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L. Pertierra, P. Convey, A. Barbosa, E. Biersma, D. Cowan, J. Diniz-Filho, A. de los Ríos, P. Escribano-Álvarez, C. Fraser, D. Fontaneto, et al.

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1 **REVIEW**

2 ***Advances and shortfalls in knowledge of Antarctic terrestrial and***
3 ***freshwater biodiversity***

4 **Pertierra LR^{1,2,3,4}, Convey P^{5,6}, Barbosa A^{7,†}, Biersma EM⁸, Cowan D⁹, Diniz-Filho**
5 **JAF^{10,11}, De los Ríos A¹², Escribano-Álvarez P¹, Fraser CI¹³, Fontaneto D^{14,15},**
6 **Greve M², Griffiths HJ⁵, Harris M², Hughes KA⁵, Lynch HJ¹⁶, Ladle RJ^{11,17}, Liu XP¹³,**
7 **le Roux PC², Majewska R^{18,19}, Molina-Montenegro MA²⁰, Peck LS⁵, Quesada A²¹,**
8 **Ronquillo C⁴, Ropert-Coudert Y²², Sancho LG²³, Terauds A^{24,25,26}, Varliero G^{9,27},**
9 **Vianna JA^{3,28,29}, Wilmotte A³⁰, Chown SL²⁶, Olalla-Tárraga MÁ¹, Hortal J^{4,11}**

10 ¹Departamento de Biología, Geología, Física y Química Inorgánica, Universidad Rey Juan Carlos, Mostoles,
11 Spain.

12 ²Department of Plant & Soil Sciences, University of Pretoria, South Africa.

13 ³Millennium Institute of Biodiversity of Antarctic and sub-Antarctic Ecosystems BASE, Santiago, Chile.

14 ⁴Department of Biogeography and Global Change, Museo Nacional de Ciencias Naturales-CSIC, Madrid,
15 Spain.

16 ⁵British Antarctic Survey, Cambridge, United Kingdom.

17 ⁶Department of Zoology, University of Johannesburg, Johannesburg, South Africa.

18 ⁷Departamento de Ecología Evolutiva, Museo Nacional de Ciencias Naturales-CSIC, Madrid, Spain.

19 ⁸Natural History Museum of Denmark, University of Copenhagen, Copenhagen, Denmark.

20 ⁹Centre for Microbial Ecology and Genomics, Department of Biochemistry, Genetics and Microbiology,
21 University of Pretoria, Pretoria, South Africa.

22 ¹⁰Departamento de Ecología, Instituto de Ciências Biológicas, Universidade Federal de Goiás, Goiânia,
23 Brazil.

24 ¹¹National Institute for Science and Technology in Ecology, Evolution, and Biodiversity Conservation (INCT
25 EECBio), Universidade Federal de Goiás, Goiânia, Brazil.

26 ¹²Departamento de Biogeoquímica y Ecología Microbiana, Museo Nacional de Ciencias Naturales-CSIC,
27 Madrid, Spain.

28 ¹³Department of Marine Science. University of Otago, Dunedin, New Zealand.

29 ¹⁴Natural Research Council, Water Research Institute (CNR-IRSA), Verbania, Italy.

30 ¹⁵National Biodiversity Future Center (NBFC), Palermo, Italy

31 ¹⁶Department of Ecology and Evolution, Stony Brook University, New York, United States.

32 ¹⁷Institute of Biological and Health Sciences, Federal University of Alagoas, Maceió, Brazil.

33 ¹⁸Faculty of Biosciences and Aquaculture, Nord University, Bodø, Norway

34 ¹⁹Unit for Environmental Sciences and Management, North-West University, Potchefstroom, South Africa.

35 ²⁰Instituto de Ciencias Biológicas, Universidad de Talca, Talca, Chile.

36 ²¹Departamento de Biología. Universidad Autónoma de Madrid, Cantoblanco, Spain.

37 ²²Centre d'Etudes Biologiques de Chizé, La Rochelle Université, France.

38 ²³Departamento de Biología Vegetal II. Universidad Complutense de Madrid, Madrid, Spain.

39 ²⁴Australian Antarctic Division, Department of Climate Change, Energy, the Environment and Water,
40 Kingston, Australia.

41 ²⁵Securing Antarctica's Environmental Future, Queensland University of Technology, Brisbane, Australia.

42 ²⁶Securing Antarctica's Environmental Future, Monash University, Melbourne, Victoria, Australia.

43 ²⁷Rhizosphere Processes Group, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

44 ²⁸Faculty of Biological Sciences, Pontificia Universidad Católica de Chile, Santiago, Chile.

45 ²⁹Millennium Institute Center for Genome Regulation, Santiago, Chile.

46 ³⁰InBios Research Unit. University of Liège, Liège, Belgium.

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48 *corresponding author. E-mail: luis.pertierra@gmail.com

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50 †Deceased: This work is dedicated to the memory of Andrés Barbosa, who sadly passed
51 away in 2023. His large contributions to Polar Research extend to this work, as he died
52 while we were preparing the second version of this manuscript. He will be sorely missed.

53

54 **Abstract**

55 Antarctica harbours many unique features of life yet much about the diversity and
56 functioning of Antarctica's life remains unknown. Evolutionary histories and functional
57 ecology are well understood only for vertebrates, while research on invertebrates is
58 largely limited to species descriptions and some studies on environmental tolerances.
59 Knowledge on Antarctic vegetation cover showcases the challenges of characterizing
60 population trends for most groups. Recent community-level microbial studies have
61 provided insights into the functioning of life at its limits. Overall, biotic interactions remain
62 largely unknown across all groups, restricted to basic information on trophic level
63 placement. Insufficient knowledge of many groups crucially limits the understanding of
64 ecological processes on the continent. Remedies for the current situation rely on
65 identifying the caveats at each ecological discipline and finding targeted solutions. Such
66 precise delimitation of knowledge gaps will allow defining a more aware, representative
67 and strategic systematic conservation planning of Antarctica.

68

69 ***The value of Antarctic biodiversity research***

70 Antarctica, one of Earth's last great wildernesses, harbors unique and underappreciated
71 biodiversity (1). In just two centuries of exploration, research on Antarctic ecosystems
72 has generated critical insights into the evolution and functioning of biodiversity at the
73 cold, nutrient-deficient and dry limits to life on Earth (2, 3). Antarctic ecosystems provide
74 vital services (4), including modulating global oceanic and atmospheric systems, and the
75 continent is a bellwether of the planet's climate state, given its rapid transformation and
76 its global connections and impacts (5).

77 Antarctic terrestrial biodiversity faces significant threats from global environmental
78 change and human pressures, including wildlife disturbance and invasive alien species
79 (6, 7). Its isolation, extreme conditions, and comparatively low disturbance levels (1)
80 make Antarctica a key sentinel for global change (4). In recent decades, extensive
81 international research cooperation has led to significant breakthroughs in understanding
82 of Antarctic biodiversity, overturning previous paradigms of evolutionary patterns and
83 processes across biological scales (8, 9). The co-existence of several national biological
84 research programs studying the relatively low diversity of the continent make the
85 inventory of Antarctic organisms more complete than in many other regions. Despite
86 such significant funding, scientific progress has been uneven, with research biased
87 towards mainstream fields of study, the most accessible or charismatic species (10).
88 Substantial knowledge gaps remain, particularly on complex functions and remote and
89 cryptic ecosystems and species (11). Early syntheses of available knowledge of Antarctic
90 biodiversity have, however, largely overlooked the substantial biases resulting from
91 shortcomings in understanding the continent's ecological dynamics (12), critically limiting
92 the development of effective conservation efforts (13). This underscores the need for a
93 more informed account of recent advances, gaps, and biases in biodiversity knowledge
94 to guide future research and conservation investments (14). In this analytical review we
95 provide a comprehensive assessment of the state of knowledge of all terrestrial
96 biodiversity in Antarctica (see materials and methods (15) as well as supporting data files
97 (16)). We compiled all records on Antarctic species identities into TerrANTALife, a
98 database covering all terrestrial and freshwater eukaryotic species, and amplicon
99 sequence variants (A.S.V.) of prokaryotes (9, 17) of the continent. Data coverage was
100 evaluated through discovery rates and spatial distribution of survey completeness for
101 spatio-temporal occurrence data, and using major global repositories (18-22) for
102 mapping out coverage of other aspects of biodiversity (Fig. 2). We classify knowledge
103 limitations (hereafter 'shortfalls') into basic areas of ecological and evolutionary research
104 (14): (I) species inventory; (II) evolution of Antarctic life; species' (III) spatial and (IV)
105 temporal dynamics; trait-based (V) environmental tolerances and (VI) ecosystem
106 functions; and (VII) biotic interactions. We assess the severity of these knowledge
107 shortfalls relative to the scientific and conservation value of the missing information.
108 Policies that account for uncertainty and knowledge gaps are better suited to advance
109 scientific research and conservation practice under the Antarctic Treaty System (13, 23).
110 Lastly, the current state of ecological knowledge was assessed by a panel of Antarctic
111 biodiversity experts through an IDEA (Investigate, Discuss, Estimate and Aggregate)
112 elicitation process (24) (Fig. 3).

113

114 ***Advances in describing Antarctic biodiversity and evolution***

115 About 2,100 terrestrial eukaryotic species have been identified from Antarctica, including
116 nearly 1,000 fungi (half of them lichen-forming), more than 400 animals, 300 plants, and
117 over 400 SAR/protists (such as stramenopiles, alveolates, rizarians and other unrelated
118 unicellular organisms such as amoebae) (17). For most groups, over half of the known

119 Antarctic species have been discovered in the last 50 years (Fig. 1), partly driven by the
120 growth in Antarctic research following the International Geophysical Year (1957/58) and
121 the International Polar Year (2007/08). Many endemic species, especially prokaryotes,
122 remain undiscovered (25). Limited species descriptions for all major groups and
123 underexplored regions reveal significant potential for further discoveries (Fig 1.).
124 Comprehensive inventories are essential for effective area protection and threat
125 assessment (13, 26), and indirectly for safeguarding future bioprospecting potential.

126 Knowledge of animal diversity varies widely (27), from almost comprehensive vertebrate
127 inventories to moderately complete checklists for invertebrates like microarthropods,
128 other soil and freshwater microinvertebrates, and ecto- and endo-parasites (Fig. 1).
129 Knowledge of ancestry and phylogenetic relationships is, however, limited to a few
130 species, mostly of megafauna (Figs. 2-3). Expanding molecular studies to
131 microarthropods and other microinvertebrates has revealed new species and inferred
132 species-level divergences in mites (28), springtails (29), tardigrades (30), nematodes
133 (31) and rotifers (32), although species counts remain uncertain for parasites,
134 gastrotrichs and flatworms. With a limited fossil record, diversification patterns can be
135 alternatively inferred from population genetics and time-calibrated phylogenies based
136 on non-Antarctic lineages (33, 34). Although marine vertebrates breeding on land are
137 relatively well-studied, they also show major gaps in the knowledge about their speciation
138 (35) and hybridization (36) processes.

139 Knowledge of floral diversity is generally adequate for the two native vascular plants
140 species (Antarctic hair grass, *Deschampsia antarctica* and Antarctic pearlwort,
141 *Colobanthus quitensis*) and the greater diversity of bryophytes and lichen-forming fungi
142 (Fig. 2 and S1). In contrast, knowledge of free-living microalgal and fungal groups is
143 poorer, with further taxonomic progress expected from molecular analyses. Molecular
144 and phylogeographic tools have clarified relationships among plant populations and
145 some dispersal dynamics. While the phylogeography of some Antarctic plants has been
146 assessed phylogenetically in depth (37), most Antarctic flora has yet to be studied using
147 molecular methods. Similarly, comprehensive phylogenetic and phylogeographic studies
148 are limited to a few lichen genera (e.g. (38, 39)).

149 Antarctic microorganisms are, in general, poorly known across all groups, from algae,
150 protists and fungi, to bacteria, archaea, and viruses) (Fig. 3 d-h). Nevertheless, increased
151 surveys coupled with molecular techniques have uncovered a rich cryptic diversity often
152 hiding in plain sight (40). Knowledge of the molecular diversity of snow (41) and
153 freshwater algae is limited, although a diatom compendium is now available (42).
154 Comprehensive surveys of autotrophic microorganisms are restricted to a few regions of
155 terrestrial Antarctica such as the McMurdo Dry Valleys, with estimates suggesting that
156 more than half of the species remain undescribed (e.g. Cyanophyta, (43). In contrast,
157 heterotrophic protists are better known, though total species numbers are uncertain (44).
158 Considerable information gaps remain for other unicellular Eukaryota, such as yeasts
159 (45). Broad characterizations of microbial metacommunities in regions like Victoria Land
160 (46) have identified over 80,000 bacterial Amplicon Sequence Variants for the continent
161 (17). While inventorying microbial diversity in subglacial and endoglacial environments
162 and the atmosphere entails specific technological challenges, there have been many
163 significant breakthroughs of life surviving at extreme habitats in recent years (47-49).
164 Finally, knowledge of virus diversity remains extremely poor, albeit a few highly localized

165 surveys in freshwater and soil systems have identified at least 10,000 genotypes across
166 virus families (e.g. (50, 51)). Thus, viruses represent the last frontier of Antarctic diversity.

167

168 ***Advances in mapping the spatio-temporal dynamics of Antarctic biota***

169 Surveys of terrestrial biodiversity in Antarctica have been uneven in both space and time
170 (52). Inference methods accounting for survey effort (53) show that biodiversity
171 inventories remain poor for many areas (Fig. 1b). Georeferenced species occurrence
172 records on the Global Biodiversity Information Facility (GBIF) meta-repository vary widely
173 between taxonomic groups (Fig. 2 and S2). Nonetheless, GBIF mobilizes occurrence
174 records for many species that are little known in most other respects (18). Relatedly,
175 species distributions modelling has been widely used to assess the risk of invasive
176 species expansion (e.g. (54)), but have been seldom applied native species distributions
177 compared to the Southern Ocean marine biota.

178 Repeated surveys and monitoring programs are absent for most groups and regions.
179 Long-term fauna and vegetation trend data exist for very few locations (Argentine
180 Islands, Signy Island, Baily Peninsula and Cape Hallett), where surveys have been
181 sporadically repeated over 30-60 years without any planned program (e.g. (55, 56)).
182 Experts identified substantial gaps in knowledge of population trends across almost all
183 major Antarctic biodiversity groups (Fig. 3 b-h). However, decade-long multi-taxa
184 monitoring stations recently set up in areas such as the Victoria Land Dry Valleys are
185 starting to offer unique insights into local ecosystem dynamics (57). Expanding this
186 approach is promising, but faces the critical challenge of the lack of long-term funding
187 for maintaining such monitoring stations.

188 Large vertebrates illustrate the value of long-term research. Dynamic population trend
189 studies across species ranges have been consolidated for many breeding vertebrates,
190 such as in the Mapping Application for Penguin Populations and Projected Dynamics
191 series (58). These data reveal increasing abundance of some penguin species (e.g.
192 *Pygoscelis papua*) and declines in others (*P. antarctica*). Satellite imagery and repeated
193 surveys of breeding colonies enable comprehensive mapping of seabird or seal species
194 (e.g. (59)). For several seals, penguins, and other seabirds, robust data exist on
195 population ecology aspects such as predator-prey dynamics (60) or breeding phenology
196 (61).

197 In contrast, knowledge of spatio-temporal patterns of Antarctic invertebrates ranges from
198 moderate to poor (Fig. 3b). Biogeographic studies remain scarce but with some notorious
199 exceptions establishing regional population ancestry and paleobiogeographic inferences
200 in groups like Collembola (e.g. (62)) with even some species-specific, large-scale studies
201 (29). Nematodes lack even preliminary species inventories for the continent, hampering
202 phylogeographic analyses (but see e.g. (31)). Studies of invertebrate population
203 dynamics are largely restricted to describing life cycles and bio-demographic rates (e.g.
204 in tardigrades (63) and nematodes (64)). Interannual abundance and population trends
205 of native soil microarthropods remain poorly studied, with very few studies on temporal
206 population dynamics (56).

207 Data mobilization is high for the Antarctic flora (Fig. 2 b-c), albeit knowledge about spatio-
208 temporal patterns of plants and fungi is moderate (Fig. 3 c-d). Detailed ground surveys
209 have allowed assessing population trends for vascular plants and some mosses in
210 Maritime Antarctica, including the rapid expansion of vascular plants in Signy Island

211 during the last decade, linked to regional warming (65). The non-native grass *Poa annua*,
212 introduced to Thomas Point, King George Island in the 1980s, has spread widely and
213 with increasing speed since, with a resilient soil seedbank that has hampered eradication
214 (66). Remote systems like drones and satellite imagery are advancing vegetation
215 mapping on the continent (67). Rapid shifts in moss and lichen populations have been
216 detected, but are generally monitored, with notable exceptions, only for a few groups and
217 locations, such as East Antarctica (68). Albeit restricted, studies of lichen community
218 dynamics show that this group may be particularly sensitive to climate change (e.g. (69)),
219 and surveys in remote regions like Shackleton Glacier (~87 °S) offer future opportunities
220 for range shift monitoring (70, 71).

221 Knowledge on microbiome spatio-temporal patterns lags behind flora and fauna (Fig 3
222 e-h). Nonetheless, remote sensing mapping of the total extent of green snow algae in
223 the Antarctic Peninsula offers a promising way forward (72). Moreover, biogeographic
224 regionalizations of diatoms and cyanobacteria respectively indicate high endemism and
225 well-defined bioregions within Antarctica (42, 73). Some local-scale limnetic studies
226 provide gross estimates of algal blooms which may serve as proxies for freshwater
227 Cyanophyta biomass (74) Techniques like environmental DNA metabarcoding are
228 rapidly advancing the understanding of soil microbial diversity spatio-temporal variations,
229 offering novel insights on the structure and temporal trends of microorganism communities
230 across environmental gradients (75).

231 **Advances in characterizing functional traits and abiotic tolerances**

232 All Antarctic taxa face severe knowledge gaps about functional traits, their variability,
233 and, above all, their ecological significance in extreme environments (Fig 2-3 and S3).
234 Basic knowledge about the functional strategies and trait-function relationships of
235 Antarctic primary producers is still required to understand their adaptations, and the lack
236 of systematic trait inventories prevents from comparing with organisms from other
237 regions. The apparently high number of Antarctic species with substantial functional trait
238 data is misleading, as it is limited to certain characteristics of a few plant and animal
239 groups (Fig. 3 a-d). Most studies of environmental tolerances have focused responses
240 to low temperatures, regional climate change and ozone layer depletion (7). Without
241 accurate information on species across space and time, which is lacking for many groups
242 (Fig. 3 b-h), it is impossible to understand how traits such as temperature tolerance vary
243 within communities among seasons and geographic locations. These knowledge gaps
244 hinder conservation, as traits can predict species' responses to environmental change,
245 and inform bioprospecting, e.g. by identifying new molecules of pharmacological
246 importance.

247 The most detailed functional trait information available is for breeding vertebrates,
248 particularly about the physiology, reproduction and foraging strategies of penguins and
249 seals (76, 77). However, ethical constraints make characterizing abiotic stress
250 tolerances in vertebrates challenging, thus requiring to rely on correlative niche modelling
251 and adaptive genomic studies to infer their responses to environmental change (78).

252 Virtually no trait information is available for many invertebrate groups, with the notable
253 exceptions of cold and desiccation tolerance strategies studied for a handful of model
254 arthropods like the mite *Alaskozetes antarcticus*, the springtail *Cryptopygus antarcticus*
255 and the dipterans *Belgica antarctica* and *Parochlus steineri* (e.g. (79, 80)). In non-
256 arthropod microinvertebrates, functional studies also focus on abiotic stress tolerance,

257 including cold and desiccation tolerance, as well as other edaphic factors such as salinity
258 (e.g. nematodes (81), tardigrades (82), and rotifers (83)). Whilst functional ecology
259 studies are limited to a small fraction of the microinvertebrate species living in species-
260 rich regions like the Antarctic Peninsula, they cover a high proportion of those resident
261 in species-poor areas such as the Dry Valleys. Thus, advancing functional knowledge
262 requires prioritizing underrepresented guilds in species-rich regions.

263 Various studies have examined the responses to extreme conditions of the two native
264 vascular plants of the Maritime Antarctic, including photoprotection, photosynthetic
265 activity, desiccation, cold tolerance and fitness (e.g. (84, 85)), although adaptations to
266 low temperature, desiccation and radiation stress remain poorly understood. For the
267 more diverse bryophytes, trait coverage is generally poorer than for other aspects of
268 biodiversity (Fig. 3c). Case studies in the Maritime Antarctic are limited to a few bryophyte
269 species and locations, focusing on climate warming responses (e.g. (86)). In contrast,
270 the fewer bryophyte species present in Continental Antarctica have been studied
271 relatively extensively (e.g. (87)).

272 The assessment of functional knowledge by experts was higher for lichens than other
273 groups (Fig. 3d), with many studies focusing on growth (e.g. (69)) and metabolic activity
274 (88). Research in Maritime and Continental Antarctica has addressed the influence of
275 abiotic factors like temperature, light and water availability on lichen photosynthesis and
276 growth (89, 90). Strong links between lichen diversity, annual growth, average
277 temperature, and precipitation have also been demonstrated across the continent (91).

278 Studies on microorganisms have been mostly limited to snow algal growth and
279 tolerances, and baseline knowledge on freezing and radiation resistance (e.g.(92)).
280 Genomic, metagenomic and proteomic research on Antarctic prokaryotes is already
281 yielding insights into functional traits at the community level (e.g., (93)), though *in situ*
282 functional assay data are scarce. For instance, recent soil habitability studies have
283 identified the functional attributes of microbial communities driven by abiotic gradients
284 (75, 94), but metatranscriptomic studies documenting gene-expression at the community
285 level are severely hampered by the low mRNA extraction yields resulting from the low
286 biomass and low transcription rates in many Antarctic habitats, particularly soils. Some
287 community-level functional data exist on carbon fixation, respiration rates, nitrogen
288 cycling and trace gas (CO₂, H₂O) assimilation (93-95), yet microbial community
289 responses to abiotic conditions remain poorly understood. Recent *in situ* and *ex situ*
290 studies have explored the effects of radiation, temperature, nutrient supplementation
291 and/or soil wetting (e.g. (96)), but largely focusing on microbial community composition
292 rather than on its functionality. While the abiotic and, to a lesser extent, biotic drivers
293 behind the response of microbial community structure to environmental gradients are
294 beginning to be disentangled (97, 98), their influence on ecosystem functioning over
295 space and time is still unresolved.

296

297 ***Advances in understanding species interactions and ecological networks***

298 The role of biotic interactions in structuring Antarctic terrestrial ecosystems remains
299 largely unexplored. Competitive interactions have been classically considered to play a
300 minor role in Antarctica compared to other regions due to the reduced biodiversity and
301 extreme abiotic pressures (99). Growing evidence of such interactions, albeit still limited,
302 is now emerging at all levels (11, 100). Although there is a basic understanding of which
303 are the primary producers, grazers, predators, parasites and detritivores in terrestrial

304 food webs (101), interactions are seldom quantified, and the original expectations of
305 progress (102) have only been materialized for a few systems (103). Indeed, databases
306 hold virtually no records of ecological interactions even for groups with data about other
307 aspects of biodiversity (Figs. 2-3 and S4), despite the critical importance of this
308 knowledge for biosecurity and living resources management, which requires
309 understanding the resilience of ecological networks to disturbances.

310 Complex hypotheses about interactions have only been assessed in the best-studied
311 animal groups, such as coastal macrofauna (seals and seabirds) (104). Trophic
312 interactions between different elements of the terrestrial food web can, however, be
313 informed by stable isotope studies (e.g. (105), although few such studies are yet
314 available (but see (106)). Lists of ectoparasites, epibionts and endoparasites of Antarctic
315 vertebrates have recently been published (107) and a recent study describes forms of
316 neutral commensalism of tardigrades associated with seabird nests (108).

317 Several studies have assessed potential competition and facilitation amongst native and
318 non-native vascular plants (109), but little attention has been given to bryophytes and
319 lichens, which are the primary components of Antarctic vegetation. Although competition
320 for space would appear to be the most important biotic interaction affecting these groups,
321 its impact on the composition and structure of their communities in Antarctica has not
322 been studied in depth. Symbiotic relationships, such as between lichen photobionts and
323 mycobionts, have been more widely explored (e.g. (110)), and the symbiotic forms of
324 rhizobacteria, fungal endophytes of plants have received increasing attention (111).
325 Plant competition and succession under climate change is also emerging as a growing
326 field that requires long term *in situ* monitoring and/or *ex situ* experimentation (109).

327 The analysis of interspecific microbial interactions remains a more complex challenge,
328 but the study of carbon pathways (11) and the use of quorum sensing techniques (112)
329 offer additional insights into the characterization of trophic connectivities in polar
330 ecosystems. Nonetheless, interactions between primary producers (phototrophic and
331 chemoautotrophic taxa), heterotrophic prokaryotes and microscopic eukaryotes are very
332 poorly understood (but see (113)), perhaps with the exception of the recently
333 characterized soil food webs of the McMurdo Dry Valleys (114). Virus and bacteriophage
334 activity remains largely unexplored, although metabarcoding is starting to inform about
335 their influence on Antarctic host species and communities (51, 115). Knowledge of
336 species interactions is entirely lacking for SAR/Protist species (Fig. 3d).

337

338 ***Future directions for Antarctic biodiversity science and identifiable priority gains*** 339 ***of knowledge for conservation practice***

340 Systematic knowledge acquisition in Antarctica that maximizes the value of information
341 for understanding and preserving its biodiversity requires four consecutive steps: I)
342 completing biodiversity inventories; II) obtaining robust spatial and temporal data
343 coverage; III) collecting the information required to address the remaining knowledge
344 shortfalls; and IV) managing and mobilizing data into centralized information repositories
345 that allow biodiversity trends to be assessed.

346 ***I. Representative biodiversity inventories.*** Many species remain to be discovered or
347 (re)described, including differentiating cryptic taxa. The increasing application of
348 molecular approaches is enhancing the identification of species and cryptic speciation
349 events, leading to rapid increases in knowledge of microbial diversity. The main
350 challenges remaining in the description of Antarctic terrestrial and freshwater diversity

351 arise primarily from survey limitations and the paucity of experienced taxonomists. Two
352 main steps are required to overcome these challenges: training of specialists and
353 increasing application of evolutionary and environmental omics approaches (like recent
354 work on soil biodiversity detection (116)). Environmental DNA surveying requires
355 systematic implementation, but also the availability of both voucher specimens with
356 precise taxonomic identifications, and more comprehensive and quality-controlled
357 sequence databases and biological sample repositories (9).

358 **II. Increasing spatio-temporal coverage.** Biodiversity science relies on the availability
359 of representative collections. A systematic monitoring favors a better understanding
360 global change dynamics and conservation practice. Many ice-free locations and inland
361 waters in Antarctica have not been surveyed or resurveyed since the early 20th Century
362 or the initiation of substantive scientific research activities in the 1950s (25). Thus,
363 virtually no recent spatial data are available to fill knowledge gaps in areas including
364 environmental tolerance breadth, patterns of functional traits and forms of biological
365 interactions for most of the continent. Improved characterization of species' distributions
366 requires spatially targeted broad field surveys to reduce spatial biases in remote areas
367 such as the Prince Charles Mountains or the Queen Maud Mountains (e.g. (71, 116)
368 together with development of remote sensing imagery and analyses (25).

369 **III. Data upscaling and standarization.** Environmental vulnerability studies have
370 informed policy-making discussions about the protection of, for example, the emperor
371 penguin as an Antarctic Specially Protected Species (117), but are still lacking for
372 terrestrial biota. Overall, current gaps in knowledge about species interactions make it
373 very difficult to understand the cascading effects of global change beyond the impacts
374 on each species considered in isolation (7). Interdisciplinary studies that evaluate
375 relationships between groups through, for instance, genomic, fatty acid and/or isotope-
376 based analyses of food webs, are required. Disentangling biotic interactions will also
377 require promotion of interdisciplinary integrative research that examines functional
378 relationships between groups, such as the diversity and influence of viruses in Antarctic
379 host species and communities (115). Baseline descriptions of species co-occurrence
380 should be augmented by manipulative field experiments or, alternatively, growth
381 chamber experiments that realistically mimic Antarctic field conditions (e.g. (118)). Due
382 to their complexity and plasticity, standardized collection remains both a challenge and
383 a necessary step in the characterization of functional aspects. Standardized protocols
384 are required to ensure that future studies of the responses of different groups to global
385 change are comparable.

386 **IV. Data mobilization, centralization and reanalysis.** A critical component of
387 knowledge acquisition is data mobilization and centralization, i.e., data retrieval from
388 bibliographic sources, institutional repositories and/or private databases and
389 harmonization into open repositories with transparent data audit and consolidation (18).
390 Data mobilization, centralization and reanalysis ultimately make important contributions
391 to providing policy-makers with the critical summaries of biodiversity and ecosystem
392 functioning trends required for supporting their strategic conservation planning efforts.
393 Importantly, recent calls have raised the need to integrate existing Antarctic biological
394 data from de-centralized sources (119). The complementary adoption and expansion of
395 monitoring 'model bio-sentinel' organisms and 'priority areas' can help identify rapid
396 changes (120), alleviating current knowledge gaps. In this work we have identified
397 species and groups of organisms that have data across multiple aspects of biodiversity
398 (Fig. 3). Further assessment of the representativeness of these organisms would
399 elucidate how well they provide baseline systems of reference, and contribute to prioritize

400 additional target groups or species. In this context combining both (i) works increasing
401 data completeness for particular species with (ii) in-depth case studies would provide
402 basic, yet representative, understanding of their responses to global change, contributing
403 to maximize conservation gains under limited funding. An assessment of priority
404 knowledge gains such as conducted here can set the basis to develop strategic
405 programs to fill critical knowledge gaps. However, the full 'value of information' that
406 balances the scientific, economic and societal costs and gains of prioritizing research to
407 improve completeness across key aspects of biodiversity remains to be ascertained for
408 Antarctica (12).

409

410 **Conclusions**

411 Recent scientific advances have shed new light on the functioning of Antarctic
412 ecosystems. Major gaps in knowledge of Antarctic biodiversity still hamper our
413 understanding of the functioning of its ecosystems, however, limiting the effectiveness
414 of conservation policies and actions. This continent-wide review of biodiversity
415 knowledge shortfalls provides a basis for future integrative analyses of research needs,
416 and ways to inform conservation requirements in a changing environment, not only for
417 Antarctica, but also as a potential model approach for scaling up shortfall assessments
418 from a single taxonomic group to whole biomes that can be applied to other regions. To
419 address these shortfalls, future research planning should establish targeted international
420 collaborative programs focused on addressing these key questions. Despite more than
421 a century of Antarctic research and exploration under a unique umbrella of international
422 scientific cooperation, there is still much to learn about the ecology and biogeography of
423 this enigmatic continent. Moreover, the pervasive impacts of contemporary human-
424 induced environmental change urgently require these knowledge gaps to be filled to
425 better safeguard the continent's unique biodiversity and the ecosystem services it
426 provides.

427

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1060

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1065

1066 **Data and materials availability:** The Antarctic biodiversity checklists generated for this
1067 work are available in (17). Materials and methods, supplementary figures S1-S4 and
1068 supplemental references are available in (15). All supporting data and code needed to
1069 evaluate the conclusions in the paper are deposited at Zenodo (16).

1070

1071 **SUPPLEMENTARY MATERIALS**

1072 **This PDF file includes:**

1073 Materials and Methods

1074 Supplementary Figures S1-S4

1075 Supplemental References

1076

1077 **FIGURE LEGENDS**

1078 **Fig 1. A) Antarctic species discovery rates.** Historical discovery rates of new species
1079 that are present in terrestrial and freshwater ecosystems of Antarctica. Curves indicate
1080 the total number of species inventoried through time for the four eukaryotic kingdoms
1081 (*sensu lato*): Animalia (red), Fungi (blue), Plantae (light brown), and SAR/Protist (yellow;
1082 including stramenopiles, alveolates, and rizarians and other unrelated unicellulars such
1083 amoebas). The curated list of 2193 known eukaryotic species analyzed here (16) was
1084 compiled in (17). For all these species the year of first discovery and description in
1085 Antarctica, together with the first description worldwide (for species present on other
1086 continents), were taken from global meta-repositories (18, 26). B) **Spatial distribution
1087 of the completeness of biodiversity inventories.** Survey completeness indicates how
1088 well the local species composition is characterized by the available occurrence data
1089 (data files S3-S4). It is calculated as the slope of the relationship between survey effort
1090 –measured as number of occurrence records– and the number of new species added to
1091 the local inventory. High completeness indicates slope values close to 0 (i.e. no new
1092 species are recorded with extra surveys), whereas progressively lower completeness
1093 values indicate progressively higher current rates of addition of new species to the local
1094 inventory with new surveys. Completeness was calculated with KnowBR (53) for local
1095 inventories at a grid size of 50x50 km, randomizing the order of entrance of new records
1096 in each cell to account for temporal unevenness in survey effort. Occurrence records for
1097 all the Antarctic eukaryotic terrestrial species was retrieved first from the Global
1098 information Biodiversity Information Facility (GBIF) repository. This dataset was
1099 complemented with Wauchope et al.'s (26) compilation of additional records from
1100 scientific literature and technical reports such as protected area management plans,
1101 which is available at the Australian Antarctic Data Centre (121).

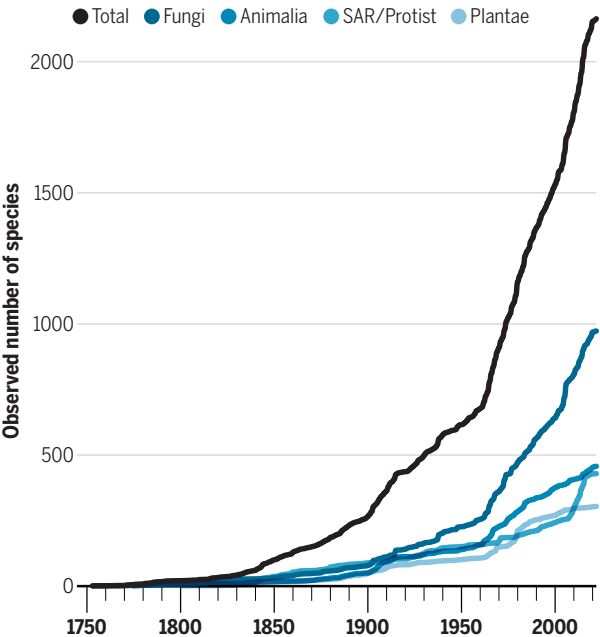
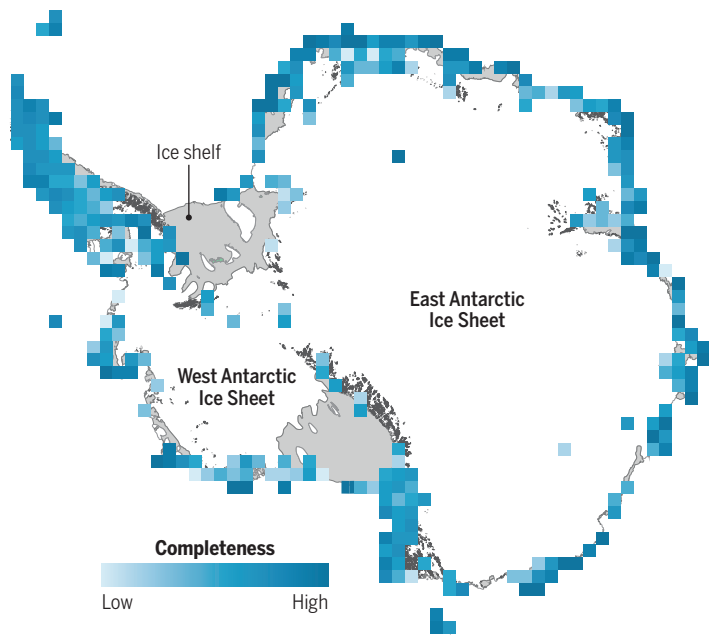
1102 **Fig 2. A) Cross-availability of data on different ecological and evolutionary aspects**
1103 **per species for all Antarctic eukaryots. A) Venn diagrams depicting cross-availability**

1104 of ecological and evolutionary data for all Antarctic species within each of the four
1105 eukaryote kingdoms, measured as counts of species with data entries in centralized
1106 meta-repositories representative of five disciplines (16). The disciplines represented and
1107 their indicators are: 1) Biogeographic distribution knowledge: georeferenced GBIF
1108 occurrence records (54); 2) Evolutionary knowledge: genome sequences deposited in
1109 Genbank (19); 3) Functional traits knowledge: measured trait info availability in either
1110 Pantheria for fauna or Plant Traits Database (TRY) (21) for flora; 4) Abiotic tolerance
1111 knowledge: profiling of thermal limits gathered in the Globtherm dataset (22), expanded
1112 with Antarctic literature; and 5) Biotic relationships knowledge: between-species
1113 interactions listed in the Global Biotic Interactions database (GLOBI) (20). B) **Species
1114 coverage and mean entry levels per Antarctic biodiversity group in global
1115 ecological data repositories. Upper graph panel.** Proportion of species per taxonomic
1116 subgroup (percentage of Antarctic sp. total) with existing data in the five repositories
1117 listed in Fig. 3. **Lower graph panel:** Average number of data entries per species in each
1118 biological group per discipline (functional traits excluded since trait repositories are very
1119 different among groups and/or non-existent and cannot be compared). Colour codes
1120 indicate kingdoms, and acronyms specific groups, as follows: animals (red) include
1121 macrofauna (MF), parasitic invertebrates (PI) and soil invertebrates (SI); fungi (blue) are
1122 divided into lichenic (LF) and non-lichenic (NLF) species; plants (light brown) are
1123 represented only by embryophytes (EM); and SAR/protists (yellow) are divided into
1124 heterotypic protists (HP) and algae (AL). Supplementary material file 1 provides more
1125 detailed information on methods, supporting data and data analysis code as well as
1126 extended visual examinations of the selected indicators coverage per functional
1127 subgroups (e.g. soil invertebrates vs parasites) across all four kingdoms.

1128 **Fig 3. Assessment of biodiversity knowledge gaps and implications for applied
1129 conservation practice through an expert elicitation.** The 29 participant experts were
1130 consulted to evaluate Antarctic science progression around the seven main biodiversity
1131 knowledge shortfalls: Species diversity, Biogeographic distributions, Population
1132 dynamics, Evolutionary relationships, Functional traits, Abiotic tolerances and Biotic
1133 relationships(14). Scores indicate the joint knowledge progression perceived by the
1134 experts towards having a baseline knowledge in each discipline about eight eukaryotic
1135 and prokaryotic groups present in the terrestrial Antarctic (16). X axes indicate the
1136 scoring provided by the experts. Scores close to 0 indicate large knowledge gaps and
1137 scores close to 100 indicate a large coverage. The “best estimate” (i.e. the prevailing
1138 view) is shown together with uncertainty levels (constructed from min/max perceived
1139 estimates and confidence levels) using the IDEA elicitation formula (24). Note that
1140 “algae” includes both cyanophyta, green algae and diatoms, as they are typically studied
1141 together. Non-algal heterotrophic protists are abbreviated as 'htr'. Bars are colored by the
1142 shortfall filling importance for conservation identified by experts. This importance was
1143 calculated as the integration of the depth of the knowledge gap set by Antarctic
1144 biodiversity experts, and the joint general value for conservation practices (set as climate
1145 change action, biosecurity, pollution control, living resources management and area
1146 protection) set by 5 shortfall science experts. Blue colors indicate high filling importance,
1147 and red colors indicate comparatively low one.

1148

1149

A Antarctic species discovery rates**B Spatial distribution of the completeness of biodiversity inventories**

Current relative knowledge: **Less** **More**
0 25 50 75 100

Value of new knowledge to conservation: **Low** **High**

