Consensus Study Report

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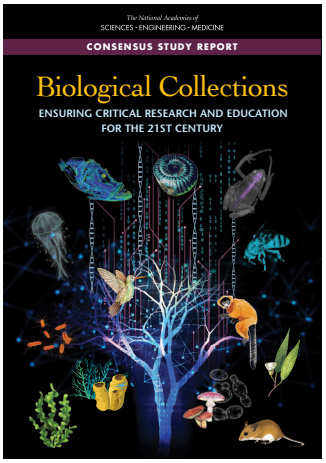
HIGHLIGHTS



Biological Collections:

Ensuring Critical Research and Education for the 21st Century

For centuries, scientists have sought and collected different types of organisms to learn more about their forms, functions, origins, distributions, and evolution. Pooling and conserving these organisms into *biological collections*—systematized repositories of life in all of its many forms—is a cornerstone of quality research and education in many areas of science and innovation (see Box S-1). U.S. natural history collections and living collections, which continually propagate and multiply organisms, comprise more than 1 billion specimens. The specimens are increasingly accompanied by a rich complement of additional biological material and data that generate new insights about life on Earth and open new avenues of inquiry in almost every field of science, medicine, and technology.

Biological collections are an invaluable, and often irreplaceable, component of the nation's scientific enterprise. Unfortunately, their sustainability is under threat. The causes are many, including a general lack of understanding of their value and their contributions to research and education, a lack of appreciation for what is required to maintain them effectively, and inadequate coordination and interconnection among and between collections.

Recognizing the importance and the vulnerabilities of the nation's biological collections, the National Science Foundation (NSF) has endeavored to provide broad financial support through its Division of Biological Infrastructure (DBI) within the Directorate for Biological Sciences (BIO). Conducted at the request of NSF, this report explores the contributions from biological collections, outline critical needs and challenges they face, and makes recommendations that could provide momentum to maintain and grow biological collections and their use to advance science into the future.

The Value of Today's—and Tomorrow's—Biological Collections

Numerous publications have documented how biological collections underpin basic discovery science. For example, the fruit fly *Drosophila melanogaster* has been used as a model organism for genetic research since Thomas Hunt Morgan used it to elucidate the role that chromosomes play in heredity, for which he was awarded the 1933 Nobel Prize. The discovery of the enzyme *Taq* polymerase in a bacteria strain deposited in a living stock collection led to the advancement and accessibility of next-generation sequencing technologies. The development of the revolutionary genome-editing technique known as CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) was also, in part, the result of research on materials sourced from living microbe collections.

Biological collections also support much of the applied research that drives innovation and provides crucial knowledge about such pressing societal challenges as the effects of global change, biodiversity loss, sustainable food production, ecosystem conservation, and improving human health and security. Hormones can be extracted from decades-old natural history collections, making it possible to infer the physiological state of the individuals at the time of capture. Investigations using U.S. and international museum collections and private collections were the first to demonstrate how species respond to climate change by shifting locations, adapting to new conditions, or experiencing local extirpation.

Biological collections are powerful educational assets for learners of all ages, backgrounds, skills, and perspectives. They provide a tangible platform that can draw people into *lifelong learning*—ongoing efforts to foster, develop, and

BOX S-1 What Are Biological Collections?

Biological collections typically consist of organisms (specimens) and their associated biological material, such as preserved tissue and DNA, along with data—digital and analog (such as handwritten field notes)—that are linked to each specimen. Non-living specimens, which include organisms preserved by scientists and naturally preserved remains, such as fossils, are commonly referred to as natural history collections. Living specimens include research and model organisms that are grown and maintained in genetic stock centers, germplasm repositories, or living biodiversity collections.

FIGURE S-1 Examples of biological collections in the United States. (A) spider in amber, University of Colorado Museum of Natural History Paleontology Section; (B) bats, Museum of Southwestern Biology, University of New Mexico; (C) Fusarium graminearum, Fungal Genetics Stock Center, Kansas State University; (D) Xenopus, National Xenopus Resource, Marine Biological Laboratory; (E) various herbarium specimens, New York Botanical Garden Virtual Herbarium; (F) Charles Doe egg collection, Florida Museum of Natural History; (G) Ichthyology Cleared and Stained specimens in jars, University of Kansas Biodiversity Institute; (H) bacterial strain on petri dishes, American Type Culture Collection.

expand one's knowledge and skills– whether through formal education, employment in science, technology, engineering, and medicine (STEM), or by pursuing personal interests throughout life. Biological collections can be incorporated into classroom and non-school settings, or serve as a means to provide research experience. Educational kits, classroom visits, field trips, summer camps, online courses, tutorials, blogs, citizen science programs, and teacher workshops are a few of the educational tools and programs created by biological collections staff.

VISION AND RECCOMENDATIONS FOR THE NEXT DECADE

The significance of biological collections as research infrastructure continues to grow in ways that were unanticipated 20 or even 10 years ago. With strategic thinking and steady resource investments, biological collections could continue to be at the heart of scientific advances and education for the foreseeable future. Looking ahead, the committee developed a common vision for the biological collections community in the next decade:

> *To provide long-term support for collections-based scientific research, instill a culture of proper stewardship for and access to biological specimens, build and grow biological collections to better represent global biodiversity in space and time, promote access to biological collections as important educational resources for the general public, and encourage the exchange of biological resources and knowledge.*

Achieving this common vision will require that the biological collections community—curators, collection managers, directors, and users of biological collections—address four interrelated issues:

1. upgrading and maintaining the physical infrastructure and the growth of collections;
2. developing and maintaining of the tools and processes needed to transform digital data into an easily accessible, integrated platform as cyberinfrastructure increases in complexity;
3. recruiting, training, and supporting of a diverse workforce of the future; and
4. ensuring long-term financial sustainability.

Realizing this vision will require enhanced communication and collaboration within the biological collections community and beyond. The major aim of this report is to stimulate a national discussion regarding the goals and strategies needed to ensure that U.S. biological collections not only thrive but continue to grow throughout the 21st century and beyond.

Building and Maintaining a Robust Infrastructure

Biological collections infrastructure needs to be maintained and continue to grow in order to keep up with the advance and evolution of scientific research itself. The infrastructure extends beyond the physical space and equipment used to house and maintain the specimens in a collection. It includes the technologies to produce digital data, and the cyberinfrastructure to store, analyze, and aggregate data and the trained staff, students, and volunteers who acquire, curate, manage, ensure the quality, and coordinate the scientific and educational uses of biological collections. There is no one-size-fits-all list of physical infrastructure requirements and biological collections would benefit from both individualized strategic plans and shared community standards and protocols to meet future scientific needs.

Recommendation 4-1: The leadership (directors, curators, and managers) of biological collections should assess and define the infrastructure needs of their individual facilities and develop comprehensive strategic plans in accordance with those needs and their strategic missions.

Recommendation 4-2: Biological collections should take advantage of existing training opportunities and collaborative platforms at the national and international levels, such as those offered through the International Society for Biological and Environmental Repositories and the Organisation for Economic Co-operation and Development certification programs, especially as new aspects of the work evolve, such as regulations compliance, data management, and new techniques and materials for collections storage and documentation.

Recommendation 4-3: Professional societies, associations, and coordination networks should collaborate and combine efforts aimed at addressing community-level infrastructure needs of the nation's biological collections.

Recommendation 4-4: The NSF Directorate for Biological Sciences should continue to provide funding support for biological collections infrastructure and expand endeavors to coordinate support within and beyond the Directorate.

Generating, Integrating, and Accessing Digital Data

Producing specimen data in digital formats is a vital first step toward enhancing the discoverability and use of biological collections. Digitization[1] and the cyberinfrastructure that underlies how digital data are stored, managed, and used have fundamentally transformed the biological collections community. Although digitization efforts have involved hundreds of collections, gaps in phylogenetic, geographic, temporal, and taxonomic information are evident. Investment in the development of new technologies and cost-effective high-throughput workflows for digitizing some collections that, to date, have lagged will enhance both the number of specimens and taxonomic scope of digitized collections.

A unified cyberinfrastructure that connects all types of biological collections, such as living and natural history collections, could accelerate research and provide innovative educational opportunities. Moreover, a permanent national cyberinfrastructure that supports the needs noted above in terms of expanded digitization of dark data, improvement in data quality, and increased accessibility to digital data would certainly spur data use. Without this resource, collections—both physical and digital—will continue to be underused.

Recommendation 5-1: The leadership (directors, curators, and managers) of biological collections should provide the necessary mechanisms for staff to keep pace with advances in digitization and data management through training in digitization techniques and publishing of standardized quality data that can be efficiently integrated into portals.

Recommendation 5-2: Professional societies should initiate and cultivate opportunities for research collaborations within the biological collections community. These collaborations should include working with the computer and data sciences communities to promote the development and implementation of tools to build the cyberinfrastructure (e.g., data storage, annotation, integration, and accessibility to expand the use of biological collections to a broader range of stakeholders).

Recommendation 5-3: The NSF Directorate for Biological Sciences should continue to provide funding for the digitization of biological collections and for the cyberinfrastructure to support both living and natural history collections.

Cultivating a Highly Skilled Workforce

If biological collections are to not just survive, but thrive throughout the 21st century, they will need effective, visionary, and well-supported leaders, in addition to competent and innovative scientists and educators. Biological collections require personnel with multifaceted and complex competencies. The path forward will require collaboration among the nation's biological collections as well as partnerships with other professional communities, incentivized with the support of NSF.

Recommendation 6-1: The leadership of individual collections, host institutions, relevant professional societies, and collections funders should collaborate to develop and strengthen the workforce pipeline through community-level action on the following issues: critical skills; workforce analysis; diversity, equity, and inclusion; education and training coherence; and alternative staffing models.

Recommendation 6-2: As part of its programmatic endeavors to promote a robust biological infrastructure, the NSF Directorate for Biological Sciences should support initiatives that focus explicitly on systemic, systematic, and thoughtful development of the biological collections workforce pipeline. In partnership with other Directorates, such a programmatic focus should encompass future (e.g., students and postdocs) and existing collections personnel (e.g., early-career and senior curators and collections managers), predicated on maintenance and growth of biological collections infrastructure to meet diverse needs of societal import.

Securing Financial Sustainability

Long-term financial viability is critical to the ongoing and growing use of biological collections for research and innovation. Maintenance and replacement of aging physical

[1] The conversion of textual, image, or sound-based specimen information to digital formats.

infrastructure, continual upgrades to cyberinfrastructure, additional personnel to manage growing digital resources, upgrades to meet the needs of new emerging types of collections, new quality standards, and evolving requirements for permits and safety regulations are some of the funding needs that, while essential, may go beyond what annual budgets have covered historically. The biological collections community will need to act as one in order to develop partnerships, centralize a pooled set of data and resources, track the use of collections in research and education using diverse metrics at the community level to show the national and international impact of U.S. collections, and identify new approaches to funding.

Recommendation 7-1: The leadership of biological collections (directors, curators, and managers) of biological collections should work with business strategists and communication experts to develop business models for financial sustainability and infrastructure of biological collections.

Recommendation 7-2: Professional societies should develop extensive networked training platforms for sharing best practices for financial management and planning and business models for collections of all sizes and types. This could be an ongoing activity centered at a national biological collections center and should include both natural history and living collections together.

Recommendation 7-3: The NSF Directorate for Biological Sciences should continue to provide stable, long-term funding to support investigators who rely on biological collections for research and education.

THE NEED FOR COLLABORATIVE ACTION

Coordination, discussing priorities and sharing of knowledge will be critical for the biological collections community to be able to meet current and future needs and address the dynamic challenges of society and rapid global change. The biological collections community needs an inclusive, integrated platform to strengthen the position of biological collections as a unified scientific infrastructure for the nation over the next decade and beyond. A national collections-focused action center dedicated to the support and use of biological collections could fill this need.

Recommendation 8-1: NSF, in collaboration with other institutions that provide funding and other types of support for biological collections, should help establish a permanent national Action Center for Biological Collections to coordinate action and knowledge, resources, and data-sharing among the nation's biological collections as they strive to meet the complex and often unpredictable needs of science and society.

Recommendation 8-2: NSF should lead efforts to develop a vision and strategy, such as a decadal survey, for targeted growth of the nation's biological collections, their infrastructure, and their ability to serve a broader range of users and scientific and educational needs.

Recommendation 8-3: The NSF Directorate for Biological Sciences should expand its partnership capabilities more broadly across NSF, other federal agencies, international programs, and other sectors. Such partnerships can maximize investments in support of a national Action Center for Biological Collections, the development of a national vision and strategy, and help spread the cost of such major endeavors beyond the NSF Directorate for Biological Sciences.

COMMITTEE ON ENSURING CRITICAL RESEARCH AND EDUCATION FOR THE 21ST CENTURY

James P. Collins (*Co-Chair*), Arizona State University; **Shirley A. Pomponi** (*Co-Chair*), Florida Atlantic University; **Andrew C. Bentley**, University of Kansas; **Rick E. Borchelt**, University of California, Berkeley; **Kyria Boundy-Mills**, University of California, Davis; **Joseph A. Cook**, University of New Mexico; **Lynn D. Dierking**, Oregon State University; **Scott V. Edwards** (NAS), Harvard University; **Manzour H. Hazbón**, American Type Culture Collection; **Talia S. Karim**, University of Colorado; **George I. Matsumoto**, Monterey Bay Aquarium Research Institute; **Pamela S. Soltis** (NAS), University of Florida; and **Barbara M. Thiers**, New York Botanical Garden. Staff of the National Academies of Sciences, Engineering, and Medicine: **Audrey Thévenon** (Study Director), **Keegan Sawyer** (Senior Program Officer), **Jessica De Mouy** (Senior Program Assistant), and **Alyssa R. Frederick** (Christine Mirzayan Science & Technology Policy Fellow)

For More Information . . . This Consensus Study Report Highlights was prepared by the National Academies of Sciences, Engineering, and Medicine based on the Consensus Study Report *Biological Collections: Ensuring Critical Research and Education for the 21st Century* (2020). The study was sponsored by the National Science Foundation's Division of Biological Infrastructure. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project. Copies of the Consensus Study Report are available from the National Academies Press, (800) 624-6242; http://www.nap.edu or via the Board on Life Sciences web page at http://www.nationalacademies.org/bls.

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