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The Time is Right for an Antarctic Biorepository Network

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PNAS OPINION

The time is right for an Antarctic biorepository network

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We need to establish a biorepository network of Antarctic specimens to not only address the most critical questions in Antarctic science but also to improve human welfare and mitigate the impacts of climate change. Image credit: Shutterstock/Wirestock Creators.

Antarctica is a central driver of the Earth's climate and health. The Southern Ocean surrounding Antarctica serves as a major sink for anthropogenic CO_2 and heat (1), and the loss of Antarctic ice sheets contributes significantly to sea level rise and will continue to do so as the loss of ice sheets accelerates, with sufficient water stores to raise sea levels by 58 m (2). Antarctica's marine environment is home to a number of iconic species, and the terrestrial realm harbors a remarkable oasis for life, much of which has yet to be discovered (3). Distinctive oceanographic features of the Southern Ocean—including the Antarctic Circumpolar Current, the Antarctic Polar Front, and exceptional depths surrounding the continent—coupled with chronically cold temperatures have fostered the evolution of a vast number of uniquely cold-adapted species, many of which are found nowhere else on the Earth (4). The Antarctic marine biota, for example, displays the highest level of species endemism on the Earth (5). However, warming, ocean acidification, pollution, and commercial exploitation threaten the integrity of Antarctic ecosystems (6). Understanding changes in the biota and its capacities for adaptation is imperative for establishing effective policies for mitigating the impacts of climate change and sustaining the Antarctic ecosystems that are vital to global health.

A major impediment to scientific progress in Antarctica is access. Its extreme weather, remoteness, and inaccessibility to some regions make the logistics of conducting Antarctic research extraordinarily challenging and expensive. Yet across the world, museums and universities possess an extensive, largely untapped wealth

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of Antarctic specimens, including dried and frozen samples, and DNA extracts. In the United States, many Antarctic collections are held by principal investigators (PIs) funded by the National Science Foundation (NSF; Fig. 1), who are largely unaware of data standards (e.g., Darwin Core Standard—a community-developed and evolving set of data standards established to maximize sharing, use, and reuse of biodiversity data) and protocols for specimen management (e.g., the International Society for Biological and Environmental Repositories Best Practices guidelines for managing specimens). They also lack the resources to properly curate their collections. As a result, the majority of Antarctic biological specimens are invisible and inaccessible to the broader scientific community. The time has come to establish a biorepository network of Antarctic specimens for addressing the most critical questions in Antarctic science, improving human welfare, and mitigating the impacts of climate change.

Consistent, policy-driven implementation of collection standards and requirements for specimen sharing would strengthen and democratize access to biological samples from a region with unique geopolitics. The Antarctic Treaty (AT) was signed originally in 1959 by 12 nations whose research activities extended to the southern continent. The AT came into operation in 1961, and at the heart of its objectives, the AT established the continent for peaceful purposes and the free exchange of scientific investigation and results without recognition of any territorial claims to the continent. Greater specimen sharing would enable the now 43 signatories to the AT, including 29 nations with “consultative” (i.e., decision-making) status, to uphold treaty requirements. In support of maximizing use of Antarctic specimens for research, education, conservation, and management that abides by FAIR standards (Findable, Accessible, Interoperable, and Reusable), we endorse the development of an international Antarctic biorepository network.

A virtual Antarctic hub would educate scientists on specimen management practices, link scientists with the appropriate institution(s) for curating their collections, and facilitate collaboration and communication among scientists to minimize redundant sampling and anthropogenic impacts on Antarctica while at the same time maximizing sampling opportunities. Importantly, an Antarctic biorepository network would be integrated, avoiding redundancy with large data aggregators such as the Global Biodiversity Information Facility (GBIF) and iDigBio that are digitizing the world’s biodiversity collections.

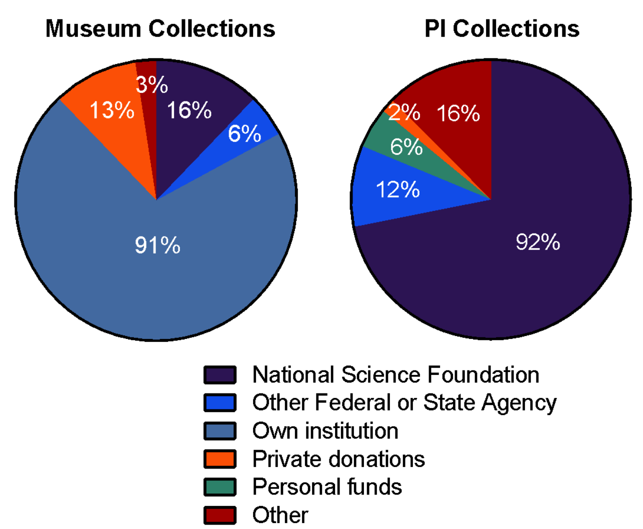

Fig. 1. Funding sources for the Antarctic collections of museums (left) and principal investigators (right) in the United States. Data were obtained from a survey deployed to Antarctic scientists, museum curators, and collection managers in 2021. Percentages for each category do not sum to 100% because respondents could select more than one funding category.

Rapidly Changing Biodiversity

Studies of Antarctic biology began in earnest with early explorations of the Southern Ocean and the frozen continent during the 19th century. Following the International Geophysical Year (1957–1958), an effort to coordinate and expand scientific data from around the globe, many countries have invested significant resources in Antarctic science. The extraordinary biota of Antarctica demonstrates remarkable adaptations and novel biodiversity across a range of taxa. Their study has produced, and will continue to yield, discoveries of priceless scientific value. Earlier this year, for example, the most extensive breeding colony of fishes ever recorded was discovered in the Weddell Sea (7). And magnificent images of the sunken ship *Endurance*, from the 1914–1917 Shackleton expedition, revealed an unusual community of organisms perched on the wreck.

Anthropogenic drivers of global change place Antarctic ecosystems at increased risk, threatening biodiversity, introducing invasive species, homogenizing biodiversity, and perturbing ecosystems (3). Projected deviations in climate will likely lead to accelerated changes, although with regional differences (8). In East Antarctica, which has been considered more stable than West Antarctica, temperatures last March were reported at an unprecedented 70 °F above “normal.” Multiple stressors associated with climate change (i.e., ocean acidification and deoxygenation, warming, pollution, and invasive species) are disrupting biogeochemical cycles and altering species abundance and distribution in complex ways that are not entirely understood or predictable based on current scientific knowledge (9). Unique adaptations to the extreme conditions of Antarctica, and in some cases reduced phenotypic plasticity associated with living in a relatively stable environment, long generation times, and restricted opportunities for migration, have rendered many Antarctic species particularly vulnerable to change (9).

The Protocol on Environmental Protection to the AT mandates protection of Antarctica and its biodiversity through a variety of measures, including designation of Antarctic Specially Protected Areas (ASPAs). Most of Antarctic’s terrestrial biodiversity resides within permanently ice-free areas (approximately 0.2% to 0.5% of the Antarctic continent or between 22,000 and 46,000 square kilometers), of which only 1.5% is within an ASPA (10, 11). Moreover, a critical criterion for establishing an ASPA, to protect the “type locality or only known habitat of any species,” has only been applied to 108 of 386 type localities (12).

To effectively implement this criterion requires a continually updated and robust dataset of species distributions and in some cases, such as microbial diversity, detailed molecular analyses of existing samples (12). A biorepository could facilitate this. Islands in the Southern Ocean have already experienced invasions by the “worst” invasive species (based on ecological and socioeconomic impact as identified by the International Union for the Conservation of Nature), and the northern tip of the Antarctic Peninsula is now home to non-native, temperate, cold-tolerant species (13). Marine Protected Areas (MPAs) encompass 12% of the Southern Ocean under the jurisdiction of the Commission for the Conservation of Antarctic Living Resources (CCAMLR), an international commission that determines the use of marine living resources in Antarctica, but only 4.6% of the CCAMLR area includes no-take areas afforded full protection from resource extraction (14). Complicating matters, this 4.6% does not adequately represent the biodiversity of benthic communities near the ocean’s bottom and pelagic communities in the water column (14).

An Invaluable, Underutilized Resource

Collections of organisms, environmental and tissue samples, and derivative data provide a resource of exceptional value to science and society, contributing to our understanding of environmental contaminants, biological invasions, and the impacts of climate change (15). An excellent example is a recent analysis of fishes collected over a 25-year period as part of the Palmer Station Long-Term Ecological Research program, curated by the Virginia Institute of Marine Science in Gloucester Point. This study has shown that reduced larval abundance in a key species of the Antarctic food web, the silverfish *Pleuragramma antarctica*, coincides with loss of sea ice (16).

In the United States, specimens from Antarctica reside in institutional collections and PI’s laboratories (Fig. 2). Although the NSF has well-developed guidelines and requirements for data sharing, similar requirements for managing and sharing Antarctic samples have only recently been established. They require PIs to deposit specimens into a repository within two years of collection or by the end of a research funding award, whichever comes first. This short timeline will require the scientific community to become rapidly educated on specimen management.

However, many PIs are unaware of best practices for curation and specimen management that have been developed in the museum community, and many lack resources to implement them. Moreover, the current NSF requirements do not apply to legacy collections. As a result, Antarctic specimens that could be used to address challenges facing Antarctica are largely inaccessible. Development of an international Antarctic biorepository network would be within the mandate of the AT by furthering the goal of shared information to include scientific specimens and would improve the ability of AT consultative nations to identify critical habitat for inclusion in ASPAs.

Last February, Antarctic biologists from the United States, and museum curators and collection managers, convened a three-day, NSF-funded workshop to identify and define the values of an Antarctic biorepository in hopes of expanding the scope and inclusivity of Antarctic science while, at the same time, accelerating scientific progress. A preworkshop survey assessed the status of Antarctic biological collections in the United States and attitudes regarding the needs and potential benefits of developing an Antarctic biorepository.

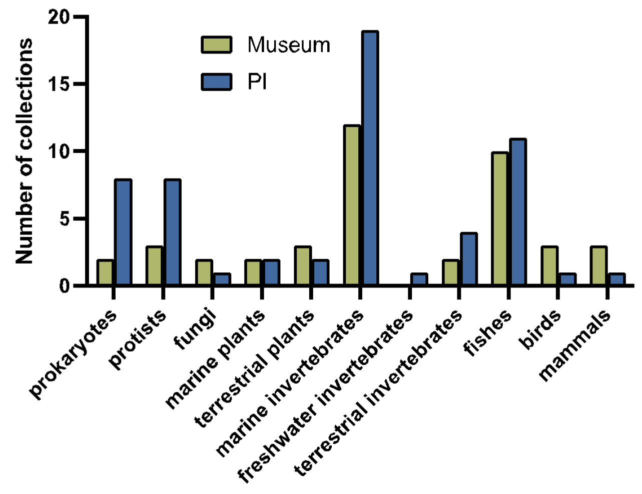

Fig. 2. Number of Antarctic taxon-specific collections held by museums versus principal investigators. Data were obtained from a survey deployed to Antarctic scientists, museum curators, and collection managers in 2021.

Researchers received 87 survey responses representing 56 institutions.

Survey results indicated that (a) PIs hold extensive Antarctic collections, largely funded by the NSF; (b) PIs have limited resources and knowledge of how to curate and provide access to samples; (c) PIs desire access to institutional specimens but require guidance to do so; and (d) PIs have a keen interest in depositing specimens into a biorepository but they lack the time, knowledge, and/or financial resources to accomplish this.

Taking Action

Antarctica’s ecosystems and their lack of adequate protection require that we take several steps. Right now, Antarctic collections are dispersed among many institutions across the globe. Workshop participants concurred that the most effective and efficient structure for an Antarctic biorepository network would be an Antarctic virtual hub that would improve visibility of existing nodal collections, provide training in specimen collection and management, and link PIs with appropriate collection manager(s) and curator(s) to enhance specimen management, deposition, and value. Collections across nodes would be discoverable through a central portal integrated with existing digital data aggregators, such as the Global Biodiversity Information Facility and Antarctic Biodiversity Portal.

To embark on such an important project, we must educate the scientific community about best practices for collection and curation, specifically those practices necessary to adhere to a specimen management plan. Connecting collection managers with PIs as they prepare proposals will be critical to collection, deposition, and future access. Training in specimen best practices adhering to common standards (e.g., Biodiversity Information Standards, Global Biodiversity Information Facility, The Society for the Preservation of Natural History Collections, iDigBio, and Global Genome Biodiversity Network) would be provided through the Antarctic biorepository central hub and through NSF-funded workshops and webinars. Collection nodes could participate in training because repositories may differ in their specimen management protocols with respect to their specialties.

A biorepository project must also support the deposition of legacy collections. Although museum collections are well curated and accessible through online data aggregators, PI collections are neither easily discoverable nor are they professionally managed or curated. For some taxa, collections held by PIs exceed those held by museums (Fig. 2). NSF funding, grant supplements, or awards for Collections in Support of Biological Research should help PIs, especially those nearing retirement, deposit their collections in biorepositories. Research Experiences for Undergraduate (REU) awards to support specimen deposition and foster collaborations between PIs and collection managers could also contribute to this goal while simultaneously training young scientists in best practices of specimen collection and curation. NSF funding in support of legacy collection deposition, especially for collections that enhance taxonomic, genomic, and morphological diversity, biogeographic distribution, and/or time series, would strengthen conservation efforts and provide research opportunities for other investigators. Availability of legacy collection awards should be communicated to PIs to plan for the ultimate dispossession of their collections.

Importantly, enhanced visibility of, and access to, Antarctic specimens will provide opportunities to increase diversity, equity, and inclusivity in Antarctic science. Conducting fieldwork in Antarctica often requires extended time away from home in a remote setting, which is not always feasible or desirable. The steep learning curve required to manage Antarctic field research and logistics puts scientists who lack Antarctic experience at a disadvantage. Creation of an Antarctic biorepository would eliminate some of these barriers and provide research opportunities for researchers who might not consider themselves Antarctic investigators, thereby increasing competitiveness for grants and driving high-quality science. Greater accessibility to specimens through a biorepository, and support through the REU and grant supplements, would also broaden participation in Antarctic science by enhancing opportunities for public outreach and undergraduate research in Antarctic biology.

Antarctic biological collections represent an underused resource of exceptional value to science. They should be used to their full potential for developing and tracking ecological baselines to understand anthropogenically driven changes and creating policy for mitigating impacts. An Antarctic biorepository network would promote collaboration, coordination, and communication among partners and facilitate broader and more effective use of Antarctic specimens for research, education, outreach, and conservation. Such a network will also enhance and grow Antarctic research, in some cases bypassing logistic hurdles and costs associated with field deployments, thereby widening use of Antarctic specimens. Reducing needs for field deployments will also help minimize human impact on the Antarctic environment that results from unnecessary or redundant sampling.

> **"We envision increased opportunities not only for Antarctic investigators but also for investigators new to Antarctic science, enabling research when field seasons are not logistically possible or practical."**

An Antarctic biorepository network that offers significant opportunities for training in sample processing would ensure high standards of collection and documentation of specimens, thus securing quality preservation of biological samples, adding value to previous and ongoing investments in Antarctic research—while, at the same time, promoting diversity and early-career development. In summary, an Antarctic biorepository network would accelerate progress and broaden participation in Antarctic science and inform policies for conserving a resource of exceptional value.

Data, Materials, and Software Availability. Data from the survey are available through the Antarctic Biorepository Workshop website: https://sites.google.com/d/14sqUVNbp5ADYMJ-bdBIh2dE5Xg66vKXj/p/1AQjT8fHcCiidPuep1AeWzdpmeMcRIX5B/edit.

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