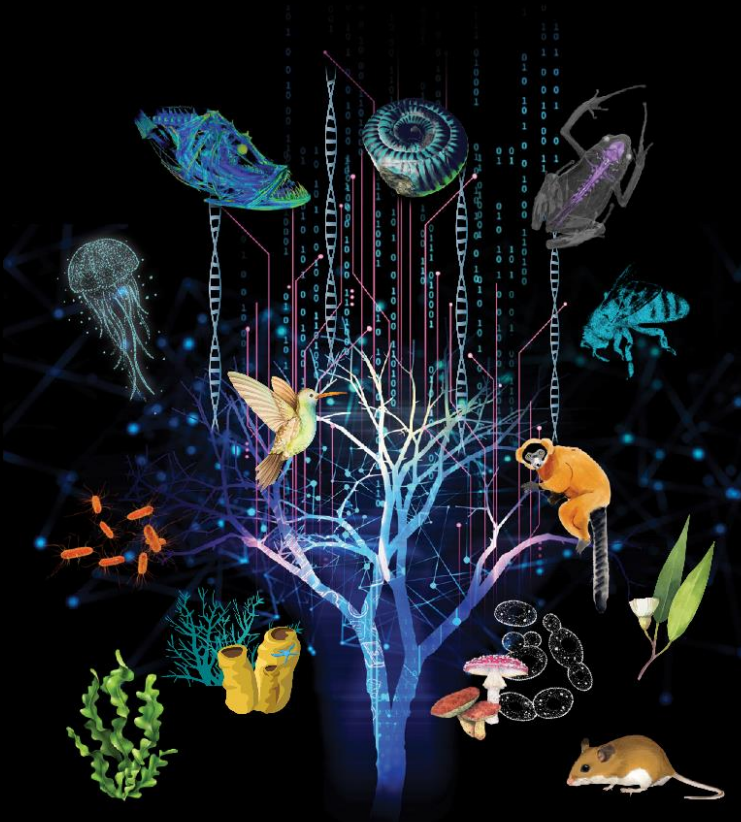


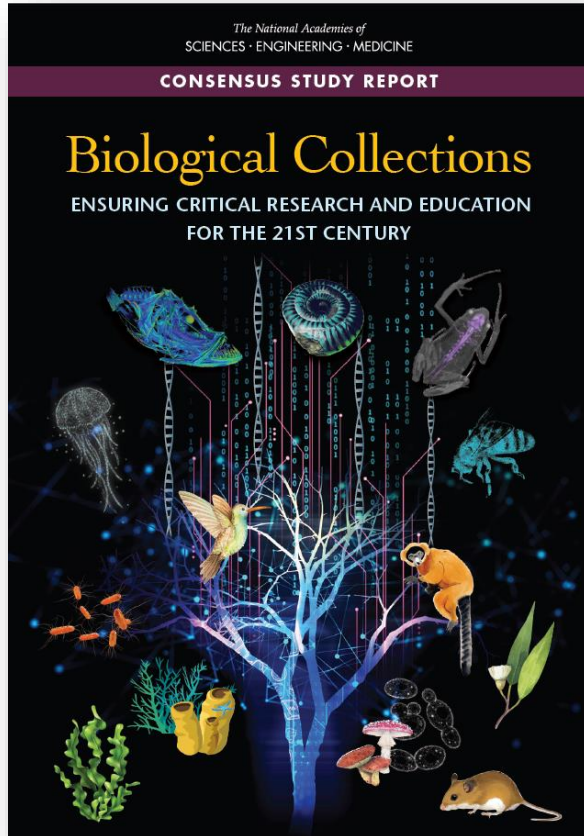
*The National  
Academies of*

SCIENCES  
ENGINEERING  
MEDICINE



# Biological Collections

ENSURING CRITICAL RESEARCH AND EDUCATION  
FOR THE 21ST CENTURY



# **Biological Collections:**

## Ensuring Critical Research and Education for the 21<sup>st</sup> Century

Report Briefing  
September 10, 2020

Co-Chairs

Shirley Pomponi, Florida Atlantic University  
James P. Collins, Arizona State University

Board on Life Sciences

# The Committee & Staff



From left to right:

- **Shirley Pomponi** (Co-chair) - Florida Atlantic University
- **Audrey Thévenon** (Staff)
- **Joseph Cook** - University of New Mexico
- **James Collins** (Co-chair) - Arizona State University
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- **Barbara Thiers** - New York Botanical Garden

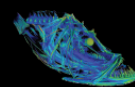
# Chapter 1: Motivation for the Study (1)

- Biological collections are an invaluable, and often irreplaceable, component of the nation's scientific enterprise.
- Their health depends on the underlying infrastructure that assembles, maintains, and provides access to the collections.
- Sustainability of the nation's biological collections is under threat:
  - Lack of understanding of their value and contributions to research and education
  - Lack of appreciation for what is required to maintain them effectively
  - Inadequate coordination and interconnection among and between collections
- Without changes in support and organization, prior and current investments for building the nation's biological collections will be diminished, and their immense potential will be severely limited.



# Motivation for the Study (2)

- The National Science Foundation recognizes the importance and vulnerabilities of the nation's biological collections.
- NSF's Division of Biological Infrastructure (DBI) provides broad financial support for biological collections.
- The breadth of needs for maintaining biological collections exceeds the capabilities of any one federal agency.
- NSF asked NASEM for guidance on questions regarding long-term sustainability, including operational structures, policies, and social cultures that could provide momentum to maintain and grow biological collections.



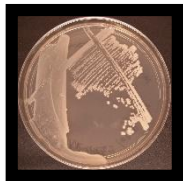
# Statement of Task (abbreviated)

- Explore the contributions of biological collections of all sizes and institutional types to research and education.
- Envision future innovative ways in which biological collections can be used to advance science.
- Outline the critical challenges to and needs for use and maintenance of biological collections.
- Suggest a range of long-term strategies that could be used for their sustained support.





# 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—that are linked to each specimen.



Non-living specimens include organisms preserved by scientists and naturally preserved remains, such as fossils, 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.



Focused on collections that receive, or are eligible to receive, support for infrastructure or digitization from NSF.



# The Committee's Approach

- Committee's expertise, peer-reviewed literature, and information-gathering events.
- Identified areas of tension that stem from the scope of the study and that are inherent within the biological collections community:
  - Collections are diverse—taxonomically, organizationally, and in their missions and needs.
  - There are inherent differences between living stock collections and natural history collections.
  - The communities surrounding natural history and living collections operate largely independently of one another.
- The report is intended to launch a national conversation about the future of biological collections.





# Vision for the Next Decade

For biological collections to survive and thrive...

*Provide* long-term support for collections-based scientific research, *instill* a culture of 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.



# Realizing This Vision (1)

- Explores ways that biological collections contribute to society (Chapters 2 and 3).
- Addresses how the biological collections community is working toward a common vision in light of today's challenges.
- Recognizes that future success of biological collections depends on addressing four interrelated issues:
  - 1) Upgrade and maintain physical infrastructure and growth of collections (Chapter 4)
  - 2) Develop and maintain tools and processes needed to transform digital data to an easily accessible and integrated cyberinfrastructure platform (Chapter 5)
  - 3) Recruit, train, and support the workforce of the future (Chapter 6); and
  - 4) Ensure long-term financial sustainability (Chapter 7).



# Realizing This Vision (2)

Realizing this vision will require enhanced communication and collaboration within the biological collections community and beyond (Chapter 8).



# Chapter 2: Advancing Discovery, Inspiring Innovation, and Informing Societal Challenges

- A vast, data-rich repository
- Fundamental support for scientific research
  - Preserve and expand knowledge
  - Enable biological discoveries
  - Drive innovation
  - Widen understanding of complex societal issues
  - Unanticipated uses
- Evaluate impact–metrics



# Sample Contributions of Biological Collections

- Enabling Biological Discoveries
  - Bacteria at ATCC - Discovery of Taq polymerase enabled next-generation sequencing technologies
- Understanding and Forecasting Effects of Climate Change
  - Vertebrates in Yosemite - Document changes in elevation, abundance, and body size of species
- Ensuring Food Security and Crop Management
  - Herbarium records - Sighting of wild relatives to collect new germplasm
- Improving National Safety and Public Health
  - All Biological collections - Identify distribution, reservoirs, vectors, and surveillance over time of pathogens



# Chapter 3: Contributions to Science Education and Lifelong Learning

- Increase student knowledge and understanding in formal education settings.
- Prepare students for a data-driven world.
- Enhance student research experiences.
- Inspire a life-long appreciation for science in informal education settings.
- Engage life-long learners in citizen science.
- Broaden participation in STEM.





# Select Educational Materials Developed by the Biodiversity Literacy in Undergraduate Education (BLUE) Initiative



## Data Ethics

Data ethics and the use of digital data



## Nature's Flying Machines

Explore the physics of flight and the adaptations that make powered flight



## Data is the New Science

Introduce emerging biodiversity data resources.



## Amphibian Diversity

Investigate the relationship between precipitation levels and species diversity.



## The Power of Data Standards

Investigate data standards within the context of the alpine chipmunk and the

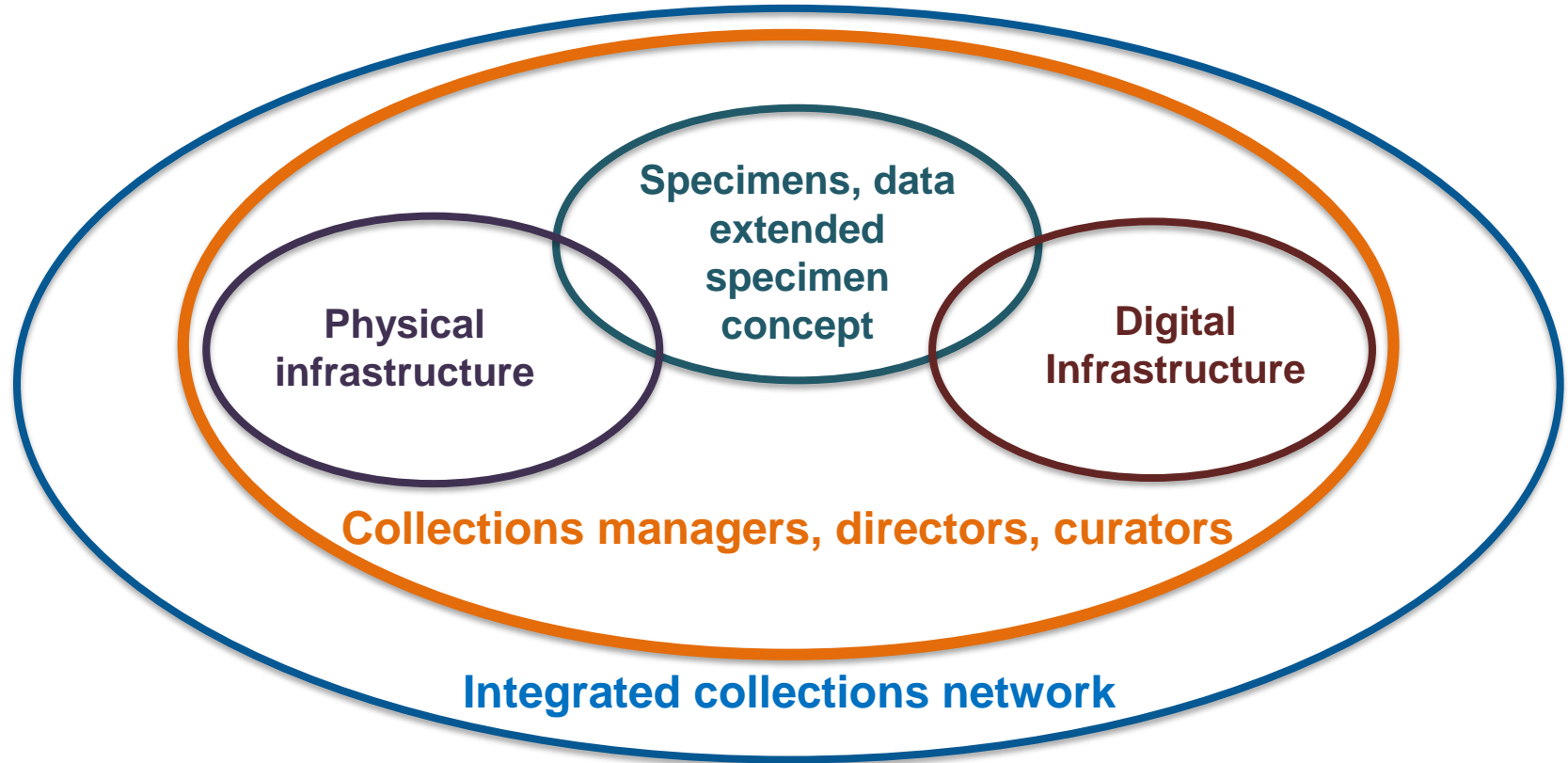


## Liberating Data for Research

Familiarize yourself with the informational content of biodiversity



Infrastructure has many intersecting components.



# Chapter 4: Building and Maintaining a Robust Infrastructure

## CHALLENGES

Biological collections require ongoing preventive maintenance

Living stock collections require consistent quality control

Biological collections need room to grow

Biological collections need to be accessible

Biological collections need to meet the needs of a dynamic scientific enterprise

## PATHS FORWARD

Future-proof infrastructure

- Strategic planning
- Emergency preparedness
- Duplicate specimens

Establish shared standards and technologies for living stock collections

Establish a national registry of biological collections

# Conclusions

- There is **no one-size-fits-all** list of physical infrastructure requirements and biological collections would benefit from individualized strategic plans.
- **Some aspects of infrastructure will benefit from shared community standards and protocols** (e.g., quality control for living stock collections).
- Biological collections **need to grow** as scientific research advances. Institutions need to acknowledge the demands collection growth places on infrastructure.
- Consideration needs to be given to **biological collections as a shared and distributed scientific resource for the nation**.



# Recommendations for Individual Biological Collections

**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. The strategic plans should outline approaches to:

- continually **address ongoing preventive maintenance** and, in the case of living collections, **quality control requirements**; and
- improve and potentially build new infrastructure, both of which actions are particularly important if **collections growth** is a component of the strategic mission.

The **strategic plan should be revisited** every three to five years to ensure that it continues to meet the evolving needs of collections and their users.

**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 ISBER and OECD 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**.

# Recommendations for the Biological Collections Community

**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, including:

- develop a [platform to pool and share resources](#) such as strategic plans, best practices, and training opportunities so that these can serve as resources for the broader biological collections community;
- develop and implement strategies to [adopt quality control programs to improve uniformity among living stock collections](#) and ensure the availability of high-quality biological resources that best fit the needs of the user;
- [create a national biological collections registry](#) to document the location, size, and holdings of the collections in the United States. The registry should be curated and updatable. In addition, proactive processes to identify collections should be established, ensuring that collections of all types are well represented in the registry; and
- use the national registry to [conduct periodic community-wide assessments of needs](#) to inform the development of both individual and community-level strategies to maintain and upgrade infrastructure.



# Recommendations for the National Science Foundation

**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**. Specifically, NSF should:

- support **new and improved infrastructure** to accommodate the pressing needs created by **continued collections growth**;
- require a **specimen management plan** for all research proposals that includes collecting or generating specimens that describes how the specimens and associated data will be accessioned into and permanently maintained in an established biological collection; and
- facilitate the **creation and support of an independent consortium** to develop collaborative platforms and mechanisms to pool and share resources for strategic planning, preventive maintenance, quality control and assurance, collections growth, establishing a national collections registry, and other community-level assets.

# Chapter 5: Generating, Integrating, and Accessing Digital Data

## CHALLENGES

Dark data (undigitized collections)

Inefficient data pipeline

Variability in data quality and format

Limitations affecting data usability

Inadequate methods for data integration and attribution

Limited mechanisms to support a cyberinfrastructure that promotes collaboration

## PATHS FORWARD

Innovative approaches to reducing dark data

Increase data visibility

Tools to improve data quality

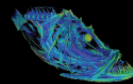
Promote integration and attribution

Develop a national cyberinfrastructure

Connect data to promote coordination and collaboration

# Conclusions

- Harnessing the opportunity for data-driven discoveries and transdisciplinary collaboration will depend on a **continuing effort to digitize new and existing biological collections**.
- **National and global portals and catalogues have made important contributions** to the biological collections community by providing a platform to access, exchange and share data and promote standardization and consistency.
- Integration of specimen data with non-biological data sources will require **implementation of a network of cyberinfrastructure resources not yet realized**.
- **Without a permanent national cyberinfrastructure** that supports expanded digitization of dark data, improvement in data quality, **collections—both physical and digital—will continue to be underused**.



# Recommendations for Individual Biological Collections

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**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.

# Recommendations for the Biological Collections Community

**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) and **expand use to a broader range of stakeholders**.

# Recommendations for the National Science Foundation

**Recommendation 5-3:** The NSF Directorate for Biological Sciences should [continue to provide funding for digitization of biological collections and cyberinfrastructure](#) to support both living and natural history collections. Specifically, NSF should:

- [partner with other Directorates within NSF](#) (e.g., physicists, chemists, computer sciences, and education) [and beyond](#) (HHS, USDA, FDA, DOI, NOAA, NASA, DOE, etc.);
- establish [ongoing mechanisms for the biological collections community to meet, develop best practices](#), and work towards goals such as establishing and implementing unique identifiers, clear workflows, and standardized data pipelines; and
- promote and fund the development of cyberinfrastructure, tools, and technology to effect the [efficient multi-layer integration of data and collections attribution](#).



# Chapter 6: Cultivating a Highly Skilled Workforce

## CHALLENGES

Insufficient number of trained staff with multifaceted and expanding range of necessary skills

Underdeveloped biological collections workforce pipeline

Insufficient education programs to support development of next-gen biological collections workforce

Uncoordinated training and professional development options

Limited efforts to broaden participation in workforce

Insufficient institutional recognition and support for curation

## PATHS FORWARD

Launch community wide conversation on critical skillsets

Monitor & evaluate workforce capabilities/needs

Promote diversity as integral to workforce development pipeline

Harmonize staff training & professional development

Connect with relevant communities of experts.

Innovate staffing strategies

# Conclusions

- If biological collections are to not just survive but thrive, **they will need effective, visionary, and well-supported leaders** in addition to competent and innovative scientists and educators.
- **Cultivating a highly skilled collections workforce**, one that serves the data-intensive, globally connected, and often fast-paced needs of science and society, **is essential to the long-term sustainability of the nation's biological collections.**
- There are still **many unknowns about the biological collections workforce**—its size, scope, diversity, and impact on the scientific enterprise.
- A deeper understanding of **the scope and needs of the existing collections workforce** requires collaborative, coordinated action.



# Recommendations for Individual Biological Collections and the Biological Collections Community

**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](#). Define critical, broadly applicable [skillsets needed](#) to lead, manage, and care for biological collections and expand and promote their uses for the national and global scientific enterprise and the benefit of society.
- [Workforce Analysis](#). Conduct a [comprehensive analysis of the existing collections workforce](#) that, at a minimum, examines the professional responsibilities, demographics, education and training, incentives, compensation and benefits, and perceptions of greatest needs and opportunities for career development. Such an [analysis should be conducted on a periodic basis](#) (e.g., every 5 to 7 years) to inform community-level conversations and strategic action plans.
- [Diversity, Equity, and Inclusion](#). Develop and implement programs to [build a more diverse, equitable, and inclusive workforce](#). These programs should include elements such as restructured classroom and mentoring practices, student internships, research opportunities to ensure opportunities are more visible and accessible to diverse students and early-career professionals, and dedicated funding programs for internships and conference travel, workshops, and mentoring programs for diverse students and early-career professional.

# Recommendations for Individual Biological Collections and the Biological Collections Community

## Recommendation 6-1 (*continued...*):

- **Education and Training Coherence.** Harmonize the design and offerings of biological collections—focused curricula, certificate, and degree programs **to fill current and future workforce education and training needs**. This effort should include developing partnerships and cooperative arrangements with professional societies (e.g., for collections management training and taxonomic expertise), professional networks (e.g., in formal and informal education), and professional programs (e.g., museum studies, library studies, data science), respectively, to facilitate the design and implementation of biological collections-focused education and training programs in skillset areas not traditionally part of scientific training, and creating an online registry or portal to facilitate centralized access to information sharing about available education and professional development opportunities.
- **Alternative Staffing Models.** Provide guidance on alternative, innovative staffing strategies, including mechanisms to formalize student or volunteer involvement in collections management, **that can help address staffing shortages, meet critical skillset needs**, and serve as a mechanism to **deepen collections knowledge among a broader range of people**.

# Recommendations for the National Science Foundation

**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**.

# Chapter 7: Securing Financial Sustainability

## CHALLENGES

Short vs long-term support

Limited funding and limited pool of funders

Under-appreciation of the value of biological collections

Communicating outcomes and impacts

Estimating financial value and cost of biological collections

Financial obligations for growth & maintenance of collections and associated digitized data

Lack of business management training

## PATHS FORWARD

Develop long-term strategic frameworks to build a diversified funding portfolio

Build funding partnerships

Communicate: messaging

Demonstrate ROI & cost/benefit

Develop strategic business models

Develop complementary funding for research & infrastructure

Train & share best practices

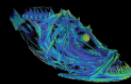
Willingness to pay

National vision for distributed biological collections network



# Conclusions

- Physical infrastructure, cyberinfrastructure, workforce, and the evolving requirements for quality and accessibility of specimens with associated data place **growing financial demands on biological collections**.
- Not all biological collections have **sufficient expertise** to develop comprehensive funding models.
- Efforts **to identify new strategies for sustaining and growing biological collections** will require initiatives from individual collections well as collaborative action of the biological collections community.
- To show the national and international impact of U.S. collections and identify new approaches to funding the collections community will need to:
  - **track use of collections in research and education using diverse metrics at the level of the collections' community, and**
  - **act as one to develop partnerships.**



# Recommendations for Individual Biological Collections

**Recommendation 7.1:** The leadership (directors, managers and curators) of biological collections should [work with business strategists and communication experts to develop business models](#) for financial sustainability and infrastructure of biological collections. Included in this discussion should be the development of a mechanism to:

- [diversify funding portfolios and develop relationships with non-traditional partners](#) who may provide collections support;
- [assess a per-specimen acquisition and maintenance cost](#). This assessment would depend on the size and nature of the collection—both physical and digital; and
- [explore revenue streams that could include pay-for-use models](#), the establishment of MTAs and licensing systems, or perhaps pay for value-added for digital datasets configured for a particular purpose. Each of these approaches must be done in ways that avoid driving costs to levels that are prohibitive for researchers.

# Recommendations for the Biological Collections Community

**Recommendation 7.2:** Professional societies should develop extensive networked training and 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.

# Recommendations for the National Science Foundation

**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](#). Specifically, they should:

- [work with other federal agencies](#) to address research infrastructure support and needs;
- [provide funding for the management and infrastructure of the collections](#) themselves;
- [collaborate](#) with host-institutions and other funders [to establish new mechanisms and funding to collect, aggregate, and synthesize metrics process and performance for biological collections](#); and
- support the accessioning, curation, digitization, and long-term care of specimens as well as the publishing of their associated data through a [mandated specimen management plan](#).

# Chapter 8: The time to act is now!

- A broad consensus of scientists has emphasized that **anthropogenic impacts** such as habitat conversion, overexploitation of resources, pollution, and climate change, **are catastrophically challenging Earth's systems**.
- **Biological collections provide the temporal, spatial, and taxonomic samples needed to document effects of changes in the biodiversity of natural and managed ecosystems**. Important clues to understanding, adapting to, and mitigating environmental changes reside in the living and natural history collections that are the focus of this report.
- **Biological collections can make transformative impacts on pressing societal issues** by facilitating new collaborations among diverse disciplines, ultimately stimulating new perspectives and new synergistic initiatives.
- More than ever, **biological collections have an energized community ready to step up to meet these grand basic biological and societal challenges**.

# A framework for collaboration and innovation is needed

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- Many of the recommendations are **beyond the capability of individual collections to implement.**
- **Several research communities have established central hubs, multi-tiered networks, associations, or synthesis centers,** funded through NSF grants or other federal and state support.
- The biological collection community could **leverage the organizational structure of centers and networks as a model to establish an Action Center for Biological Collections.**

# An Action Center for Biological Collections

- 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.**
- Its mission would focus on **all** biological collections and offer a collaborative platform to provide actionable and lasting solutions for the collection community at large.

# National Decadal Survey for Biological Collections

- Many scientific communities work together to set priorities for research and building infrastructure needs to accomplish those priorities.
- A biological collections-focused decadal survey would establish a set of priorities that could only be accomplished with a concerted effort of the community, rather than one biological collection.
- A decadal survey for the biological collections community needs to involve the natural history and living stocks collections communities.
- The collections community needs to make stronger connections with disciplines not traditionally associated with biological collections. Cross-directorate participation in a decadal survey would help to strengthen these connections.



# Recommendations for the National Science Foundation

**Recommendations 8-1:** NSF 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.

**Recommendations 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.

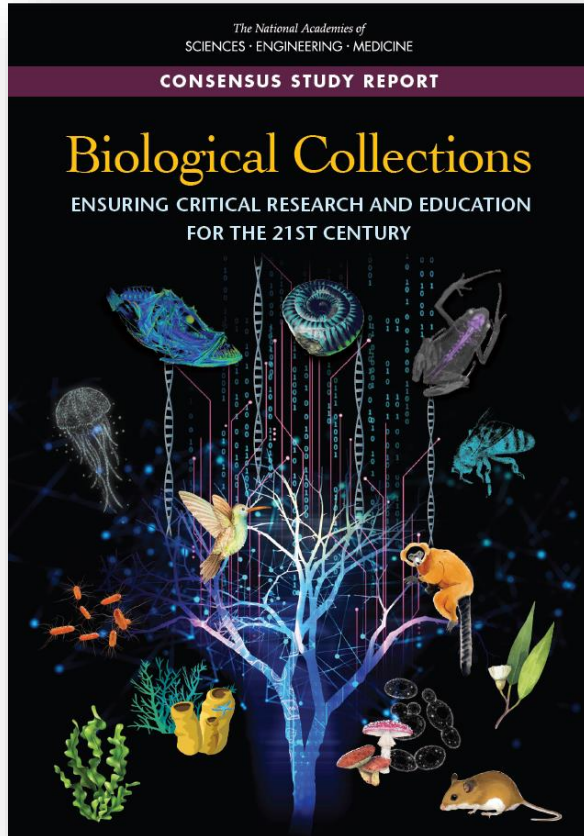
**Recommendations 8-3:** NSF should [expand partnership capabilities more broadly across NSF, other federal agencies, international programs, and other sectors to maximize investments](#) in support of Recommendations 8-1 and 8-2.

# Acknowledgements

- NASEM Staff: Audrey Thévenon, Keegan Sawyer, and Jessica DeMouy
- Invited speakers
- Members of the public
- Report reviewers
- Committee members

This study was conducted at the request and with the support of the  
National Science Foundation





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