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Antarctic biogeography revisited: updating the Antarctic Conservation Biogeographic Regions

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ABSTRACT

The Antarctic Conservation Biogeographic Regions (ACBRs), originally proposed in 2012, are now established as an important tool in Antarctic science, conservation, management and policy. Here, we provide a revised version of the ACBRs, reflecting updates in underlying spatial layers, together with the results of new analyses justifying the inclusion of a 16th bioregion. This updated version now covers all ice-free areas of Antarctica and is publicly available through the Australian Antarctic Data Centre. In light of the interest in the ACBRs across a variety of research fields, we also provide a new set of summary statistics for the updated spatial layer, including landscape metrics, climate data, protected area coverage and an overview of human activity. The updated ACBRs represent a contemporary, practical and evidence-based foundation for understanding, conserving and managing Antarctic biodiversity at a continental scale.

Keywords

Antarctic biodiversity, Antarctic Conservation Biogeographic Regions, biogeographical zones, conservation planning, multivariate analyses, spatial ecology.

INTRODUCTION

The original Antarctic Conservation Biogeographic Regions (ACBRs) were the culmination of a multinational collaboration that reviewed and refined the conservation biogeography of Antarctica (Terauds *et al.*, 2012). The original analyses delineated 15 biologically distinct regions (ACBRs, also referred to as bioregions or ecoregions) that covered most of the ice-free area of the Antarctic continent and Antarctic Peninsula. The ACBRs were endorsed at the XXXV Antarctic Treaty Consultative Meeting (ATCM, Resolution 6, 2012) and are now considered an integral part of international Antarctic science, policy and management.

Their importance in this regard is exemplified by their extensive use across a range of studies; including in the assessment of current levels of area protection (Shaw *et al.*, 2014; Hughes *et al.*, 2016), spatial analyses of biodiversity (e.g. Convey *et al.*, 2014; Fraser *et al.*, 2014; Chown *et al.*, 2015), non-native species (McGeoch *et al.*, 2015), as part of broader biogeographical reviews (Ebach & Parenti, 2015) and by their inclusion in a revision of the Terrestrial Ecoregions of the World that is nearing completion (see Olson *et al.*, 2001 for original delineation and http://www.worldwildlife.org/biomes for an overview). Furthermore, all new management plans for proposed Antarctic Specially Protected Areas (ASPAs), and updates to existing management plans for ASPAs, which are presented to the Committee for Environmental Protection (CEP) to the Antarctic Treaty System, now include the ACBR in which they are situated (ATCM Resolution 6, 2012).

Here, we present an update to the original ACBRs. We had multiple objectives in this revision. Foremost of these was to ensure that the bioregions reflected the most current representation of Antarctic ice-free areas. In that respect, we provide an updated spatial layer of the ACBRs based on the newest version of the Scientific Committee on Antarctic Research (SCAR) Antarctic Digital Database (ADD) rock outcrop layer (Version 7 – www.add.scar.org). This layer was made publicly available in January 2016, and represents the best current knowledge of all ice-free areas in Antarctica. We also take this opportunity to present new analyses that justify the inclusion of a 16th bioregion and rectify minor errors in the original delineation.

In light of the interest in the ACBRs across a variety of research fields, and their predominance as a tool in contemporary Antarctic science, management and policy, we also provide a new set of summary statistics for the updated spatial layer, including landscape metrics, climate data, protected area coverage and an overview of human activity. In addition to updating and making available the new ACBR

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layer (http://dx.doi.org/10.4225/15/5729930925224), we also provide updated point and polygon layers of the current ASPAs (http://dx.doi.org/10.4225/15/572995579CD36), to reflect changes that have occurred since 2011 when the original layers were compiled (ERA, 2011).

METHODS

Updating the Antarctic Conservation Biogeographic Regions

The spatial extent of the original ACBRs was based on the 1 : 1 million resolution rock outcrop layer from Version 5 of the Antarctic Digital Database. Oceanic Antarctic islands (Balleny Islands, Peter I Øy, and Scott Island) were excluded, as were islands north of 60° S. We first overlaid the original ACBRs on the newest ADD rock outcrop layer (Version 7 – 'medium resolution' www.add.scar.org) and transcribed the original boundaries onto the new layer. We chose the medium resolution layer as this is the current equivalent of the 1 : 1 million resolution used in the original delineation. Due to a high level of similarity between ADD v5 and ADD v7 rock outcrop polygons, particularly those at the boundaries of the ACBRs, the ACBR boundaries could be mapped across to the new layer seamlessly, without the need for splitting any ice-free polygons. During this process, we also identified any new polygons that were within the broader area of each ACBR delineation and ensured all were assigned to that ACBR. Finally, we merged any contiguous polygons within each ACBR. All spatial layer manipulations were done using R (R Core Team 2015 – package RASTER Hijmans, 2015) and ARCGIS (10.3).

Evidence for a 16th ACBR

The only substantial area of ice-free land that was not covered by the original ACBRs was situated in east Antarctica, around the Prince Charles Mountains and associated coastline, lying between ACBR 5 (Enderby Land) and ACBR 7 (East Antarctica). Although the biodiversity in this area was not clearly differentiated from other ACBRs in the original analyses of Terauds *et al.* (2012), here we undertake new analyses, comparing the community structure and composition across the ACBRs (including the new ACBR) and also explicitly comparing the new 16th ACBR with each of the original ACBRs. We used the same biodiversity dataset used by Terauds *et al.*, 2012; with the R packages VEGAN (Oksanen *et al.*, 2015) and MVABUND (Wang *et al.*, 2014). These analyses took the form of: (1) permutational multivariate analyses of variance using distance matrices (VEGAN::ADONIS); permutational analysis of similarities using dissimilarity matrices (VEGAN::ANOSIM) and multivariate generalized linear models (MVABUND::MANYGLM). The latter method differs from the first two in that it does not use distance-based metrics to make the comparisons, therefore alleviating some of the issues with the mean−variance relationship associated with those techniques (see also Warton *et al.*, 2012).

To facilitate these analyses, we pooled the original species presence data into 10 km grid cells that had been generated across the entire ice-free area of Antarctica. Using these cells

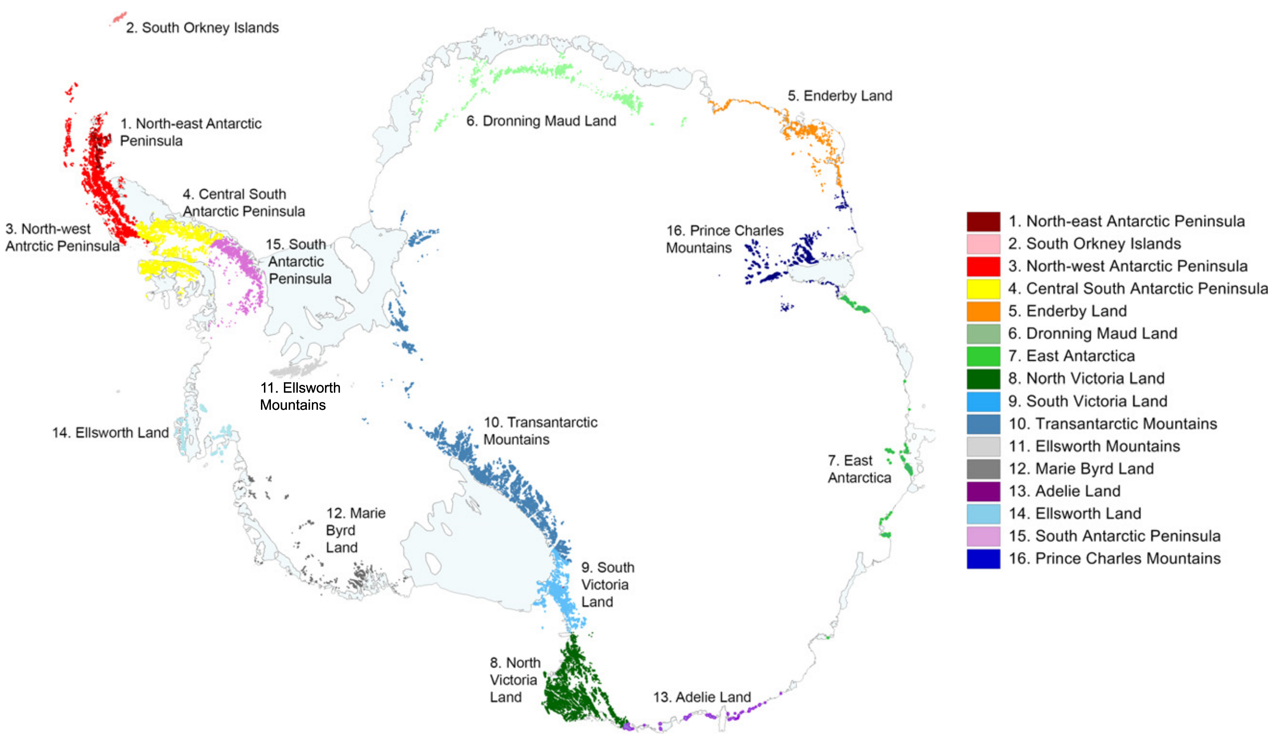

Figure 1 Updated version of the Antarctic Conservation Biogeographic Regions (ACBRs v2).

Table 1 Summary statistics for updated Antarctic Conservation Biogeographic Regions (ACBRs v2).

ACBR identifier	ACBR name	Total ACBR area (km^2)	Mean area of individual ice-free polygons (km^2)	Mean altitude (m)	Mean annual temperature (°C)	Number of ASPAs (for biodiversity)*	Areas of ASPA in ACBR (km^2) (for biodiversity)*	% of ACBR covered by ASPAs (for biodiversity)	Number of stations or permanent infrastructure	Number of tourist landings (2014–2015)
ACBR1	North-east Antarctic Peninsula	1215	3.33	412.6	−7.4	1 (0)	0.4 (0)	0.03 (0)	4	1503
ACBR2	South Orkney Islands	160	1.52	21.0	−3.2	3 (3)	4.8 (4.8)	3.03 (3.03)	2	1038
ACBR3	North-west Antarctic Peninsula	5183	1.00	572.2	−6.9	21 (17)	103.1 (100.5)	1.99 (1.94)	38	213074
ACBR4	Central South Antarctic Peninsula	4962	1.09	911.8	−11.6	2 (2)	77.4 (77.4)	1.56 (1.56)	1	6
ACBR5	Enderby Land	2188	2.21	549.9	−15.6	1 (1)	4.9 (4.9)	0.23 (0.23)	4	0
ACBR6	Dronning Maud Land	5523	5.31	1851.4	−23.9	2 (2)	9.1 (9.1)	0.17 (0.17)	9	81
ACBR7	East Antarctica	1109	3.46	114.9	−12.9	9 (8)	43.4 (27.9)	3.91 (2.51)	8	0
ACBR8	North Victoria Land	9431	2.18	1486.8	−21.8	6 (5)	4.4 (4.4)	0.05 (0.05)	5	669
ACBR9	South Victoria Land	10038	12.80	1109.6	−22.5	16 (11)	432.8 (431.2)	4.31 (4.29)	3	1296
ACBR10	Transantarctic Mountains	18480	5.53	1732.7	−25.5	1 (1)	42.6 (42.6)	0.23 (0.23)	1	0
ACBR11	Ellsworth Mountains	2859	5.44	1801.5	−24.9	0	0 (0)	0 (0)	0	701
ACBR12	Marie Byrd Land	1128	2.39	1054.8	−17.4	0	0 (0)	0 (0)	1	15
ACBR13	Adelie Land	178	1.7	222.5	−16.4	1 (1)	0.05 (0.05)	0.03 (0.03)	2	0
ACBR14	Ellsworth Land	217	1.26	479.2	−13.1	0	0 (0)	0 (0)	0	96
ACBR15	South Antarctic Peninsula	2875	1.55	1149.0	−18.1	0	0 (0)	0 (0)	0	0
ACBR16	Prince Charles Mountains	5992	9.20	937.4	−24.2	4 (3)	25.6 (5.0)	0.43 (0.08)	3	0

*Based on updated ASPA polygon layer (data.aad.gov.au, DOI 10.4225/15/572995579CD36) as 'sites' (n = 794), the species data as the multivariate response (n = 1830) and the ACBR designation as the grouping factor (i.e. a factor with 16 levels), we used all three methods to test for differences in community composition across the ACBRs. In the third method, we also used the multivariate binominal model, with the community matrix as the response and ACBR as the single covariate (again, as a factor with 16 levels), to test for differences in community composition between each ACBR and the new ACBR (see Wang *et al.*, 2012 for more details on the multivariate binomial model).

Summary statistics

Total ACBR area was calculated by summing the area of all individual discrete ice-free patches. Mean altitude above sea level of each ACBR was obtained from the 200 m resolution Digital Elevation Model (DEM) provided by the Radarsat Antarctic Mapping Project (RAMP – Liu *et al.*, 2001). For mean temperature, we first calculated the spatially explicit (10 km resolution) daily average of 3 hourly records from the Antarctic Mesoscale Prediction System (AMPS; http://www2.mmm.ucar.edu/rt/amps/), reprojecting it to match the projection of the ACBR layer, and taking the mean across the ice-free area of each ACBR for 2014. The ASPA polygon and point layers (ERA, 2011) were updated to reflect recent changes, ensuring that any recently de-designated ASPAs (ASPA 114 Northern Coronation Island; ASPA 118 Summit of Mount Melbourne; ASPA 130 Tramway Ridge) were removed from the dataset, and that any newly designated ASPAs (ASPA 172 Lower Taylor Glacier and Blood Falls; ASPA 173 Cape Washington and Silverfish Bay; ASPA 174 Stornes; ASPA 175 High Altitude Geothermal sites of the Ross Sea region) were added. The new ACBR layer (hereafter ACBR v2) was then used to 'clip' the new ASPA layer, so only the portion overlapping with the ice-free areas was retained. The number and area of ASPAs were then calculated from the ACBR v2 layer and the clipped ASPA layer. Tourist visits for the 2014–2015 season were obtained from the International Association of Antarctic Tour Operators (IAATO, 2015) and station locations and numbers were obtained from the Council of Managers of National Antarctic Programs (COMNAP, 2014) and the ADD version 7 Facilities_point spatial layer (www.add.scar.org).

RESULTS AND DISCUSSION

The total area of the ACBRs increased from 66,815 to 71,537 km^2. We note that while this is higher than the current best resolution area of ice-free Antarctica (45,886 km^2 – calculated from the ADD 'high resolution' V7 rock outcrop layer, excluding oceanic islands and removing duplicate or merging overlapping polygons), the medium resolution is more practical for spatial planning purposes and provides a small buffer around the actual edges of the ice-free areas, in keeping with the intent of the original delineation (Terauds *et al.*, 2012). Most of the increase (99%) was attributable to the addition of the 16th ACBR – hereafter known as the Prince Charles Mountains (ACBR 16). The delineation of this bioregion, together with the process of updating and correcting the original layer, resulted in the new ACBR layer covering all ice-free land in Antarctica (Fig. 1).

The multiple tests performed here all confirmed significant differences in community composition across the 16 ACBRs: VEGAN::ADONIS (F = 4.6, P < 0.001, 10,000 permutations); VEGAN::ANOSIM (ANOSIM R = 0.23, P < 0.001, 10,000 permutations) and MVABUND (Test statistic = 68.9, P = 0.011). In addition to these broad differences, the detailed MVABUND::MANYGLM analyses showed that the new ACBR (ACBR 16 – Prince Charles Mountains) was significantly different to each of the other ACBRs in the multivariate model (Wald statistic range: 2.1–12.7; P < 0.05 in each case), clearly justifying its inclusion in the updated version.

Based on the RAMP Digital Elevation Model, the mean altitude of the ACBRs, ranged from below 100 m at the South Orkney Islands (ACBR2) to above 1800 m in Dronning Maud Land (ACBR6; Table 1). Temperature was strongly (negatively) correlated with altitude (Pearson product moment correlation, t = −4.2, P < 0.001) with the coldest ACBR on average being the Transantarctic Mountains (ACBR 10; Table 1). Four ACBRs had no area protection in the form of ASPAs, and five had no area protection for the purposes of protecting biodiversity (Table 1). South Victoria Land had the highest proportion of its area protected by ASPAs (4.3%) and 11 of the 16 ACBRs had < 1% of their area protected by ASPAs. Most human activity was concentrated in ACBRs on the Antarctic Peninsula, with both scientific and tourist activities highest in the North-west Antarctic Peninsula (ACBR 3; Table 1).

The ACBRs have been formally recognized by the Antarctic Treaty Parties as a useful tool to support activities relevant to their interests, including as a dynamic model for the identification of new Antarctic Specially Protected Areas. Since this endorsement, their role in Antarctic conservation and management has escalated, and they continue to provide a robust foundation for conservation and management of terrestrial Antarctica. As noted in the original delineation, these ecoregions are purposely broad in scale, and do not preclude localized differences at finer scales. As more biodiversity data become available, especially at a phylogeographic level, future assessments will continue to be made using emerging multivariate methods and other analytical techniques. However, the analyses presented here confirm that the ACBRs v2 are a contemporary, practical and evidence-based representation of Antarctic biogeography at a continental scale.

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BIOSKETCHES

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Author Contributions: A.T. conceived the idea. A.T and J.R.L developed the spatial layers, analysed the data and wrote the paper.

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