protected vs unprotected vegetation, which is necessary to determine the representativeness of ASPAs. Without data on this, it is difficult to determine (i) whether, for instance, the 16.1 km² of protected vegetation reported represents a large or small proportion of the total vegetation area across the continent, (ii) if vegetation protection is representatively distributed across the different ACBRs, or (iii) whether the concentration of protected vegetation in ACBRs 2 and 3 reflects a naturally higher vegetation cover in these regions, or indicates spatial unevenness of the ASPA system. Until recently, assessing the proportion of protected to unprotected vegetation within each ACBR was not possible due to an absence of continent-wide datasets for any of the main groups of vegetation, and due to the difficulty of comparing protected cover estimates derived at different resolutions and/or from different methodologies.

This lack of knowledge has hindered progress towards developing a more spatially representative protected area system for Antarctica's terrestrial vegetation, a key objective outlined in Annex V to the Environmental Protocol. Through its Five-Year Work Plan, the Antarctic Treaty Consultative Meeting's (ATCM) Committee for Environmental Protection (CEP) has committed to providing guidance on the further development of a systematic environmental-geographical framework for protected areas (Antarctic Treaty Secretariat, 2025). With the recent availability of continent-wide vegetation datasets in Antarctica from satellite-derived cover maps (Walshaw et al., 2024) and continent-wide species distribution models (Terauds et al., 2024a), as well as advances in systematic conservation planning methodologies (Giakoumi et al., 2025; Hanson et al., 2025; Margules and Pressey, 2000), it is now possible to begin addressing these protection objectives.

Here we use these new data and methodologies to 1) ascertain the current status of vegetation protection in Antarctica by assessing the proportion of protected vegetation within each ACBR, and 2) identify new candidate sites for protection, using a spatial prioritisation algorithm that aims to meet a 30% protection target across ACBRs. This study represents an important development in generating the evidence base required to assist the CEP in advancing the systematic development of the ASPA system.

2. Methods

2.1. Assessing the proportion of protected vegetation

We used satellite-derived vegetation cover data at the continental scale to assess how much of each ACBR's vegetation cover is protected within the current ASPA system. Vegetation cover data were accessed from Walshaw and Gray (2024), who provide 10 m-resolution maps of green vegetation (bryophytes, green algae, vascular plants) and lichens

across ice-free areas south of 60°S (see Supporting Information section 1.1). Green vegetation and lichen datasets were combined in QGIS software (v3.30.3) to produce a single terrestrial vegetation map for further analysis. Although these satellite-derived maps identify hotspots of primarily green vegetation at the continental scale, they under-represent other Antarctic vegetation communities, particularly lichens and dark-pigmented vegetation (de Jonge et al., 2026; Walshaw et al., 2024).

The ASPA polygons and ACBR layer were obtained from the Australian Antarctic Data Centre (Terauds and Lee, 2016; Terauds et al., 2024b). ASPAs with a terrestrial component were included in the analysis, except for ASPA 104 on Sabrina Island (Balleny Islands), as the Balleny Islands were not considered in the original ACBR analysis (Terauds et al., 2012) and they contained less than 0.007 km² of satellite-detected terrestrial vegetation. Overall, 69 (of 75) ASPAs remained for further analysis. In QGIS, the satellite-derived vegetation cover data were intersected with each of the ASPA polygons to calculate the area of protected vegetation.

Next, we aggregated the vegetation cover estimates within ASPAs, as well as within each ACBR, to calculate the proportion of protected and unprotected vegetation relative to the total amount in each ACBR, as well as across the continent as a whole (Table S1). Any satellite-detected vegetation that did not intersect with an ACBR, due to different ice-free area estimates used to generate both datasets, was assigned to its nearest ACBR. The majority of the vegetation (>90%) was either overlapping or within 1 km of its nearest ACBR, with the furthest detection being ~90 km away. We recognise that some small offshore islands, with limited (if any) biological survey data, may contain significant diversity and thus could potentially inform further ACBR subdivision in the future. However, the current ACBRs represent the best available biogeographic regionalisation for Antarctica at present.

2.2. Identifying new sites for vegetation protection

2.2.1. Systematic conservation planning framework

We used a spatial prioritisation algorithm, implemented using the prioritizr package (v8.0.6.5; Hanson et al., 2025) in R (v4.4.2; R Core Team, 2023), to identify areas of land, known as Planning Units (PUs), for conservation. Specifically, we used a minimum set objective, whereby the algorithm prioritised a set of complementary priority sites containing conservation features of interest (in our case terrestrial vegetation), that collectively met defined representation targets (in our case 30%), while minimising the overall cost, thus enabling cost-

efficient solutions (Hanson et al., 2025; Carwardine et al., 2010; Margules and Pressey, 2000). The systematic conservation planning prioritisation required (i) spatial layers detailing the location of vegetation features (Fig. 1), (ii) layers representing the cost of protecting those features, and (iii) targets for protecting those features, which we set at 30%, to align with the global Kunming-Montreal Biodiversity Framework.

2.2.2. Preparing spatial layers for the prioritisation

All spatial layers were prepared in QGIS before being imported into R for the prioritisation. They included:

2.2.2.1. Vegetation features. We used two continent-wide datasets to represent vegetation features in the prioritisation (Fig. 1). These included satellite-derived vegetation cover data (Walshaw and Gray, 2024) and predictions from species distribution models for 17 vegetation groups (hereafter taxa) (Terauds et al., 2024a; Fig. S1). The species distribution models are available from the Australian Antarctic Data Centre with associated methods (see ‘Abstract’ at the data link), although it should be noted that these outputs have not undergone peer review and there is not yet an associated scientific article (Terauds et al., 2024a). However, model predictions were included alongside the satellite-derived vegetation dataset to help account for uncertainty in the satellite data (such as providing predictions in some areas below satellite detection limits), and to incorporate additional aspects of vegetation representativeness, such as the presence of specific taxa (further details can be found in Supporting Information section 1.2). As we used a high threshold (90%) for determining taxa presence/absence in each PU from the modelled output, there were several ACBRs (11, 12, 14, 15) that ended up with no modelled output above this threshold (and the South Orkney Islands were excluded from the original modelling due to lack of predictor variables). This means that only satellite data were available within these ACBRs and there is no measure of representativeness for the 17 taxa, meaning the model predictions contributed unevenly to vegetation representation across the 16 ACBRs. Integrating additional sources of vegetation data in the future will help fill gaps in these satellite-derived and modelled vegetation datasets, particularly across the continental Antarctic (Patterson et al., 2025a; Walshaw et al., 2024). Additionally, independent ground validation of the satellite-derived and modelled vegetation datasets was not undertaken as part of this study. Consequently, the identification of priority sites for vegetation protection are constrained by the quality and accuracy of these underlying datasets and future ground validation campaigns will

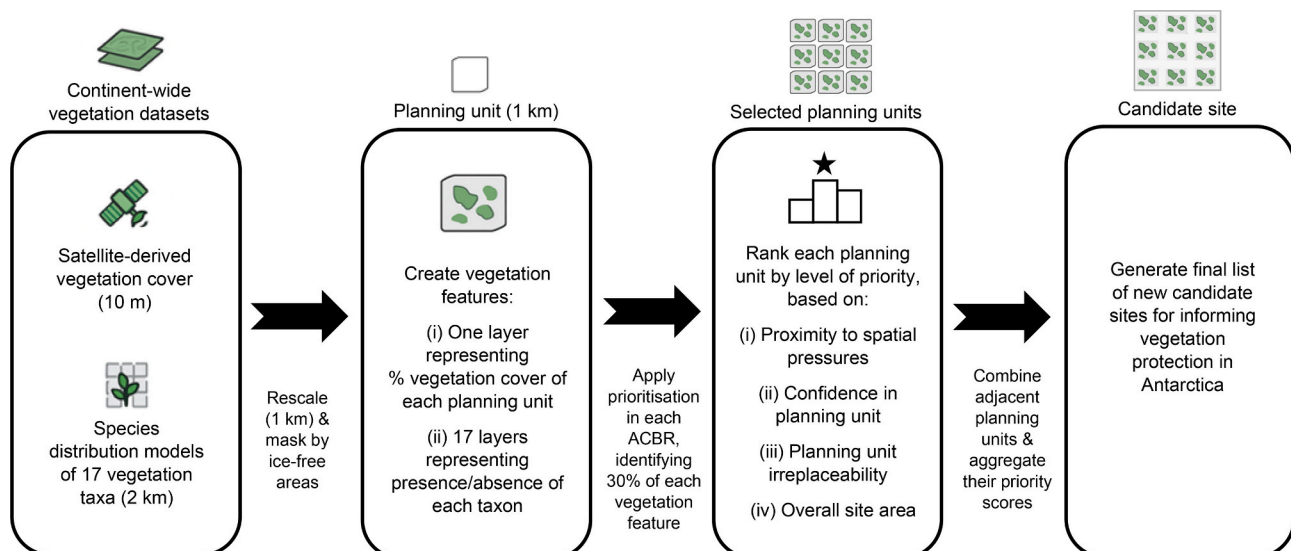


Fig. 1. Workflow for the prioritisation of terrestrial vegetation in Antarctica.

be essential to confirm presence and extent of vegetation within these identified sites.

For the prioritisation, we defined PUs as 1 km × 1 km grid cells, representing a compromise between the spatial resolution of the available datasets, computational efficiency and an appropriate scale for management. To identify PUs containing vegetation, we clipped a 1 km grid for Antarctica to the extent of the satellite-derived vegetation cover (10 m-resolution) and modelled taxa distribution (2 km-resolution) layers. We then masked the PUs by the medium resolution rock outcrop layer from the Antarctic Digital Database (Gerrish et al., 2024), to retain only those containing ice-free ground. Next, we summed the satellite pixels within each PU to calculate the proportion of vegetation cover. Modelled taxon presence was recorded by assigning applicable PUs a value of 1 per taxon, if present. This produced 18 vegetation feature layers, one representing PUs with satellite-derived vegetation cover, and the remainder representing presence layers for each modelled taxon. These PUs were also intersected with the ASPA polygon layer to identify vegetation features within existing protected areas.

2.2.2.2. Cost. We trialled two inverse cost layers for the prioritisation, with ‘cost’ represented by the proximity of vegetation to three potential spatial pressures (Table S2), for which continental point location datasets were available: non-native species (Hughes et al., 2025), Antarctic infrastructure (COMNAP, 2024) and visitor landing sites (IAATO, 2024; Lee, 2019). We tested two approaches, where (i) cost decreased with distance to pressure (Table S2), and (ii) cost increased with distance to pressure (inverse of Table S2), with each being the inverse of the other. The first approach was intended to prioritise ‘remote’ vegetation for protection, assuming that these patches have been less exposed to pressures, and are therefore more pristine and should be prioritised. The second approach prioritised under-pressure vegetation, assuming that ‘remote’ vegetation requires less additional protection. However, the inverse layers did not meaningfully change the location of selected PUs in the prioritisations (Fig. S2), likely reflecting sparse vegetation cover and/or limited data availability. Nevertheless, as the prioritisation requires a cost layer, we selected the ‘under-pressure’ layer for use in the final prioritisation. However, as the cost layers did not reliably inform the prioritisation of remote or under-pressure vegetation, we also incorporated the proximity of vegetation to the three potential spatial pressures as a layer at a later stage in the analysis to help rank the relative priority of PUs (see Section 2.2.4. *Ranking sites by level of priority*), reasoning that the most potentially threatened sites should be the higher priority.

2.2.3. Running the prioritisation

To obtain a representative solution, we carried out a regional prioritisation, with a 30% inclusion target set for each vegetation feature within each ACBR (Fig. 1; Supporting Information section 1.3). This was designed to account for areas with lower relative abundance/diversity of vegetation (which are characteristic of many locations in the continental Antarctic) and ensure balanced representation of vegetation features in ASPAs across the continent (Supporting Information section 1.3). This approach is intended to provide a useful starting point for informing further systematic vegetation protection within each ACBR.

In addition to the main prioritisation with the satellite-derived and modelled vegetation feature layers, sensitivity analyses were also performed in which prioritisations with the satellite and modelled feature layers were carried out individually. The satellite- and model-only solutions differed, with the model-only prioritisation identifying approximately 15% more PUs at the continental scale than the satellite-only prioritisation (~26% of PUs in the satellite-only solution overlap with the model-only solution) (Fig. S4). This discrepancy likely reflects differences in the information represented by the two datasets, the incomplete spatial coverage of both datasets, and the inclusion of only 17 modelled taxa. Consequently, the combined prioritisation was

considered to provide a more comprehensive representation of Antarctic vegetation than either dataset could alone provide, by reducing the reliance on a single data source with potential bias and uncertainty (Patterson et al., 2025a; Walshaw et al., 2024). The frequency of the PU selection in the three solutions (satellite/model/combined) was also one of the factors used to rank the relative priority of PUs (see Section 2.2.4. *Ranking sites by level of priority*).

We also added a ‘locked in’ constraint to the conservation planning problem, to ensure that PUs within existing ASPAs were selected in the solution (as they already offer protection for the vegetation within, and thus already contribute towards the 30% representation target in each ACBR). As the prioritisation considers any PUs that intersected with the ASPA polygon layer to be protected, this occasionally meant that ‘protected’ PUs contained small amounts of technically unprotected vegetation when the PU wasn’t fully covered by the ASPA polygon. We calculated this to be 2.26 km² (6%) of the satellite-detected vegetation. This methodological limitation may have prevented vegetation patches adjacent to current ASPAs, and potentially exposed to high levels of human activity, from being selected, particularly in densely vegetated PUs immediately surrounding ASPAs in ACBRs 2 and 3, including areas such as Fildes Peninsula and Robert Island in the South Shetland Islands.

Finally, to reduce the spatial fragmentation of the solution and facilitate more practical conservation planning, we promoted connectivity among PUs through the application of a boundary penalty in prioritizr (penalty = 200 and edge factor = 0.5). This meant that the prioritisation penalised isolated PUs in favour of well-connected ones. After running the conservation planning problem in R, the prioritised PUs were exported as a raster layer and imported into QGIS for further analysis.

2.2.4. Ranking sites by level of priority

The prioritisation did not indicate which of the many selected PUs should be prioritised above others. As our analysis was conducted at a large spatial scale with hundreds of selected PUs, expecting immediate consideration of all of them as new ASPAs is not realistic. Therefore, we included an additional step of ranking PUs by level of priority, in order to provide guidance for policymakers by highlighting key sites in each ACBR (Fig. 1). To do this, we:

1. Reviewed the PUs, and removed those primarily over ocean or ice ($n = 42$).
2. Ranked each remaining PU according to four selection criteria (Table 1, Columns 1 and 2 give each criterion and its rationale), each scaled from 0 (lowest priority) to 1 (highest priority) (Table 1, Column 3 gives details of how scaling was done).
3. Combined adjacent PUs into new candidate sites, based on those with vertices or edges in contact. A small number of PUs in close proximity but not in contact (in ACBR 4) were combined into one candidate site.
4. To obtain an overall criteria value for each candidate site, we aggregated the values from the combined PUs, with a different aggregation method for each of the four selection criteria (Table 1, Column 4).
5. Summed the four aggregated criteria to create an overall priority score (0–4) for each candidate site (Table S3).

Using the final priority scores, we categorised each candidate site as higher, medium or lower priority using Jenks natural breaks classification (Table S3). Next, we named each site using the SCAR Composite Gazetteer (SCAR, 2025), and labelled them by suggested type: expansion of an existing ASPA boundary or a new distinct site (not contiguous with an existing ASPA) (Table S3). The proximity of each candidate site to the three potential spatial pressures: non-native species (Hughes et al., 2025), Antarctic infrastructure (COMNAP, 2024) and visitor landing sites (IAATO, 2024; Lee, 2019), as well as the presence of satellite-detected vegetation cover and the number of modelled taxa, are

Table 1

Priority criteria for ranking PUs and aggregating them into final candidate sites (assuming that each of the four criteria had an equal contribution to PU priority, given a lack of available data to suggest otherwise).

Priority criteria	Rationale	Scaling method	Aggregation method
Proximity to potential spatial pressures: 1) <i>Non-native species</i> 2) <i>Antarctic infrastructure</i> 3) <i>Visitor landing sites</i>	Based on evidence that human activities can contribute to trampling and destruction (Tejedo et al., 2009, 2012; Tejedo and O'Neill, 2018), and that non-native species can potentially compete with native vegetation species (Molina-Montenegro et al., 2019), though we acknowledge that these are potential pressures (rather than guaranteed impacts) in many locations. We considered PUs closer to pressures to be in greater need of protection, as the potential for impact on the vegetation is greater.	See Table S2 for scaling distances from each PU to the three pressures (closer proximities were assigned higher values). Distance thresholds for determining proximity to potential pressures were informed by relevant literature ^{a,b} .	Maximum index value for each of the three pressures (PUs within a candidate site), followed by the mean across these three maximum values.
Confidence in PU selection	Reflects the consistency of PU selection in sensitivity analyses in which prioritisations were performed with the satellite-derived and modelled vegetation feature layers individually (Fig. S4), in addition to the prioritisation with both satellite and modelled feature layers (as outlined above and in Fig. 1). The same PU location selected repeatedly across the three solutions indicated a higher confidence in that selection.	Selection frequency of a PU across the three solutions ranged from 1 (selected only once) to 3 (selected in all three solutions). These values were scaled as follows: 1 (0.33), 2 (0.66), 3 (1).	Maximum value for all PUs within candidate site.
PU irreplaceability	A prioritizr metric representing the relative importance of each PU in the prioritisation for achieving the set target (within each ACBR) under the minimum set objective.	Values already 0–1, with higher values indicating PUs that are more important for achieving the set target.	Mean value for all PUs within candidate site.
Overall site area	A larger area of adjacent PUs was assigned a higher priority assuming that, in general, larger sites are more resilient and facilitate more practical and cost-effective conservation planning (Hughes et al., 2021).	Min-max normalisation was applied, using the smallest (1 km ²) and largest (125 km ²) area of summed adjacent PUs, with the former assigned 0, and the latter 1.	Sum of all PUs within candidate site.

^a Distances for proximity to potential pressure from non-native species adapted from Bartlett et al. (2020).

^b Distances for proximity to potential pressure from Antarctic infrastructure and visitor landing sites, informed by Perterra et al. (2017) and Brooks et al. (2019).

provided in Table S3.

3. Results

3.1. The current status of vegetation protection in Antarctica

The most recent satellite observations at the continental scale have estimated that Antarctic terrestrial vegetation covers a total area of 40.97 km², with presence in all 16 ACBRs (Walshaw et al., 2024). Based on these estimates, we calculated that 8.8 km² (21.4%) of the total satellite-detected cover occurs within 43 of the 69 ASPAs (and within 30 of the 36 that explicitly protect vegetation), spanning seven of the 16 ACBRs (2, 3, 4, 7, 8, 9, 16, Fig. 2a–c; Table S1). Consequently, approximately 78.6% of Antarctic vegetation falls outside the current ASPA network.

There are six ASPAs whose management plans mention vegetation protection, but that lack any satellite-detected vegetation (reflecting technical limitations), including Rothera Point (ACBR 3), Marion Nunataks (ACBR 4), Yukidori Valley (ACBR 5), Dakshin Gangotri Glacier (ACBR 6), Cape Royds (ACBR 9), Davis Valley and Forlidas Pond (ACBR 10). Most of these ASPAs include vegetation that is known, from ground studies, to be of very limited extent and/or extremely sparse, with the exception being the former two ASPAs, which have more extensive lichen communities. Therefore, of the 16 ACBRs (all of which contain vegetation), 10 contain protected vegetation, including those from ACBRs 5, 6 and 10 that are without satellite detections from Walshaw et al. (2024). Of the remaining six ACBRs that lack vegetation protection, four (ACBRs 11, 12, 14 and 15) do not contain any ASPAs at all, while the remaining two (ACBRs 1 and 13) include ASPAs, but without any protection of vegetation mentioned in their management plans.

The North-west Antarctic Peninsula (ACBR 3) contained the majority (73%) of all satellite-detected vegetation cover across ice-free areas (Walshaw et al., 2024), and over 92% of all protected cover (contained within 20 ASPAs, Fig. 2a, b; Table S1). Of the vegetation cover within ACBR 3, 27.2% is protected, which itself represents 20% of all satellite-

detected vegetation cover across the continent (Fig. 2a; Table S1). This far surpasses the protection levels in other ACBRs (2, 4, 7, 8, 9 and 16) which, apart from ACBR 7, each protect less than 10% of their vegetation cover, collectively amounting to less than 2% of the continent's total detected vegetation, and just over 7% of the total protected cover (Fig. 2a–c; Table S1).

3.2. New candidate sites for informing future vegetation protection planning

The conservation planning prioritisation identified a total of 92 new candidate sites containing unprotected vegetation. The majority of these sites ($n = 76$) were new distinct locations, though some expansions of existing ASPAs were also identified ($n = 16$; Fig. 4, Table S3). Of the 92 candidates, 15 were classified as 'higher priority', located in ACBRs 1, 3, 7, 8 and 9 (Figs. 3, 4a, b; Table S3). The area of individual candidate sites ranged from 1 to 125 km², with a mean area of 8.5 km² (Table S3). ACBR 3 contained the largest number ($n = 27$) and the greatest cumulative area (236 km²) of identified candidate sites of any ACBR (Fig. S5, Table S4), reflecting its higher total vegetation cover, although this pattern may also be influenced by bias in the satellite dataset to detecting larger vegetation patches in the maritime Antarctic (Walshaw et al., 2024).

The highest priority candidate site identified in ACBR 3 was on the Fildes Peninsula (a), King George Island (candidate 8), with other 'higher priority' sites in the maritime Antarctic located on Deception Island (ACBR 3, Table 2) and the Scar Hills in Hope Bay (candidate 1, ACBR 1) (Figs. 3, 4a; Table S3). The ACBRs with lower total vegetation cover estimates, primarily ACBRs 11–15, also had a lower total number and cumulative area of selected candidates (Figs. 4k–p, 5, Table S4). However, a slightly larger proportion of candidates (50 of the 92 sites) were identified within continental Antarctic ACBRs compared to those in the maritime Antarctic (Figs. 5, S5; Table S3). The largest single candidate site identified (125 km²), also ranked as the highest priority in that ACBR, was located in the Vestfold Hills in East Antarctica (Figs. 3, 4g; Table 2), highlighting its value for biodiversity and the need to

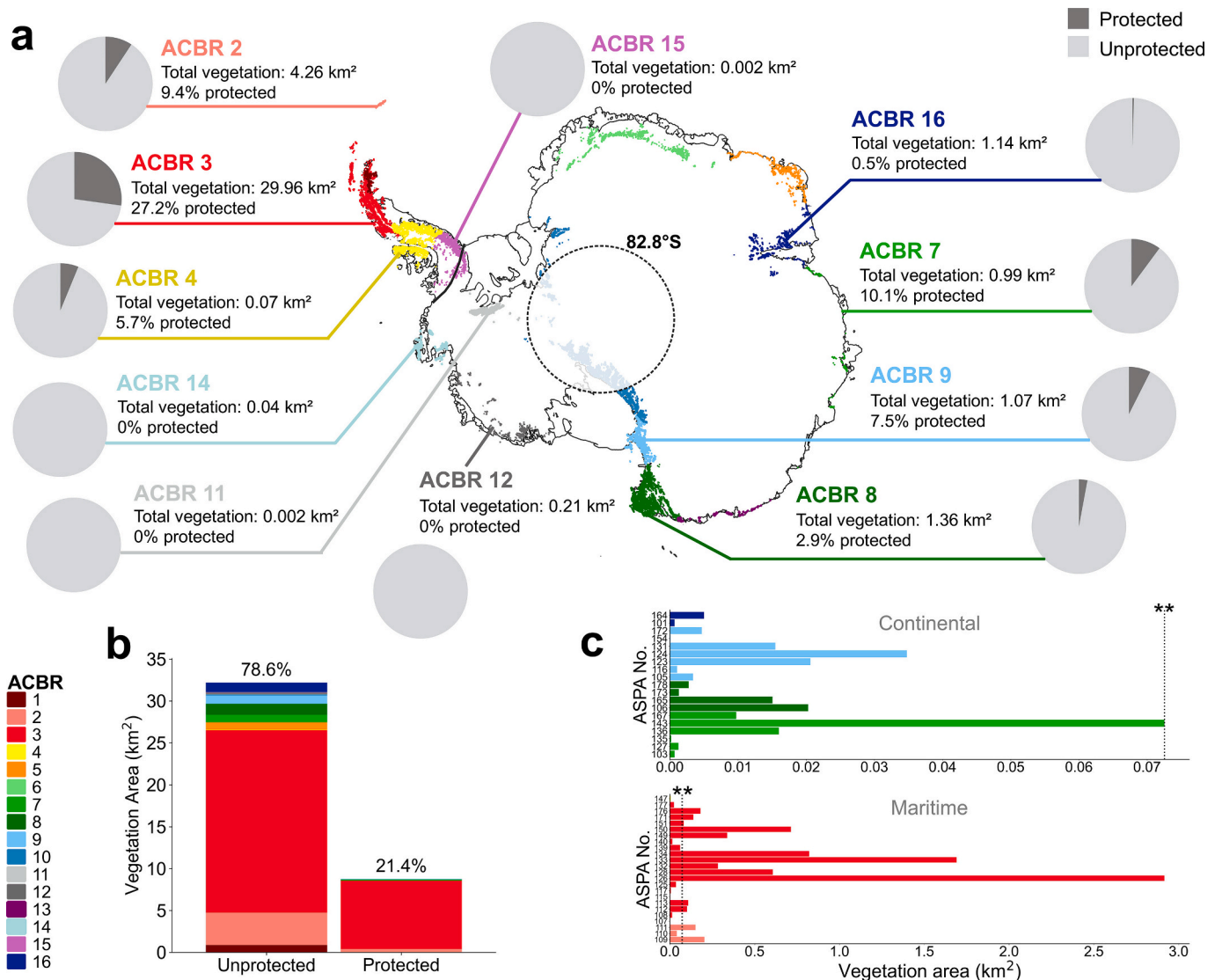


Fig. 2. The proportion of protected and unprotected terrestrial vegetation detected using medium-resolution satellite imagery across (a) the Antarctic Conservation Biogeographic Regions (ACBRs; displayed by the pie charts), including the total area of vegetation in km² displayed next to the pie charts and the percent protected on the line below, (b) the whole continent, coloured by the 16 ACBRs, (c) within Antarctic Specially Protected Areas (ASPAs) in the continental (top) and maritime (bottom) Antarctic. In (c) different scales in the x-axis were used for the maritime and continental Antarctic plots to increase the visibility of lower vegetation area estimates within the continental Antarctic ASPAs. The dotted lines with double asterisk (**) denote equivalent vegetation areas on both plots. A larger version of panel (c) is provided in Fig. S5. Four ACBRs (11, 12, 14 and 15) contain terrestrial vegetation but no ASPAs, therefore their protection percentage is 0% (see Table S1). The ‘polar hole’ is displayed at 82.8°S (where no satellite data were available), and the Gressitt line is indicated in black at the base of the Antarctic Peninsula. The ice-free area and continent outline layer are available on the Antarctic Digital Database (<http://www.add.scar.org/>), the ACBR layer from Terauds and Lee (2016), and the terrestrial vegetation layer from Walshaw and Gray (2024).

protect such sites from future infrastructure development. Other ‘higher priority’ sites in the continental Antarctic included Bailey Peninsula in East Antarctica and Taylor Valley in South Victoria Land (Figs. 3f–g, 4g, i; Tables 2, S2).

In total, both vegetation data types (satellite-derived and modelled vegetation) co-occurred in just under half of the identified new candidate sites (40 sites across ACBRs 1, 3, 5–9; Table S3). Notably, 13 of the 15 highest-ranking candidate sites (Tables 2, S3) contained both vegetation data types, highlighting their importance in contributing to multiple representation targets, but also increasing confidence in their prioritisation. The largest area of satellite-detected vegetation across all 92 candidate sites (>0.63 km²) was also observed in one of the highest-ranking sites (Barton Peninsula, King George Island) (Fig. 4c; Tables 2, S3).

4. Discussion

4.1. Effectiveness of current vegetation protection

This study presents a continent-wide assessment of how well each ACBR’s vegetation is represented within the current ASPA system. At a continental scale, 21.4% of detected vegetation is protected, with the North-west Antarctic Peninsula (ACBR 3) containing the majority of both vegetation cover and protection. However, when considered against international conservation targets, such as the Kunming–Montreal Global Biodiversity Framework, neither the continent as a whole, nor any of the 16 ACBRs, currently protect 30% of their terrestrial vegetation. The North-west Antarctic Peninsula comes close, with 27.2% of its vegetation protected, while most other ACBRs fall considerably short (Fig. 2). However, once the recently agreed ASPA

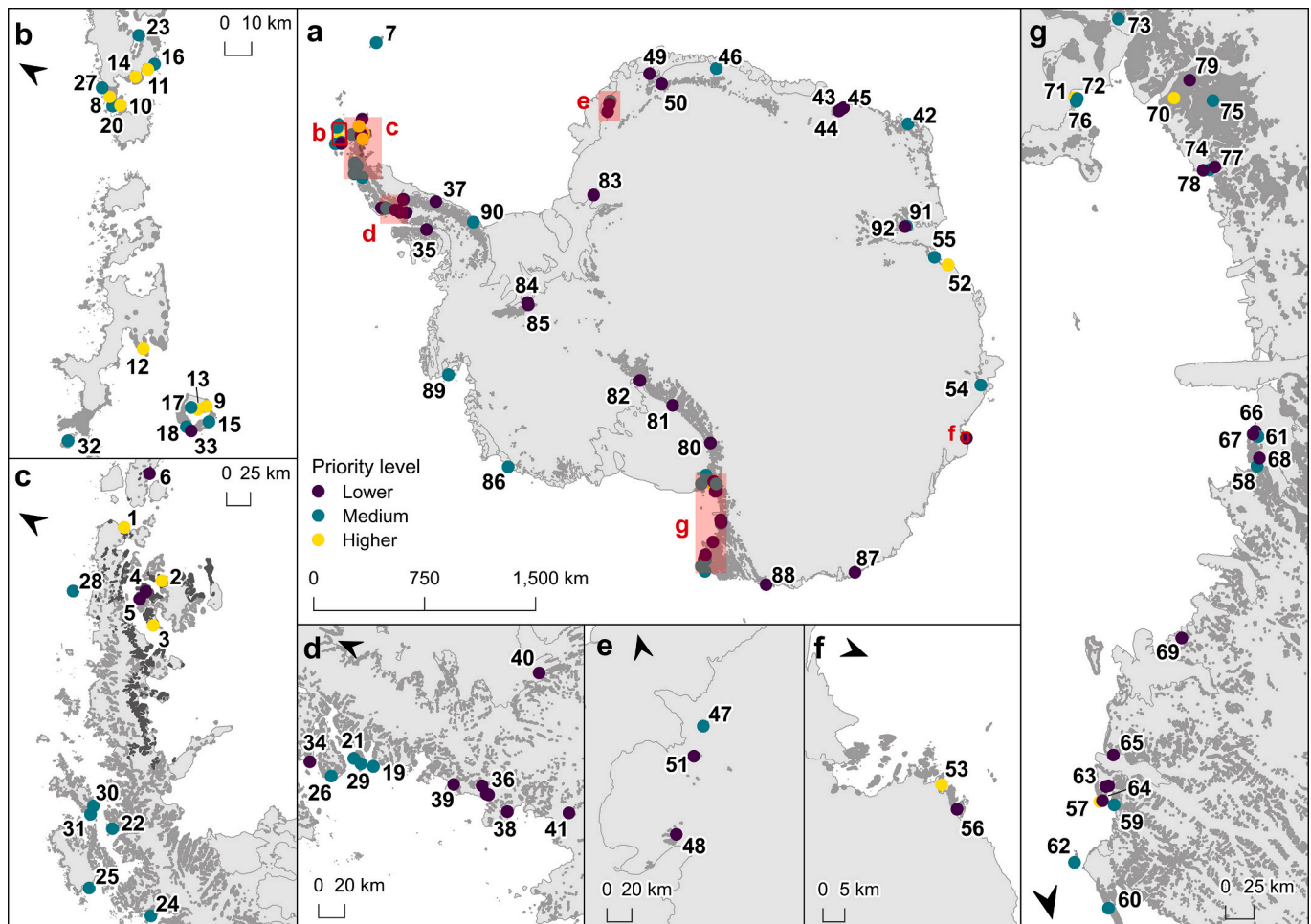


Fig. 3. Locations of 92 candidate sites (coloured points) for informing future vegetation protection across (a) the whole continent, (b) the South Shetland Islands, (c) the northern Antarctic Peninsula: dark grey shading distinguishes Antarctic Conservation Biogeographic Area (ACBR) 1 from ACBR 3 in lighter shading, (d) Fallières Coast, (e) Vestfjella region of Dronning Maud Land, (f) Wilkes Land, and (g) North and South Victoria Land. Candidate sites are numbered sequentially from 1 to 92 across ACBRs 1–16, with site order within each ACBR reflecting descending priority (refer to Table S3). Sites are colour-coded based on priority level (yellow = higher priority, blue = medium priority, purple = lower priority). The ice-free area and continent outline layer are available from the Antarctic Digital Database (<http://www.add.scar.org/>). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

'Parts of Signy Island and adjacent Islands' enters into effect in late August 2026 (Italy et al., 2025), approximately 46.7% of the total vegetation cover in the South Orkney Islands (ACBR 2) would then be protected (based on the satellite estimates from Walshaw et al., 2024). This would mean it would surpass ACBR 3 as having the highest proportion of terrestrial vegetation protected and would meet the global 30% target. Overall, in terms of regional representativeness, protection is uneven, particularly for vegetation communities within continental ACBRs, highlighting the potential for expanded protection.

Based on ground records and the satellite detections quantified by Walshaw et al. (2024), a number of current ASPAs appear to host macroscopic vegetation, though explicit protection objectives for vegetation are not mentioned in their management plans. For example, the Marine Plain in the Vestfold Hills (ASP 143, ACBR 7) supports at least six moss and 23 lichen species, though its primary designation is to protect fossil beds and other geological features (Antarctic Treaty Secretariat, 2025; Leishman and Wild, 2004; Seppelt et al., 1988; Terauds et al., 2025). Explicitly considering vegetation management within such ASPAs and their associated management plans could improve outcomes for the already protected vegetation (e.g. by highlighting sensitive vegetation areas within the ASPA).

These two issues, of uneven representation of vegetation protection across the ACBRs and the lack of explicit vegetation protection

objectives in some current ASPAs, reinforce that the current ASPA system has opportunities for increasing protection of both the diversity and coverage of Antarctic vegetation. This underscores the urgent need for (i) improved representativeness in area-based protection across ACBRs, and (ii) more active and targeted management plans that explicitly include vegetation protection objectives. This is critical given the ecological importance of these communities and their vulnerability to climate change.

4.2. Opportunities for further protection

We identify multiple new candidate options in each ACBR (Figs. 4, 5), offering a practical starting point for Antarctic Treaty Parties seeking to improve the representativeness and extent of Antarctic vegetation protection. Incorporating both satellite-derived and modelled vegetation data in the analysis allowed us to identify higher-confidence candidate sites where both data sources identified important vegetation communities, and where these communities could also be validated in the literature, such as Fildes Peninsula (b) (candidate 10, ACBR 3), Hurd Peninsula (candidate 12, ACBR 3), Vestfold Hills (candidate 53, ACBR 7) and Redcastle Ridge (candidate 63, ACBR 8) (Figs. 3, 4a, b; Table S3) (Green et al., 2015; Leishman and Wild, 2004; Márquez-Sanz et al., 2025; Ochyra, 1998; Ochyra et al., 2008; Øvstedal and Smith,

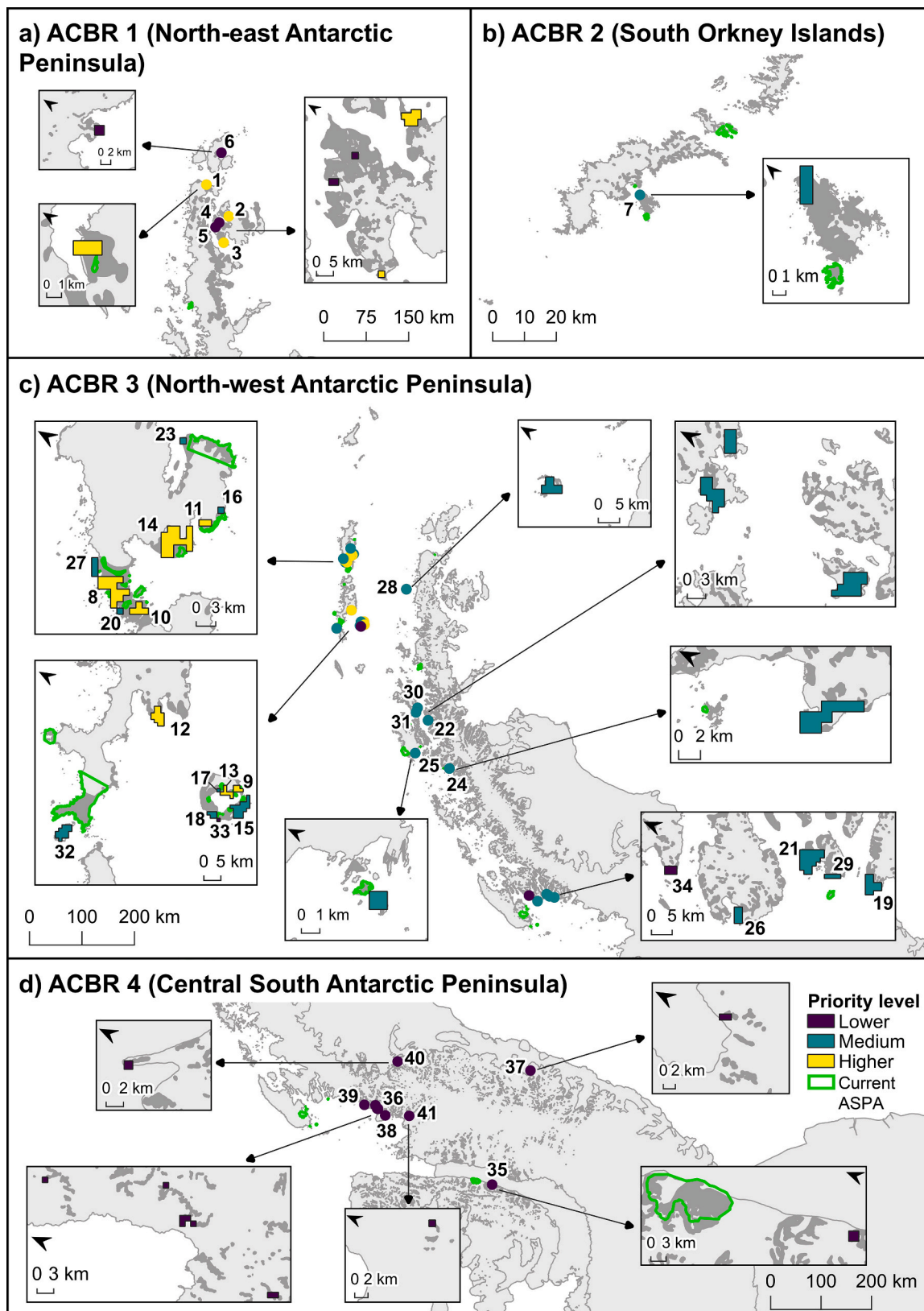


Fig. 4. The 92 candidate sites identified by the systematic conservation planning prioritisation within 16 Antarctic Conservation Biogeographic Regions (ACBR): (a–d) 1 to 4 (e–i) 5 to 9 (j–p) 10 to 16. Background maps display ice-free areas (dark grey, not to scale) making up each ACBR with point locations of candidate sites (not to scale). Inset maps display the location and area of the candidate sites (to scale), colour-coded by level of priority - yellow (higher priority), blue (medium priority), and purple (lower priority). Current Antarctic Specially Protected Area (ASPA) boundaries are outlined in light green. The ASPA boundaries are available from Terauds et al. (2024b). The ice-free area and continent outline layer are available on the Antarctic Digital Database (<http://www.add.scar.org/>). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

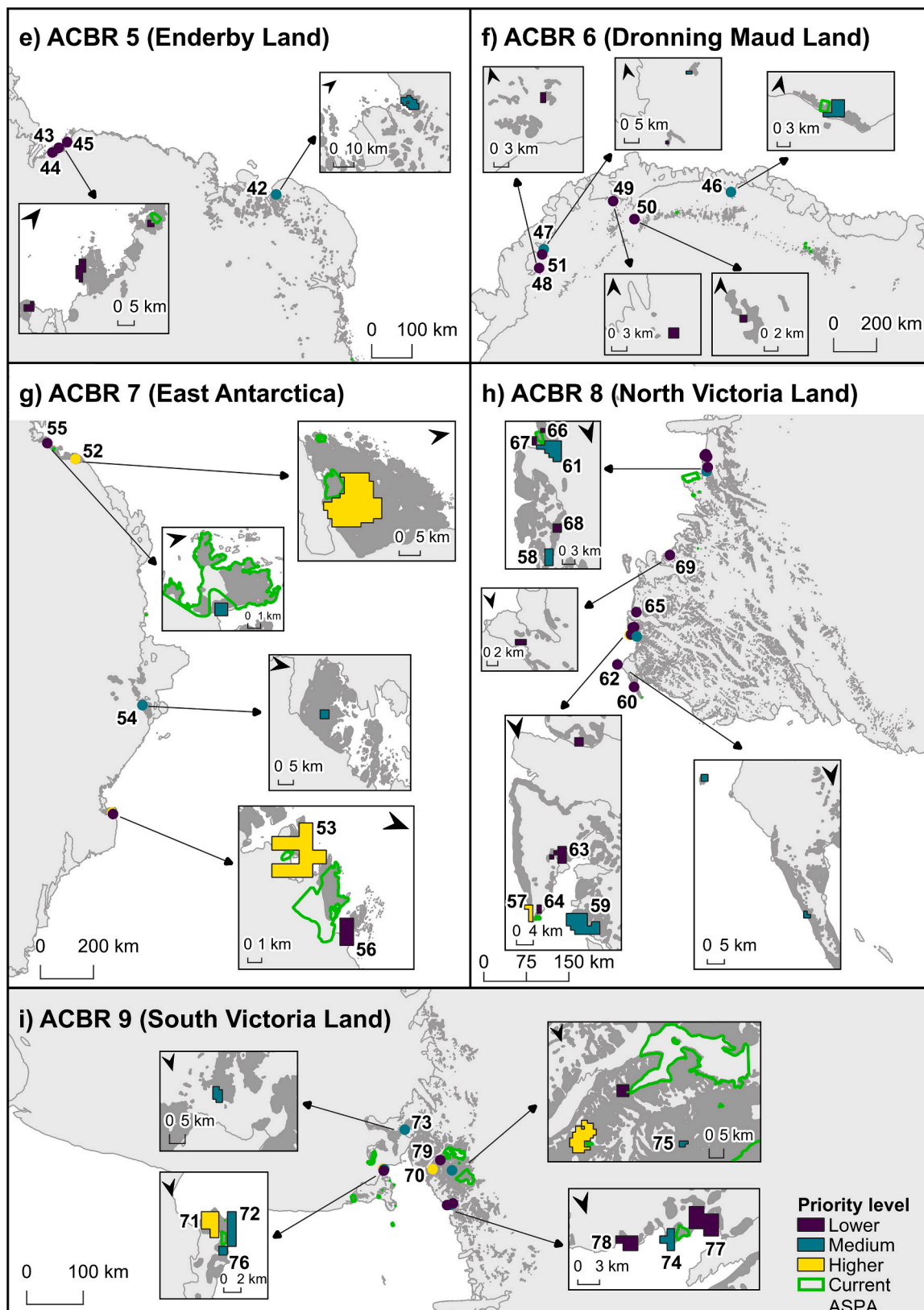
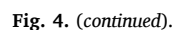


Fig. 4. (continued).

2001; Terauds et al., 2025).

Many current ASPAs are less than 1 km² in area (32%; Terauds et al., 2024b) but, due to the continental nature of this prioritisation, candidate sites <1 km² in area could not be identified. Consequently, it is

likely that the candidate sites contain internal hotspots of vegetation cover and/or the presence of taxa within them. This is particularly likely in larger candidate areas such as the Vestfold Hills (125 km²; Tables 2, S3), which was selected in its entirety as one of the most suitable



help identify the most valuable sites for protection within, as well as to confirm the vegetation presence predicted in the satellite-derived and modelled vegetation datasets. Proposed sites for ASPA designation might thus be smaller in size than is suggested by the conservation

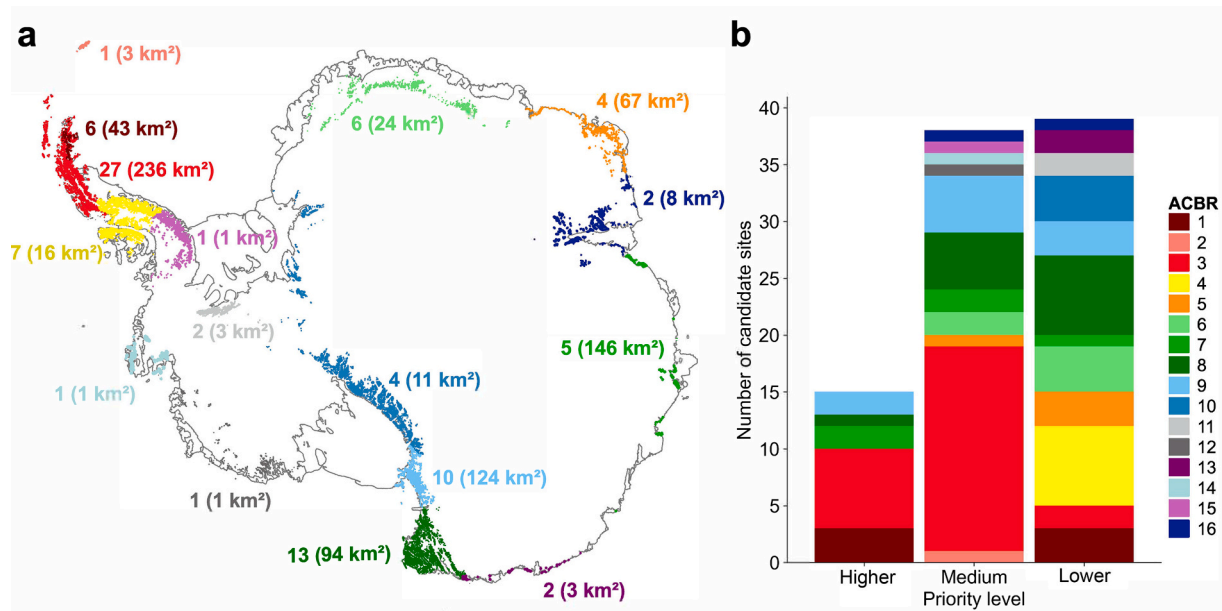


Fig. 5. Summary of candidate sites for informing future terrestrial vegetation protection in Antarctica. (a) Total number of candidate sites per Antarctic Conservation Biogeographic Region (ACBR) across the continent, with the cumulative total proposed protected area from the candidate sites displayed in brackets. (b) Number of candidate sites categorised by level of priority (higher, medium, lower) in each ACBR. The continent outline layer is available from the Antarctic Digital Database (<http://www.add.scar.org/>), and ACBR layer from Terauds and Lee (2016).

Table 2

Thirteen of the 15 highest-ranking new candidate sites, containing both satellite-derived and modelled vegetation data (the full list of the 92 candidates, along with additional details, is provided in Table S3).

Candidate number	Candidate name	ACBR	Candidate site area (km ²)	Priority index value (0–4)
2	Terrapin Hill	1	23	1.97
3	Cape Obelisk	1	4	1.75
9	Parts of Deception Island (Holtedahl Hill)	3	5	2.06
10	Fildes Peninsula (b)	3	4	1.96
11	Potter Peninsula	3	2	1.93
12	Hurd Peninsula	3	17	1.85
13	Parts of Deception Island (Crimson and Ronald Hills)	3	7	1.84
14	Barton Peninsula	3	17	1.79
52	Vestfold Hills	7	125	2.88
53	Bailey Peninsula	7	9	2.34
57	Cape Hallett	8	5	1.88
70	Taylor Valley (ground adjacent to Furlong Creek and Lake Fryxell)	9	60	2.29
71	Arrival Heights (Crater Hill and Leitch Ridge)	9	5	2.1

prioritisation here.

Other candidate sites which could be prioritised for further ground validation include those identified in the southern Transantarctic Mountains within the ‘polar hole’, where no satellite data are available (Fig. 2a). These represent sites based on modelled taxa only, including Cleft Peak (candidate 81) and Paradise Ridge (candidate 82) (Fig. 4j). Similarly, candidate sites identified in ACBRs 2, 11, 12, 14 and 15, where there were no modelled predictions for taxon presence above our threshold level (Terauds et al., 2024a; Supporting Information section 1.2), so are based only on satellite cover data. These include: parts of Signy Island (candidate 7; which overlaps with the recently agreed ASPA ‘Parts of Signy Island and adjacent Islands’), Meyer Hills (candidate 84), Bell Valley (candidate 85), Matthewson Point (candidate 86), Lindsay

Islands (candidate 89) and Mount Tricorn (candidate 90) (Fig. 4b, k–o; Table S3).

Site-specific evaluation by relevant Antarctic Treaty Parties, including field validation and appropriate expert input, will be essential to confirm the appropriateness of any candidate site for informing new ASPA proposals, in accordance with Annex V to the Environmental Protocol. Importantly, integrating vegetation data from multiple sources (e.g. opportunistic ground observations) will be critical to identify further local areas containing rich or unique vegetation communities that were not identified in this study. This is especially the case for sites that are practically difficult to access and for vegetation extent below satellite detection limits. We also used inclusion targets of 30%, which might not capture all of the rich or valuable vegetation communities in some ACBRs. For example, only one additional candidate site was needed in ACBR 2 (the South Orkney Islands) to meet the 30% coverage target, with the current ASPAs already included in the solution.

Finally, conducting the prioritisation on a per-ACBR basis, and applying a consistent inclusion target to the vegetation features (30% of satellite-derived vegetation cover and modelled taxa), was designed to address the uneven representation of vegetation within the current ASPA system. This approach ensured that each ACBR contributed candidate sites in proportion to its overall modelled and remote-sensed vegetation estimates, including areas with lower vegetation extent and/or fewer modelled taxa, that were often overlooked in the continent-wide prioritisation (Fig. S3). By promoting a more representative distribution of protected vegetation, these candidate sites directly support efforts to improve the representativeness of the ASPA system for terrestrial vegetation, in accordance with Annex V to the Environmental Protocol and the CEP’s Work Plan, and in the face of increasing pressures such as climate change and human activities.

4.3. Limitations of continental-scale vegetation data

At present, deriving vegetation data at the continental scale in Antarctica can only be achieved through satellite remote sensing and/or modelling approaches, due to the remoteness and inaccessibility of many ice-free areas which, along with lack of available terrestrial biodiversity expertise, significantly restricts the opportunity for detailed

ground surveys. However, without corresponding ground survey data, satellite and modelled vegetation estimates must be evaluated carefully in order to derive useful information. For example, using the medium-resolution satellite estimates in Walshaw et al. (2024), we identified 8.8 km² in total of protected vegetation, compared to 16.1 km² identified using high-resolution imagery by Hughes et al. (2015). These differences in detected area are largely attributable to varying sensor resolution and NDVI thresholds used to detect vegetation in each study, with Walshaw et al. (2024) applying more conservative detection criteria to coarser-resolution imagery. The latter was designed to increase confidence in the areas that were detected, but consequently meant that not all vegetated areas reached the threshold to be included. This limitation is particularly pertinent for lichens, with recent studies based on ground survey data (de Jonge et al., 2026) and high-resolution drone imagery (Bollard et al., 2022; Amarasingam et al., 2025; Sandino et al., 2025) detecting multiple orders of magnitude greater extent of lichen than the satellite imagery used in Walshaw et al. (2024). For example, model-extrapolated ground survey data on East Lagoon Island (Ryder Bay) predicted over eighteen times more lichen cover than Sentinel-2 satellite detections over the same area (de Jonge et al., 2026; Walshaw et al., 2024). Such findings indicate significant underestimates for this vegetation group detected with medium-resolution satellite imagery. Nevertheless, both Walshaw et al. (2024) and Hughes et al. (2015) yielded comparable relative estimates of protection across the ACBRs, with both detecting the majority of protected vegetation (96–97%) within ACBRs 2 and 3 in the maritime Antarctic. More specifically, Byers Peninsula (ASP A 126), Harmony Point (ASP A 133) and Cierva Point (ASP A 134) in ACBR 3 (Figs. 2c, S5) together accounted for the largest proportion (60–70%) of all protected vegetation in both studies.

Overall, the detection limit constraints of the satellite data (especially for lichens), combined with the spatial and taxonomic incompleteness of the modelled taxa (Patterson et al., 2025a; Terauds et al., 2024a), indicate that the prioritisation overlooked low-abundance and rich/diverse patches of vegetation in each ACBR. Therefore, the candidate sites generated in this study, and the accuracy of their contribution towards the 30% protection target in each ACBR, are limited to the vegetation features that were identified using the currently available data at the continental scale (Terauds et al., 2024a; Walshaw et al., 2024), and should be evaluated accordingly when informing future conservation planning. It is highly likely that the total extent of vegetation at the continental scale is underestimated in satellite imagery (Walshaw et al., 2024) and that further protection, in addition to the candidate sites identified here, would be required to meet a 30% target within each ACBR.

To improve the accuracy of vegetation estimates and identify unprotected vegetation not captured in this analysis (including cryptic communities not detectable via satellite remote sensing), the integration of additional datasets and higher-resolution remote sensing data is now vital (Perterra et al., 2024; Salinas et al., 2024; Tóth et al., 2025). Such data are now becoming available through drone surveys (Amarasingam et al., 2025; Platel et al., 2025; Sandino et al., 2025), detailed ground surveys (de Jonge et al., 2026), and additional modelling approaches (Anderson et al., 2024; Koerich et al., 2025; Patterson et al., 2025b), though it will likely be some time before such data are collated at a continental scale.

In conclusion, the new candidate sites presented here, along with their associated priority rankings, are intended to support the CEP and Antarctic Treaty Parties in identifying new areas of unprotected vegetation, and to encourage updates to current management plans to improve recognition and management of terrestrial vegetation values. These site prioritisations are based on the best currently available continent-scale data and our systematic analysis, and will require additional support through detailed ground validation surveys, engagement with appropriate expertise, and the consideration of management needs. We provide the ATCM and CEP with a systematic

framework for identifying potential priority sites to inform the establishment of a more representative ASPA network and support the protection of Antarctica's increasingly vulnerable terrestrial vegetation.

CRediT authorship contribution statement

Charlotte V. Walshaw: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mariana García Criado:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kevin A. Hughes:** Writing – review & editing, Supervision, Resources, Methodology, Conceptualization. **Claudia Colesie:** Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization. **Hannah S. Wauchope:** Writing – review & editing, Resources, Data curation. **Peter Convey:** Writing – review & editing, Supervision. **Andrew Möller Gray:** Writing – review & editing, Data curation. **Jasmine R. Lee:** Writing – review & editing, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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.biocon.2026.112121>.

Data availability

The shapefile and full list of candidate sites (Table S3) are available in the figshare repository at: <https://doi.org/10.6084/m9.figshare.30600782>.

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