ICOM international council of museums

Advances in Museum Research

ROUTLEDGE

THE FUTURE OF NATURAL HISTORY MUSEUMS

EDITED BY ERIC DORFMAN

Contents

5 The essential role of museums in biodiversity conservation

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Introduction

The complexity of forces threatening many of the most valued dimensions of the living planet is well recognized and compels a rich interplay between science that reveals the natural world and society's pathways to value and steward it (Rockström et al., 2009; Steffen et al., 2011). As collection-based institutions, natural history museums (NHMs) have long played a special role in the conservation arena. By documenting, cataloging, analyzing, and communicating the splendor and richness of life, NHMs immerse visitors in the natural world in a way they may otherwise not experience. The importance of this role is difficult to overstate—in a world where over 50 percent of people live in urban settings removed from natural systems that sustain us, NHMs can frame and maintain a collective sense of place, and root societal policy and values in the natural and cultural fabric that underlies them. NHMs provide a unique depiction of patterns of life across space and over time unavailable to any one person's perspective over their lifetime.

While the traditional role of museums has been to discover, interpret, and disseminate knowledge about the natural world, museums are ideally positioned to realize a broader and more relevant role in society: to promote informed engagement and stewardship of our biological and cultural heritage through pertinent research, institutional programming, and on-the-ground collaborations. Many NHMs have integrated biodiversity conservation into their mission and programs, and are leading the way in conservation-oriented research projects and collaborations, informing the public about issues concerning our planet's health, and promoting ecologically sustainable practices. In the 2015 Taipei Declaration on Natural History Museums and Biodiversity Conservation, the International Council of Museums Committee for Museums and Collections of Natural History (ICOM NATHIST) stated:

> Increased human activities have created catastrophic declines in biodiversity. Both ethics and logic point to a mandate to conserve vulnerable habitats and species. To achieve best practice, natural history museums take action to conserve natural habitats and populations.
>
> (ICOM NATHIST, 2015)

This role for NHMs is not new. While many NHMs have recently broadened their missions to strengthen their commitment to conservation issues, there is a deeper history to the role museums have played in recognizing and responding to threats to the richness of the living world. Over a century ago, Frank M. Chapman, a famously influential curator at the American Museum of Natural History (AMNH) in New York, promoted replacing Christmas bird "shoots" with the Audubon Society's Christmas Bird Count, one of the oldest citizen science programs in the United States, which has provided some of the most direct evidence of the impact of a changing climate on ecological communities. Chapman also saw firsthand the impacts of habitat degradation and hunting for meat and feathers on bird communities in the American Southeast and the Caribbean, and effectively used his position at the museum, and the respect for its science, to influence President Theodore Roosevelt to push market hunting limits and habitat conservation policy.

Chapman's career and conservation efforts embody the potential for NHMs to link their scientific power and reputation to fostering shifts in attitude, behavior, and political will. And there are numerous additional examples of how NHMs have made these links and influenced policy and action. For example, in the 1950s, high mortality and low reproductive success were recorded in many bird species. One hypothesis explaining these mortalities was that dichloro diphenyl trichloroethane (DDT), which was widely used as an insecticide since the late 1940s, had accumulated in adult birds and led to eggshell thinning. Scientists tested this hypothesis by comparing egg samples collected in the field with eggs deposited in museum collections prior to the widespread use of DDT. The results served as evidence to influence policy leading to the ban of DDT in the United States in 1972 (Ratcliffe, 1967, 1970; Anderson and Hickey, 1972).

In this chapter, we provide an overview of the roles that natural history museums (NHMs) have played in conservation, with a focus on collections-based work, including the long history of NHM expeditions and the contemporary trend toward museum-based genomics and bioinformatics. We also discuss innovative ways in which museums are able to contribute to conservation today, through diverse, interdisciplinary partnerships and conservation-oriented programming. Natural history museums have played a role in confronting societies' greatest ecological challenges, from species loss to tracking and responding to the impacts of climate change; we hope to illustrate how they can also lead society's approach to conservation issues into the future.

Collections and expeditions: their role in wildlife conservation

Direct observation through exploration, field research, and collections are integral components of museum science that support biodiversity conservation goals and actions. Collections are part of a museum's core scientific legacy, representing invaluable reference points for monitoring biological diversity, environmental change, and ecosystem health—available for use by multiple sectors, including science, health, and industry.

At the AMNH, scientists conduct between 50 and 100 field expeditions each year. As of 2016, the museum holds over 33 million specimens and artifacts in its collection; the Natural History Museum of London has over 80 million specimens; the Smithsonian National Museum of Natural History has over 145 million specimens; and the Field Museum of Natural History in Chicago has 23 million specimens and artifacts, just to name a few. The "heyday" of Western museum expeditions, from the 1880s to 1930s, during which well over 1,000 expeditions were sent to the remotest corners of the Earth, included, for example, the Whitney South Sea Expedition, which focused on collections for birds, plants, and other animal specimens on over 600 Pacific Islands. Modern expeditions have been reinvigorated through new initiatives such as AMNH's Explore21 program, which supports expeditions rooted in multidisciplinary partnerships and new technology, and seeks to intersect with biodiversity conservation goals through targeted explorations in regions with critically threatened habitats, or unknown diversity; an important aim given that the vast majority of the Earth's species remain to be described and studied.

The ethics and strategies guiding the collection of biological specimens and anthropological and archaeological artifacts for NHMs have been renewed and updated as the purpose of museums has evolved. Some have criticized biological specimen collection for scientific studies, claiming that collection has played a role in species extinction (Minteer et al., 2014). Modern collecting adheres to strict permitting and ethical boundaries, endeavoring to collect well below levels that would affect demography (Collar, 2000; Winkler et al., 2010; Rocha et al., 2014). Collection strategies can and should be grounded in partnerships and agreements with local resource stewards toward cogenerated biodiversity and biocultural conservation goals (for example, Housty et al., 2014).

Expeditions and collections continue to be invaluable for taxonomic and systematic study, leading to the discovery and description of new species or range extensions or contractions that inform biodiversity conservation actions and priorities. For example, AMNH's National Science Foundation–funded biotic inventory surveys in Vietnam from 1998 to 2001, led by its Center for Biodiversity and Conservation (CBC), brought together scientists and taxonomists from across the museum's scientific departments as well as from the Missouri Botanical Gardens and the Institute of Ecology and Biological Resources (IEBR) in Hanoi. These surveys resulted in the discovery of more than fifty new species, the rediscovery of species thought to be extinct, some of the first ecological research on rare and elusive species in remote areas of Vietnam, and contributions to the establishment, upgrade, or extension of protected area systems in Vietnam. The surveys also resulted in the most comprehensive and up-to-date review of Vietnam's mammal fauna at the time (Dang et al., 2008), which supported the incorporation of these frequently under-surveyed but abundant and diverse taxa into conservation strategies as indicators of ecosystem health.

There are many other examples where museum expeditions and collections have directly supported biodiversity conservation actions, such as the Rapid Biological and Social Inventories led by the Field Museum in Chicago, along with local experts. These inventories identify important biological communities in the region of interest and evaluate assets in local communities for long-term engagement. Since 1999, hundreds of local students and partners have been trained in field survey methods, and more than 150 species new to science have been discovered. The information is relayed to local and international decision-makers who set priorities and guide conservation. The inventories have supported the designation of over 32 million acres of protected wilderness in the Amazon headwaters, Cuba, and China (Field Museum, 2016).

In particular, local and regional museum collections provide fine-grained resolution and reference points for key questions concerning environmental change and pollutants, species, and ecosystem health (detecting the emergence and spread of Chytrid Fungus in museum specimens coinciding with amphibian declines; Cheng et al., 2011), emerging diseases (detecting the appearance of Lyme disease in museum tick collections; Persing et al., 1990), and climate change (testing the correlation of body size decline to climate change; Gardner et al., 2011).

Museum collections have played a critical role in local and global conservation policies related to the illicit wildlife trade. Museum specimens are ideal for providing vouchered reference specimens for scientifically and legally robust forensic identification of wildlife parts and products confiscated from illegal activities (Eaton et al., 2010). Fine-scale population assignment is particularly informative for wildlife trade management (Zhang et al., 2015). However, reference databases consisting of multiple sequences of trade-targeted species from across their range are typically lacking or impossible if derived only from the collection of a single museum. Thus, support of and collaboration among local and regional museums are critical to further these efforts and help clarify trade patterns and hot spots of trade activities or to identify populations with a high level of harvesting pressure.

New technologies now allow museum scientists to uncover growing layers of information on each specimen or artifact beyond anything that the original collectors could have foreseen, such as CT-scan tomography (Bi et al., 2013), stable isotope analysis, massively parallel sequencing, proteomics (Welker et al., 2015), ultra violet-visable (UV/VIS) spectrophotometry (Andersson et al., 1998), and machine learning algorithms for projecting species' distributions (Newbold, 2010; Peterson et al., 2011). Species distribution models (SDMs) use the relationship between observed specimen localities in geographic space and environmental variables such as climate to generate a map of suitable areas for species in a region. SDMs can help locate areas that may be suitable for a species but have not yet been surveyed, can inform the planning and designation of protected areas, and can project future changes in species distribution amid a changing climate (Peterson et al., 2011; Blair et al., 2012). Museum scientists have used specimens, remote sensing, and SDMs to improve understanding of local endemism in Madagascar, finding that multiple evolutionary processes interact to explain why so many species are restricted to small parts of the island (Pearson and Raxworthy, 2009; Blair et al., 2013). The work has important implications for conservation planning since improved understanding of ecological and evolutionary processes can improve predictions of where species are likely to be found, and hence help define which areas should be prioritized for conservation.

These new analyses and technologies are made possible in part because of advancing digitization of museum collections and increased open availability of these data sets through platforms such as the Global Biodiversity Information Facility (GBIF); SYNTHESYS, the Synthesis of Systematic Research project; as well as other global environmental and climate data sets such as WorldClim (Hijmans et al., 2005). Enhanced inventory, digitization of collections, and open sharing increasingly allow conservation scientists to leverage museum collections, new analyses, and technologies for their full potential toward informing conservation action. However, open sharing and digitization of global museum collections has also revealed some persisting gaps and challenges ahead; a GBIF task force on biodiversity data fitness convened at AMNH in 2015 stressed that the global gaps in primary biodiversity data are driven by taxonomic inaccuracies, backlogs in digitization, administrative obstacles to sharing or access, and biases in spatial coverage of data. Global natural history collections contain information on biodiversity from almost three billion specimens, all with great promise to be leveraged for wildlife conservation if remaining challenges can be addressed (Anderson et al., 2016).

Genomics research and its role in biodiversity conservation

Advances in genomics and bioinformatics have now made NHMs and their diverse collections even more valuable resources for biodiversity conservation. Traditional collections, which include vouchered specimens, provide a comprehensive and systematic sampling of genetic diversity through time and space. Specifically, historical collections capture changes in diversity over a crucial time for conservation research—spanning the duration of increased anthropogenic activity. In addition, analyses of historical, archaeological, and paleontological remains can contribute important information regarding the conservation of populations and species that cannot be obtained any other way (Leonard, 2008).

Collections contain a representation of extinct species, as well as reflect population diversity from areas where these species have been locally extirpated and artificially fragmented. For example, researchers have reconstructed genetic variation from the recent past using museum specimens of Dutch black grouse and alpine chipmunks to compare to current levels of variation, which can inform causes and effects of loss or gain of genetic diversity over time (Larsson et al., 2008; Bi et al., 2013).

Complementing these more traditional collections are new, frozen tissue repositories, which provide extraordinarily valuable specimens amenable to genomic research and other areas of conservation research. They can hold population-level samples collected less invasively, with critical examples represented by vouchered specimens. Collected and stored in ways that make them useful for high-quality deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) extraction, these materials allow for examination of genetic diversity at unprecedented levels of detail including whole genome and transcriptome sequencing.

New technologies and natural history collections can be used for important conservation research through the ever-expanding field of conservation genetics and genomics (DeSalle and Amato, 2004). While originally focused on using molecular markers for resolving questions of uncertain taxonomy for determining conservation units and simple genetic threats such as inbreeding in highly fragmented populations, this field has expanded greatly. It now provides us with a better understanding of human impact on the evolutionary processes of whole ecosystems; facilitates discovery of important biological information on species that are difficult to observe directly; and uncovers molecular ecology and cryptic diversity, emerging diseases as a threat to biodiversity, as well as the complex interactions of the individual organism and its microbiome (McMahon et al., 2014; Gómez et al., 2015). The Sackler Institute for Comparative Genomics at the AMNH has engaged in a ten-year collaboration with the Panthera Foundation on an extensive large cat molecular ecology project focused on jaguars in Central and South America and tigers and snow leopards in Asia. Using fine-scale individual genotyping of noninvasively collected fecal samples, this program has constructed detailed, landscape genetics maps that provide information on the number of individuals in a population, genetic connectivity and use of corridors, and a rigorous testing of applied conservation management strategies in range countries (Caragiulo et al., 2015).

In other examples, genetic information from museum specimens has shown that northeastern beach tiger beetles were historically present across the northeastern United States, though they are currently only found in the state of Massachusetts (Goldstein and DeSalle, 2003). Genetic data from museums guided reintroduction efforts that would preserve the integrity of evolutionary significant unit boundaries for the brush-tailed rock wallaby in Australia (Paplinska et al., 2011). These areas of study require the extensive sampling strategies that are the historical and ongoing purview of natural history museums.

Another important area in which natural history collections and genomics combine to provide important tools for biodiversity conservation is the field of wildlife forensic science. Genetic and genomic tools allow museums to advance conservation through forensic investigations that link vouchers in collections to wildlife trade, allowing for better tracking of wildlife trade sources and supporting enforcement and management of a wide range of species. These museum-based wildlife forensics initiatives strongly augment the work of management authorities by offering a resource that would otherwise be unavailable in addressing global threats to biodiversity. Use of DNA barcoding for species identification has now become one of the most important tools for monitoring the illegal trade in wildlife and enforcing the laws governing its regulation (e.g., African bushmeat trade; Eaton et al., 2010; pangolin trade, Zhang et al., 2015). Without vouchered databases created from barcoding museum specimens, this would not have been possible.

No greater resource for biodiversity conservation genomics research exists than the historical and modern collections found in the world's NHMs. These collections increase in importance and value every day as new advances in genomics technologies and bioinformatics allow us to delve deeper into the processes responsible for the diversity of life on the planet—and the best ways to retain the greatest amount of that diversity into the future.

Museums as catalysts for conservation collaboration

NHMs also play a role in conservation action by catalyzing partnerships that transform the way conservation is envisioned, framed, and led. The diversity of disciplines in NHMs coalesces expertise in, for instance, earth sciences, paleontology, comparative biology, and anthropology, as well as education and communication, providing a robust, interdisciplinary platform for conservation problem-solving and innovation. Combined expertise in ancient DNA, paleontology, anthropology, and biology, along with new computational techniques and large data sets to study species distributions, have documented anthropogenic activity that has transformed ecosystems through millennia (Boivin et al., 2016). NHMs are ideal incubators for both interdisciplinary work and transdisciplinary work that convenes scientists, local communities, and other decision-makers. As one example, NHMs are ideal for framing biocultural approaches to conservation, which consider social-ecological systems as holistic units.

Because the role of museums in convening strategic partners, fostering local capacity, or guiding policy often underpins other, more visible actions, their catalytic impact can be underappreciated (McCarter et al., 2001). Yet conservation programs at museums are leading the way in innovative, long-term partnerships that connect diverse stakeholders across local and global communities and draw from multiple sources of knowledge for conservation action. These partnerships can take a diversity of forms and involve a variety of partnerships, ranging from short-term collaboration on expeditions to long-term relationships. A selection of examples is described in Table 5.1, taken from museums across the world.

Table 5.1 Selected examples of the diverse partnerships that natural history museums can convene and the conservation outcomes they catalyse

Institution	*Program/project*	*Partners/stakeholders*	*Scale*	*Illustrative conservation outcomes (with key references)*
American Museum of Natural History, New York	Center for Biodiversity and Conservation (CBC): Metropolitan initiatives	Museum scientists, state and city agencies, local communities	Local, regional	In the New York region, the CBC has been influential in the formation of the city's conservation policies and in New Yorkers' relationships to their environment, for example, by spearheading citizen monitoring programs and the integration of biodiversity conservation in the PlaNYC. (1)
	Center for Biodiversity and Conservation: Pacific Programs	Museum scientists, national agencies, indigenous and local communities	Global	In Melanesia, the CBC has catalyzed the development of a network of protected areas that includes the largest terrestrial protected area in the Solomon Archipelago. In the Great Bear Rainforest area of coastal British Columbia managed by the Heiltsuk First Nation, a joint research agenda in accordance with Heiltsuk customary law has allowed for more effective grizzly bear management. (2)
	Center for Biodiversity and Conservation: Grupo de Conservación Flamencos Altoandinos (GCFA)	AMNH scientists, academics, national and regional agencies, local communities, NGOs, industry, global conventions	Regional	The GCFA has convened local and regional stakeholders to coordinate research and monitoring of flamingos and wetlands. Long-term engagement with communities and agencies has resulted in the establishment of local and national protected areas, Ramsar sites, and Important Bird Areas. (3)

(*Continued*)

Institution	*Program/project*	*Partners/stakeholders*	*Scale*	*Illustrative conservation outcomes (with key references)*
California Academy of Sciences, San Francisco	Institute for Biodiversity Science and Sustainability	US and Filipino museum scientists, media professionals, educators, national agencies, local communities	Global	Collaborative expeditions in the Philippines that have included outreach, education, and discussion surrounding conservation policy; facilitating work with the local governments to conserve marine life; and advancing the establishment of new marine protected areas and the expansion of existing ones. (4)
Field Museum of Natural History, Chicago	Keller Science Action Center: Chicago Cultural Alliance, Calumet Stewardship Initiative, and Chicago Wilderness	Museum biologists, anthropologists, educators, geospatial analysts, governments, communities, landowners	Local and regional	Joint programs and alliances have fostered implementation of the Chicago region's climate action plans, engaged citizens in monitoring and learning, improved quality of life at the local level, and influenced broader networks and efforts for social and environmental change. (5)
	Keller Science Action Center: Rapid Inventories	US and local museum scientists, national agencies, indigenous and local communities	Global	Since 1999, the Rapid Inventories have discovered more than 150 species new to science, increased known ranges for more than 1,000 species, and fostered the protection of 32 million acres of wilderness in the Amazon headwaters, Cuba, and China. (6)
Museo Nacional de Historia Natural (MNHN) de La Paz	Zoology Department	Museum scientists, regional and local government, local and indigenous communities, fishermen associations	Local and regional	Since 2002, the MNHN has convened diverse partners to collaboratively assess and monitor freshwater fish populations across Bolivia, and fostered conservation and sustainable management programs that support both fish populations and local subsistence and livelihood. (7)

		and local communities		new to science, increased known ranges for more than 1,000 species, and fostered the protection of 32 million acres of wilderness in the Amazon headwaters, Cuba, and China. (6)

Museo Nacional de Historia Natural (MNHN) de La Paz	Zoology Department	Museum scientists, regional and local government, local and indigenous communities, fishermen associations	Local and regional	Since 2002, the MNHN has convened diverse partners to collaboratively assess and monitor freshwater fish populations across Bolivia, and fostered conservation and sustainable management programs that support both fish populations and local subsistence and livelihood. (7)
Vietnam National Museum of Nature, Vietnam Academy of Science and Technology, Hanoi	Department of Communications and Community Education	Government ministries, Vietnam Association of Photographic Artists, Vietnam Forest Association, and nongovernmental and governmental organizations and Vietnam and international individuals	Local	The museum in Vietnam has educational programs that merge science and art and raise awareness about the importance of protecting the natural environment and biodiversity, including photographic competitions and exhibitions such as *The Beauty of Natural Forests* and *Insects of Vietnam*. (8)

1—Kiviat and Johnson, 2013; 2—Filardi and Pikacha, 2007; Housty et al., 2014; 3—Marconi, 2007; Marconi et al., 2011; 4—Gosliner and Burke, 2013; 5—Zint and Wolske, 2014; Hirsch et al., 2011; 6—McCarter et al., 2001; 7—J. Sarmiento and S. Barrera, pers. comm.; 8—Vũ Văn Liên, pers. comm.

At the Center for Biodiversity and Conservation at the AMNH, for example, we aim to transform knowledge from diverse sources and perspectives—spanning areas of scientific research as well as traditional and local knowledge—into conservation action. We convene and connect diverse audiences or stakeholders, and establish collaborations centered on research and action and capacity development. Aiming to encompass the full cycle of conservation action—from identifying needs to implementing projects to adapting and broadcasting lessons learned—the CBC fosters long-term partnerships that can promote local ownership, and inspire replication and scalability (Housty et al., 2014; Sterling et al., 2016). The center's Network of Conservation Educators and Practitioners, for instance, has convened AMNH scientists, university educators, and conservation practitioners working on the ground to collaboratively develop more than 160 free conservation training modules in multiple languages, and offer training opportunities for over 4,500 conservation trainers and professionals in the United States, Latin America, Asia, the Pacific, and Africa (Bravo et al., 2016).

As these examples illustrate, NHMs have the expertise and skills to catalyze linkages between biodiversity surveys and protected area planning, between local management of natural resources and cultural dimensions of diversity. Through these collaborations, the conservation impact of museums also includes new, more diverse protected areas around the world, and participatory research that strengthens biodiversity management, local governance, and policy.

Inspiring action and developing capacity for conservation through education

A growing body of evidence indicates that the public learns much of what it knows about science outside the formal education system. From libraries, museums, and parks, to the Internet, friends, and family, a range of resources facilitates public science learning (Bell et al., 2009; Falk and Dierking, 2010; Falk et al., 2010). Given all the topics that need to be addressed in formal education, relatively little time can be devoted to conservation education in elementary, secondary, and university curricula, so natural history museums help to fill a crucial gap by making programs relevant to students and the general public (McCarter et al., 2001). Natural history and science museums are in a unique position as a venue for communicating science because of their high credibility ratings and level of trust they invoke in the public (Novacek, 2008).

NHMs have receptive and diverse audiences, and can raise awareness and engagement in conservation among their visitors through powerful experiences in permanent exhibit halls, thematic temporary exhibitions, public programming, and sustained mentoring and training programs. Millions of people visit natural history museums every year, and visiting museums is one of the most popular out-of-home leisure activities in the United States (American Alliance of Museums, 2016). For example, 60 percent of Los Angeles residents visited the California Science Center since its renovation in 1998, including residents of all races/ethnicities, neighborhoods, incomes, and education levels (Falk and Dierking, 2010). A personal visit to a museum allows for close encounters with specimens, dioramas, and artifacts as well as hands-on learning through interpretive visuals and interactive displays. In addition, through websites and social media, museums are offering science content through news and blog posts, online exhibitions, and even online courses for credit, reaching billions of people around the world (ICOM NATHIST, 2015).

Several museums have developed permanent galleries that showcase the extraordinary biodiversity of the planet; draw attention to recent declines, extinctions, and threats; and highlight actions and solutions using specimens and models, photos, videos, dioramas, and interactives. Some examples are the AMNH's Hall of Biodiversity, the Royal Ontario Museum's Life in Crisis: Schad Gallery of Biodiversity, the Field Museum's Abbott Hall of Conservation Restoring Earth, and Spain's Exhibition of Biodiversity in the Natural Science Museum of Barcelona. Smaller museums have also incorporated permanent conservation-focused exhibitions, such as the Interaction of Nature and Man hall in the National Museum of Nature and Science in Japan, and the Diversity of Life exhibition at the North Carolina Museum of Natural Sciences. However, some well-known and popular museums have more traditional permanent galleries that have not been revised to address conservation issues (McCarter et al., 2001). The updating of exhibitions, incorporating new and dynamic content and technologies in halls and exhibitions that are considered "permanent," is an ongoing challenge for museums.

One way that museums have addressed this is through temporary exhibitions dealing with current environmental issues; such exhibitions have proliferated in recent years (Novacek, 2008). Many museums have developed special exhibitions on climate change (*Climate Change: The Threat to Life and a New Energy Future* at the AMNH), species extinction (*Extinction: Not the End of the World* at London's Natural History Museum), resource management and sustainability (*H_2O = Life* and *Our Global Kitchen* at the AMNH), and protected areas (*Art of the Parks: Celebrating 100 Years of the National Park Service* at the Rockwell Museum, Corning, New York). Temporary displays are frequently designed to travel to various destinations around the world, offering content and messages of universal relevance, with some sections developed by local teams to include case studies or stories tailored to the local context.

To further engage the public in biodiversity research and conservation, many museums have developed citizen science programs, collaborations between scientists and citizen volunteers. These expand opportunities for scientific data collection; provide access to scientific information and opportunities to engage in the scientific process for community members; and equip the public with information, skills, and tools to make informed decisions regarding resource use and management. For example, several museums in the United States have led BioBlitzes, intense, twenty-four-hour sampling periods during which scientists, naturalists, and volunteers attempt to survey and record all living species in a region. The Natural History Museum of London's Big Seaweed Search program engages volunteers in plot surveys along the beach to record seaweed and help monitor change in the sea life due to sea level rise and ocean acidification, and to monitor for invasive species. Many more examples exist, and new projects are regularly being added to museums' public engagement offerings.

Finally, in addition to public programs aimed at general audiences, NHMs also provide advanced training in biodiversity science, curriculum development, and teaching strategies in conservation through site-based and online courses for students, teachers, and practitioners. Several national programs in the United States pair university students with museum scientists to develop applied research projects (for example, the Doris Duke Conservation Scholars Program, the National Science Foundation's Research Experience for Undergraduates). In 2013, the AMNH expanded its Science Research and Mentoring Program for high school students from across New York City to provide additional opportunities in conservation biology research. Evaluations show that students previously not familiar with the field of conservation biology plan on pursuing this as a career after participating in the program. The AMNH's NCEP works to improve the availability, quality, and access to high-quality, current educational resources for conservation teachers, professionals, and trainers around the world.

Promoting understanding, awareness, and stewardship of biodiversity to broad museum audiences requires a multidimensional strategy, using appropriate messages, approaches, and technology for effective communication. NHMs have a captive and diverse public and are well positioned to mobilize large audiences into the conservation fold (Novacek, 2008). While renewing content in permanent exhibitions is an ongoing challenge for museums, new digital technologies using mobile platforms, and approaches such as crowdsourcing, gaming, citizen science, and social media offer new and exciting ways to engage audiences around the world in NHMs conservation programs.

Engaging future generations in conservation action

Over the last three decades, compelling arguments have been made for NHMs to play a central role in research leading toward conservation of biodiversity, and to embrace their responsibility to inform stewardship of life on Earth (Alberch, 1993; Krishtalka and Humphrey, 2000; Pyke and Erlich, 2010). In the face of an increasingly urgent biodiversity and climate crisis, this role for NHMs becomes essential. Almost two decades ago, Krishtalka and Humphrey (2000) argued that to fulfill their potential into the future, NHMs needed to face challenges in four areas: deploying their information to address the biodiversity crisis, educating scientists and citizens to tackle complexity, engaging visitors in conservation action, and evolving their management culture. How far have we progressed on these, and what are our challenges moving forward?

NHMs have made progress on organizing, digitizing, sharing, and collaborative use of data. Emerging threats, like climate change, require that museum data systems remain flexible and alternative data sources be creatively repurposed (Johnson et al., 2011). New technologies and approaches are continuously generating more data, so this task remains an ongoing, high-priority challenge worthy of attention and resources.

In addition to the creation of conservation units or departments, some established institutions, such as the California Academy of Sciences, are now shifting the role of conservation and sustainability efforts to the core of their institutional mission, something more museums should contemplate. Newly established NHMs can be "born" with conservation units, such as the Department of Nature Conservation at the Vietnam National Museum of Nature, which was established in 2012. Tasked with producing research on restoration and conservation threat assessment and management, this department has developed in just a few years DNA assessment processes to identify species of tigers, white rhino, elephants, king cobra, five precious wood species, and some bamboo species, to inform wildlife trade mitigation efforts.

As NHMs look ahead, an emerging and important challenge is our growing understanding of biodiversity as a collection of dynamic systems linking biological and cultural components. Such a systems approach can provide a framework for understanding individual components and their interrelationships and result in more effective conservation actions (Sterling et al., 2010). A systemic view also requires a greater focus on the human element, and NHMs have traditionally tended to decouple nature and humans. The challenge then becomes how to communicate, investigate, and support the multiple ecological, cultural, and evolutionary processes that sustain biodiversity, and to promote a dynamic view of nature within the framework of museum collections and exhibit halls. However, since NHMs typically have a range of expertise in biology, anthropology, and education, they are ideally positioned to create multidisciplinary teams using systems approaches to tackle complex problems.

While NHMs have continued to innovate in the areas of education and engagement, how can they "inspire the citizenry to become the environmental conscience of the nation" (Krishtalka and Humphrey, 2000)? NHMs need to lower the barrier to conservation action by capitalizing on easy access to information through digital and virtual platforms, and the popularity of social media to promote solutions through specific, locally relevant, choices for action. NHMs can catalyze diverse communities to co-curate exhibitions, co-create educational materials, and even identify items for sale in their shops that resonate and inspire civic engagement and action. They need to expand their toolbox, for instance, to include the principles of conservation psychology, a growing field that studies the relationship between people and the environment and the factors that influence people's attitudes and motivates behavioral changes for better stewardship of the environment (Clayton et al., 2015). Additionally, NHMs need to think beyond their walls and work with communities and stakeholders to identify strategically where exhibitions will travel, targeting not only specific countries or regions but also diaspora communities around the world, for maximum outreach and impact. Finally, NHMs could amplify conservation messaging by working across collections-based institutions (other NHMs, zoos, aquariums, and botanical gardens) to design and evaluate programs that will reinforce what individuals can do (Sterling et al., 2007).

We agree with Krishtalka and Humphrey (2000) that updated management, administrative, and leadership training are necessary at all levels for NHMs to fulfill their mission to society. A core element of this should be a concerted effort to diversify the science and conservation workforce to achieve broad and lasting conservation outcomes. Complex issues such as biodiversity conservation are best addressed by diverse, inclusive groups of people. Research by organizational scientists, psychologists, sociologists, economists, and demographers show that socially diverse groups (those with a mixture of race, ethnicity, gender, and sexual orientation) are more innovative than homogeneous groups and are less likely to stall at suboptimal solutions (Page, 2007; Phillips, 2014). Further, biodiversity conservation depends on the support of a wide variety of citizens who may differ in their core values and beliefs. A more diverse and equitable museum workforce is key to generating research agendas, policies, and actions that achieve the goals of local and global biodiversity conservation (Hovardas and Poirazidis, 2007; Foster et al., 2014).

Moving forward, we believe NHMs will have to transform how we think of, exhibit, and interpret "natural histories," as well as our role and responsibility in the biodiversity crisis, and develop innovative and heterogeneous ways of bridging separation between nature and culture, local and global, colonizer and colonized, "us" and "them." Given their rigorous science, reputation, and place in local and global communities, NHMs are poised to be cutting-edge, transformative spaces for informing and engaging a diverse community in sustaining the world's biological and cultural diversity. If they boldly embrace this evolutionary potential, they can help us imagine and catalyze a multiplicity of success stories—models for a diverse, sustainable, and resilient society.

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