CURATING TOMORROW

Museum collections and biodiversity conservation

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CURATING TOMORROW

How can UK museum collections effectively support the conservation of global biodiversity, through supporting biodiversity-related research, management and policy?

Curating Tomorrow

Curating Tomorrow is a consultancy for museums and the heritage sector, helping them draw on their unique resources to enhance their contributions to society and the natural environment, the Sustainable Development Goals, climate action and nature conservation. Curating Tomorrow also applies the museum-based skill of curating to thinking about and addressing real-world challenges, not necessarily involving museums or museum collections. Curating Tomorrow draws on high-quality information and research; combines creativity and imagination with focus, selection and attention to the real world; and has a strong focus on supporting positive change. Depending on the context, this could involve curating collections, research, ideas, partnerships, exhibitions, events, consultations, policies and/or strategies together to address key challenges and questions. It will always involve enhancing your social and environmental impact through focused action directed to positive goals. Everyone has a part to play, Curating Tomorrow can help them play it.

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Who is this booklet for?

This booklet is aimed at ecologists, conservation scientists, wildlife managers, biodiversity and environmental records workers, environmental policy makers, and museum workers. It is intended to be useful for both nature conservation and museum sectors, to promote a common understanding of the potential of natural history collections, to support their effective use and development, and, most importantly, to conserve global biodiversity.

This booklet supports the following Sustainable Development Goals:

We live in a time of unprecedented environmental change, with climate change, habitat alteration, pollution, invasive species and over-exploitation all contributing to species declines (Millennium Ecosystem Assessment 2005, IPBES 2019). Biodiversity researchers, policy workers, and site and species managers work to stem the tide of declines. Museum collections play a key role, or could play a key role, through supporting biodiversity and nature conservation-related research, management and policy; they also support public education about biodiversity, although that is not the focus of this booklet.

This booklet explores some of the problems biodiversity faces, and examples of how UK museum collections can help biodiversity workers meet these challenges. It presents some results from a study funded by the British Ecological Society in 2018-19, which aimed to develop a strategic approach to using UK museum collections to support biodiversity conservation.

This booklet is intended to be a conversation starter.

The State of Nature: an ongoing decline

Nature is in decline, and conservation action isn't making sufficient inroads. The 2019 Global Assessment by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) made the following key findings[1]:

A. Nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide.

B. Direct and indirect drivers of change have accelerated during the past 50 years.

C. Goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond may only be achieved through transformative changes across economic, social, political and technological factors.

D. Nature can be conserved, restored and used sustainably while simultaneously meeting other global societal goals through urgent and concerted efforts fostering transformative change.

[1] https://www.ipbes.net/global-assessment-report-biodiversity-ecosystem-services

A.
Nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide.

Nature embodies different concepts for different people, including biodiversity, ecosystems, Mother Earth, systems of life and other analogous concepts. Nature's contributions to people embody different concepts such as ecosystem goods and services, and nature's gifts. Both nature and nature's contributions to people are vital for human existence and good quality of life (human well-being, living in harmony with nature, living well in balance and harmony with Mother Earth, and other analogous concepts). While more food, energy and materials than ever before are now being supplied to people in most places, this is increasingly at the expense of nature's ability to provide such contributions in the future and frequently undermines nature's many other contributions, which range from water quality regulation to sense of place. The biosphere, upon which humanity as a whole depends, is being altered to an unparalleled degree across all spatial scales. Biodiversity - the diversity within species, between species and of ecosystems - is declining faster than at any time in human history.

B.
Direct and indirect drivers of change have accelerated during the past 50 years.

The rate of global change in nature during the past 50 years is unprecedented in human history. The direct drivers of change in nature with the largest global impact have been (starting with those with most impact): changes in land and sea use; direct exploitation of organisms; climate change; pollution; and invasion of alien species. Those five direct drivers result from an array of underlying causes - the indirect drivers of change - which are in turn underpinned by societal values and behaviours that include production and consumption patterns, human population dynamics and trends, trade, technological innovations and local through global governance. The rate of change in the direct and indirect drivers differs among regions and countries.

C.
Goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond may only be achieved through transformative changes across economic, social, political and technological factors.

Past and ongoing rapid declines in biodiversity, ecosystem functions and many of nature's contributions to people mean that most international societal and environmental goals, such as those embodied in the Aichi Biodiversity Targets [for the Convention on Biological Diversity, the Rio Convention] and the 2030 Agenda for Sustainable Development [the Sustainable Development Goals], will not be achieved based on current trajectories. These declines will also undermine other goals, such as those specified in the Paris Agreement adopted under the United Nations Framework Convention on Climate Change and the 2050 Vision for Biodiversity. The negative trends in biodiversity and ecosystem functions are projected to continue or worsen in many future scenarios in response to indirect drivers such as rapid human population growth, unsustainable production and consumption and associated technological development. In contrast, scenarios and pathways that explore the effects of a low-to-moderate population growth, and transformative changes in production and consumption of energy, food, feed, fibre and water, sustainable use, equitable sharing of the benefits arising from use and nature-friendly climate adaptation and mitigation, will better support the achievement of future societal and environmental objectives.

D.
Nature can be conserved, restored and used sustainably while simultaneously meeting other global societal goals through urgent and concerted efforts fostering transformative change.

Societal goals - including those for food, water, energy, health and the achievement of human well-being for all, mitigating and adapting to climate change and conserving and sustainably using nature - can be achieved in sustainable pathways through the rapid and improved deployment of existing policy instruments and new initiatives that more effectively enlist individual and collective action for transformative change. Since current structures often inhibit sustainable development and actually represent the indirect drivers of biodiversity loss, such fundamental, structural change is called for.

By its very nature, transformative change can expect opposition from those with interests vested in the status quo, but such opposition can be overcome for the broader public good. If obstacles are overcome, commitment to mutually supportive international goals and targets, supporting actions by indigenous peoples and local communities at the local level, new frameworks for private sector investment and innovation, inclusive and adaptive governance approaches and arrangements, multi-sectoral planning and strategic policy mixes can help to transform the public and private sectors to achieve sustainability at the local, national and global levels.

To explore the drivers of global environmental change in more detail, the Global Assessment reported that

- For terrestrial and freshwater ecosystems, land-use change has had the largest relative negative impact on nature since 1970, followed by the direct exploitation, in particular overexploitation, of animals, plants and other organisms mainly via harvesting, logging, hunting and fishing. In marine ecosystems, direct exploitation of organisms (mainly fishing) has had the largest relative impact, followed by land/sea-use change. Agricultural expansion is the most widespread form of land-use change, with over one third of the terrestrial land surface being used for cropping or animal husbandry. This expansion, alongside a doubling of urban area since 1992 and an unprecedented expansion of infrastructure linked to growing population and consumption, has come mostly at the expense of forests (largely old-growth tropical forests), wetlands and grasslands. In freshwater ecosystems, a series of combined threats that include land-use change, including water extraction, exploitation, pollution, climate change and invasive species, are prevalent. Human activities have had a large and widespread impact on the world's oceans. These include direct exploitation, in particular overexploitation, of fish, shellfish and other organisms, land- and sea-based pollution, including from river networks, and land/sea-use change, including coastal development for infrastructure and aquaculture.

FOR TERRESTRIAL AND FRESHWATER ECOSYSTEMS, LAND-USE CHANGE HAS HAD THE LARGEST RELATIVE NEGATIVE IMPACT ON NATURE SINCE 1970

- Climate change is a direct driver that is increasingly exacerbating the impact of other drivers on nature and human well-being. Humans are estimated to have caused an observed warming of approximately 1.0°C by 2017 relative to pre-industrial levels, with average temperatures over the past 30 years rising by 0.2°C per decade. The frequency and intensity of extreme weather events, and the fires, floods and droughts that they can bring, have increased in the past 50 years, while the global average sea level has risen by 16 to 21 cm since 1900, and at a rate of more than 3 mm per year over the past two decades. These changes have contributed to widespread impacts in many aspects of biodiversity, including species distributions, phenology, population dynamics, community structure and ecosystem function. According to observational evidence, the effects are accelerating in marine, terrestrial and freshwater ecosystems and are already impacting agriculture, aquaculture, fisheries and nature's contributions to people. Compounding effects of drivers such as climate change, land/sea-use change, overexploitation of resources, pollution and invasive alien species are likely to exacerbate negative impacts on nature, as has been seen in different ecosystems such as coral reefs, the arctic systems and savannas.

- Many types of pollution, as well as invasive alien species, are increasing, with negative impacts for nature. Although global trends are mixed, air, water and soil pollution have continued to increase in some areas. Marine plastic pollution in particular has increased tenfold since 1980, affecting at least 267 species, including 86 per cent of marine turtles, 44 per cent of seabirds and 43 per cent of marine mammals. This can affect humans through food chains. Greenhouse gas emissions, untreated urban and rural waste, pollutants from industrial, mining and agricultural activities, oil spills and toxic dumping have had strong negative effects on soil, freshwater and marine water quality and the global atmosphere. Cumulative records of alien species have increased by 40 per cent since 1980, associated with increased trade and human population dynamics and trends. Nearly one fifth of the Earth's surface is at risk of plant and animal invasions, impacting native species, ecosystem functions and nature's contributions to people, as well as economies and human health. The rate of introduction of new invasive alien species seems higher than ever before and with no signs of slowing.

Museums and the conservation of global biodiversity

Museum collections are often associated with taxonomy. However, museum collections support, or could support, the exploration of a much wider range of ecological and environmental topics that have practical applications for biodiversity conservation.

Studies of biodiversity, at within-species/population, species and community levels, rely heavily on collections to understand distribution, presence/absence, changes over time, and interspecies interactions and community ecology. Understanding what species live where is a foundation of understanding biodiversity and nature conservation. Specimen labels provide basic information on what species occur where, or at least where they once occurred. Even today, historical collections are a basic source of information on the occurrence of species in remote areas, although rapid environmental change may mean that they reveal where species once were, rather than where they still occur. Museum specimens are a major contributor to conservation assessments, such as IUCN 'Red List' assessments, and are an essential tool for work on the Convention on Biological Diversity, and for national and local biodiversity assessments. Specimens enable former assessments of distribution and identification to be reassessed, notably in light of taxonomic changes. Specimens are a source of biomolecules: they are sampled for DNA to explore relationships within and between species, informing decisions on conservation assessment and management, and reintroductions. Morphology, physiology and development can all be explored through collections, and can be related to environmental conditions.

UNDERSTANDING WHAT SPECIES LIVE WHERE IS A FOUNDATION OF UNDERSTANDING BIODIVERSITY AND NATURE CONSERVATION

CHANGES IN LEVELS OF ENVIRONMENTAL POLLUTANTS OVER TIME CAN BE REVEALED FROM SAMPLES OF ANIMAL AND PLANT TISSUES

Collections are four dimensional, with a time dimension. Derek Ratcliffe's work linking declines in egg-shell thickness of birds of prey in the UK in the second half of the 20th century to DDT poisoning was a landmark in conservation research, and relied heavily on museum collections. Changes in levels of environmental pollutants over time can be revealed from samples of animal and plant tissues, for example levels of mercury in the feathers of seabirds. Analysis of stable isotopes reveals a whole range of details on diet and trophic levels, and even migration routes of animals. Collections reveal changes in the timing of biological events (phenology), linked with environmental change. DNA sampling also helps explore genetic change over time, in terms of population dynamics, the timing of genetic bottlenecks, and changes in gene frequency over time.

How are natural history collections useful for research?

An example

Collections and mammalogy

McLean and others (2016) explored the contribution that natural history collections make towards research. They took mammalogy as an example, and analysed the contribution that museum collections made to research in articles published in the *Journal of Mammalogy* during 2005-14. They found that mammal collections contributed to research in five broad areas, and that 25% of all articles in the *Journal of Mammalogy* made use of natural history collections in some way. Their results “demonstrate that natural history collections are critical infrastructure supporting substantial numbers of research publications annually. They also reveal that use of historic specimens *in addition* to ongoing voucher [specimen] collection remains an integral approach to many research questions in mammalogy”.

The five broad research areas that museum collections supported were:

- Systematics and biogeography, as primary archives of biogeographical data illustrating biodiversity and changes over time
- Genomics, exploring genetic responses to environmental change, for example loss of genetic diversity in Alpine Chipmunks as their range changes in response to climate change
- Morphology and morphometrics, which have numerous applications in systematics and studying biological responses to environmental change
- Stable isotope ecology, which can be used to explore changes in ecology over time, migratory behaviour, and to establish breeding and wintering ranges of a variety of animals
- Parasites and pathogens, helping understand changes in the distribution of parasites and host-switching events in light of environmental change, notably climate change and introductions.

They noted the key importance of the following scientific-curatorial practices:

- Voucher specimen collection is a necessity for ongoing usefulness of collections.

- Specimens need to be curated effectively and preserved in a variety of forms, maintaining connections with ecological and other environmental information as far as possible, notably georeferencing.

- Data need to be well-managed and discoverable, and made widely available through e.g. GBIF, GenBank (genetic), Morphbank (morphological), ViPr (virological) and TimeMachine (time series).

"NATURAL HISTORY COLLECTIONS ARE CRITICAL INFRASTRUCTURE SUPPORTING SUBSTANTIAL NUMBERS OF RESEARCH PUBLICATIONS ANNUALLY"

Reference:
McLean, BS *et al*. (2016). Natural history collections-based research: progress, promise, and best practices. *Journal of Mammalogy* 97(1): 287-97.

Where are natural history collections in the UK?

UK museums contain roughly 140 million natural history specimens, including mammal and bird study skins, taxidermy mounts, bones, pinned insects, dried molluscs and other invertebrates, dried plants, lichens and fungi, specimens on microscope slides and preserved in alcohol/formalin, fossils, rocks and minerals.

There are roughly 80 million specimens in the Natural History Museum (London), and 60 million in other museums. Collections have mostly been built up since the 19th century, and collections develop at a slower rate than previously. Large museums have encyclopaedic, global collections. Regional museums often contain the best collections for their region, and even relatively small museums can be home to very important collections.

Twelve museums have more than 1 million specimens. In addition to these, the collections of the Hunterian Museum (Royal College of Surgeons, London), Lapworth Museum of Geology (University of Birmingham), Leeds City Museums and Galleries, Sunderland Museum, Great North Museum: Hancock (Newcastle upon Tyne), Tullie House Museum and Art Gallery (Carlisle), Yorkshire Museum (York), University of Aberdeen (zoology, plants and geology), Kelvingrove Museum and Art Gallery (Glasgow), Hunterian Museum (University of Glasgow), Perth Museum and Art Gallery, Elgin Museum, and Bell Pettigrew Museum (University of St. Andrews) are formally recognised for their national (in many cases international) importance by the UK and Scottish governments.

A distributed infrastructure

UK Museums with more than a million natural history specimens[2]	Number of specimens
Natural History Museum	80 Million
National Museums of Scotland, Edinburgh	10 Million
Royal Botanical Gardens, Kew	8.5 Million
Manchester Museum, The University of Manchester	4.5 Million
British Geological Survey	4 Million
Royal Botanic Garden, Edinburgh	3 Million
Cambridge University Museum of Zoology	2.8 Million
World Museum Liverpool	1.6 Million
National Museum of Wales, Cardiff	1.3 Million
Bristol Museum	1.1 Million
Sedgwick Museum of Earth Sciences, Cambridge University	1 Million
Norwich Castle Museum and Art Gallery	1 Million

[2] The best available resource for searching UK natural history collections is http://fenscore.natsca.org/

THERE ARE ROUGHLY 80 MILLION SPECIMENS IN THE NATURAL HISTORY MUSEUM (LONDON), AND 60 MILLION IN OTHER MUSEUMS

Based on a figure of 140 million natural history specimens (as a rough, but reasonable approximation), 57% of specimens are in the Natural History Museum, 28% are shared between 11 other museums each with a million specimens or more (detailed in the table above), and 15% are shared between the remainder of UK museums.

A number of English university museums receive funding from Research England (formerly from HEFCE) as a research infrastructure, and a similar scheme runs in Scotland (run by the Scottish Funding Council).[3] UKRI included collections-based institutions in a research infrastructures roadmap exercise in 2018/19. Natural history collections would fit into the 'biological sciences, health and food' and 'environmental sciences' sectors for the purposes of that exercise.[4]

[3] Royal Society (2017). A snapshot of UK research infrastructures. https://royalsociety.org/topics-policy/publications/2018/research-infrastructures-uk-snapshot/

[4] UKRI (UK Research and Innovation) (2019). UKRI Infrastructure Roadmap: initial analysis of infrastructure questionnaire responses and description of the landscape. https://www.ukri.org/files/infrastructure/landscape-analysis-2-pdf/

How can museum collections help address challenges to biodiversity in a strategic way?

Researchers, policy workers and site/species managers working to conserve global biodiversity ('biodiversity workers' hereafter) have relatively little contact with museums, and vice versa. To help address this situation, BES funded a study in 2018-19 to better understand the perceptions that biodiversity workers and UK museum workers had of the potential of UK natural history collections to support the conservation of global biodiversity.

The study received 454 detailed responses from biodiversity workers, including 224 scientists, 88 biodiversity policy workers, 53 biodiversity data workers, 23 site and species managers, and 66 people working in a combination of these areas. Respondents included many national nodes for the Convention on Biological Diversity, Global Strategy for Plant Conservation and Global Biodiversity Information Facility (GBIF); government ministries; and a wide range of agencies including IUCN, Plantlife, and Flora and Fauna International.

Responses were received from 84 countries worldwide. In the UK (and the Isle of Man), contributions were received from DEFRA, NERC, BAS, JNCC, Kew, Natural England, CEH, SNH and Historic England among others, and researchers in many universities.

In terms of UK museum workers, responses were received from 133 museum curators and collection managers, from all of the major museums, many medium-sized and small museums, and from all four constituent countries. This study is the largest of its kind.

One Hundred Questions

The study was framed around ‘One Hundred Questions of Importance to the Conservation of Global Biodiversity’ (Sutherland *et al*. 2009). The aim of that study was to compile a list of 100 questions that, if answered, would have the greatest impact on the conservation of biological diversity worldwide. The questions were developed by a team of representatives of the world’s major conservation organisations, professional scientific societies, and universities, and the work was intended to be of use to organisations wishing to support biodiversity research programmes effectively. As museums have unique resources that can potentially contribute to biodiversity conservation, the 100 questions have a high relevance. Sutherland and others’ study found that the 100 questions fell into twelve topics:

1. **Ecosystem function and services**
2. **Climate change**
3. **Technological change**
4. **Protected areas**
5. **Ecosystem management and restoration**
6. **Terrestrial ecosystems**
7. **Marine ecosystems**
8. **Freshwater ecosystems**
9. **Species management**
10. **Nature conservation organisational systems and processes**
11. **Societal context and change**
12. **Impact of conservation interventions**

One Hundred Questions - 12 topics

1. Ecosystem function and services: ecosystem services (ES) are the benefits people obtain from ecosystems. Key research areas include understanding which components of biodiversity are essential for providing ES.

2. Climate change: global temperatures are already over 1°C higher on average compared to preindustrial (1880s) levels, with polar regions having higher increases. Biodiversity is being affected at species, population, community and biome levels.

3. Technological change: how will new and emerging technologies, e.g. nanotechnology and GM crops, affect biodiversity?

4. Protected areas: how can protected areas and associated biodiversity be managed sustainably, notably in the context of social and environmental change?

5. Ecosystem management and restoration: how can ecosystems be conserved beyond protected areas to maintain connectivity and functionality with protected areas?

6. Terrestrial ecosystems: how can landscapes have multiple uses that promote biodiversity and human communities?

7. Marine ecosystems: how can negative human impacts on marine environments be minimised, providing food in sustainable ways in the context of rapid environmental change.

8. Freshwater ecosystems: global demand for water has increased four-fold in the last 50 years, mostly for food production. Land-use changes impact freshwater availability, regulation and associated ecosystems.

9. Species management: many species will continue to require specific and targeted interventions to persist, in the face of multifarious threats.

10. Nature conservation organisational systems and processes: what kinds of organisations and networks are most effective at supporting the conservation of biodiversity?

11. Societal context and change: the human population will continue to grow. Understanding the effects of societal structures and processes on biodiversity will help inform more effective policy development.

12. Impact of conservation interventions: there is relatively little information on the effectiveness of different conservation measures and actions. Achieving goals effectively will help make best use of resources in the context of global biodiversity declines.

Methods

Biodiversity workers were invited to complete an online survey to explore how they thought UK museum collections supported (or could or couldn't support) research, policy and management in relation to the topics they had expertise in, using the same topic areas as listed above.

In parallel, UK museum workers completed a similar online survey to explore how they thought UK museum collections could support the same topics.

Both groups were asked to identify what actions would help to promote more effective use of collections to conserve global biodiversity.

The two surveys were advertised widely through social media, email distribution lists, IUCN website and at conferences.

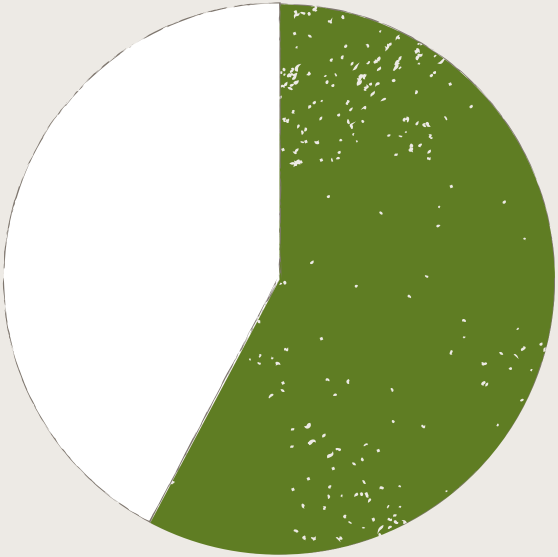
Many biodiversity workers had used natural history collections for their work, for a very diverse range of purposes, including the following examples:

- Taxonomy
- Distributional records for producing atlases, conservation assessments and understanding changes in distribution, e.g. of hymenoptera, dung beetles
- Extending baselines of biodiversity change
- Tissue sampling
- Demography and viability assessments for reintroductions
- Population genetics using ancient DNA
- Osteology
- Policy work from taxonomic reassessments, to identify and designate Important Bird Areas
- DNA sampling of specimens
- Egg morphology
- Bat morphology in response to climate and landscape change
- Genomics
- Studying mammal pathogens and systematics
- Identification of vagrant bird
- Morphology and genetics of parasites
- To identify field collections
- To study form and function of whiskers

- Estimate butterfly species richness over time
- Conservation assessments
- Historical faunistics
- Mapping distribution of spider species
- Colour measurement from bird feathers
- Australian ant ecology
- Taxonomic revisions
- Establishing the distribution of protected species
- Describing new spider species
- Genetics and morphometrics of amphibians
- Comparative studies with extinct species
- Establishing checklists of groups for countries and regions
- Collaborating with genebanks
- Extracting information to incorporate into GBIF
- Identifying species boundaries in spiders
- Archiving data from research with museums
- DNA work linked to voucher specimens of Australian vertebrates
- Hare taxonomy for conservation assessments
- Biotech based on microalgae
- Contributing to database of inverts for conservation management
- Assessing impact of Nagoya Protocol on museums
- Contributing to habitat and distribution modelling
- Distribution of seabirds in relation to sex and age
- Studies of bird moult strategies, geographic variation in productivity and survival
- Establishing Red List assessment criteria
- Analysing eggshell thickness over time in response to acid deposition in the environment
- Analysing changes in egg-laying date in birds over time
- Development of barcoding techniques
- Distributional gap analysis for modelling distributions in South America
- Regulating export of specimens
- Toxin content of terrestrial specimens to inform public health policy
- Health status of recently dead specimens to inform public health policy
- Studies of medicinal plants
- DNA to verify poaching cases
- Proof of concept for studies of plant distribution

- Digitising specimens of Kenyan plants to incorporate into larger dataset for research
- Ecological niche modelling
- Monitoring progress towards targets for plant conservation
- Verifying identifications to aid with implementation of UK conservation priorities
- Producing conservation audit for Natural England
- Diet and reproductive biology of mammals
- Studies of human responses to animals and plants
- ID training courses
- Studying otoliths and squid beaks, to understand marine animals' diets
- Study of how palaeoenvironmental collections and records are managed
- Distribution changes over time in pheasants and partridges
- Quaternary insect assemblages
- Research on museum learning and interpretation of collections
- Validating historic records using voucher specimens for producing atlases
- Datamining for incorporating into National Biodiversity Network
- Linking data on New Zealand endangered species
- Studying spread of invasive plants
- Studying metabolic rates across fish, based on otoliths
- Taxonomy and conservation assessments of deep-sea corals
- Moss taxonomy
- Morphometrics of herbarium specimens
- Drivers underpinning global plant diversity and understanding resilience to global environmental change
- Ibex horn growth to understand ecosystem processes
- Historic distributions and genetics to aid development of reintroduction programmes
- Assessing quality of biodiversity data, to develop tools to make use of museum data
- Analysing species distributions and data biases
- Modelling bird growth and energetics
- Analysing levels of lead pollution in plants linked to industrialisation
- Niche characterisation of plants

- Estimating freshwater fish richness in Trinidad
- Testing archived specimens for infection with diseases (eg chytrid fungus in amphibians) to understand epidemiology
- Trait database for species in relation to land-use impacts in Africa
- Biodiversity associated with hydrothermal vents
- Studying community dynamics and ecosystem services based on beetles
- Understanding historical networks of botanists
- Training for CITES
- Historic distributions of barnacles



58% of biodiversity workers
had given specimens to museums
to add to their collections

66% of biodiversity workers
generated potential museum specimens
in the course of their work.

Biodiversity workers were most likely to find out information on resources such as museum collections from websites, notably GBIF and other aggregators of museum data.

Biodiversity workers reported that, to make more (or better) use of UK museum collections, they would need:

- Aggregated online catalogues of collections, such as GBIF
- Complete online catalogues of particular collections
- Well-curated and accessible collections
- More specialist staff who can answer enquiries (notably specialist enquiries), and facilitate visits to study collections.

Biodiversity workers worked with a large number of national and international policies. The most frequently mentioned international policies were:

Convention on Biological Diversity
(Rio Convention)

Nagoya Protocol on Access and Benefits Sharing

CITES

IUCN Red List

EU policies
(Habitats Directive, Birds Directive, CAP)

Agri-environmental policies

Marine policies

Antarctic Treaty

Conservation-related policies

National and international climate change policy

Which of the 12 topics from the '100 Questions' study did biodiversity workers think UK natural history collections supported or could potentially support?

Which of the 12 topics from the '100 Questions' study did biodiversity workers think UK natural history collections supported, or could potentially support?	**Number of biodiversity workers**	**Currently support**	**Could support**	**Could not support**
Ecosystem function and services	83	53%	32%	10%
Impact of climate change on biodiversity and ecosystems	82	63%	26%	11%
Impacts of technological change on biodiversity	33	70%	21%	9%
Protected areas and biodiversity	110	66%	25%	9%
Ecosystem management and restoration: impacts on biodiversity	73	62%	25%	14%
Terrestrial ecosystems	125	76%	19%	5%
Marine ecosystems	44	68%	23%	9%
Freshwater ecosystems	46	76%	17%	7%
Species management	89	67%	24%	9%
Nature conservation organisational systems and processes	54	54%	26%	20%
Societal context and change, and its impact on species/habitats	68	62%	29%	9%
Impacts of nature conservation interventions	51	69%	22%	10%

These results show that 80% or more of experts in each topic thought that UK museum collections currently support or could support research, policy and management in those areas. This is a very encouraging result, demonstrating the usefulness, or at least potential usefulness, of collections to support action to address contemporary threats to biodiversity.

Drilling down further: which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?

Identifying which of the 100 questions biodiversity workers and UK museum workers thought UK museum collections can support helps to suggest some strategic directions for making use of, and developing, collections. Questions which 50% or more biodiversity workers and/or UK museum workers thought collections could support are listed below. Individual questions 50% or more of both biodiversity workers and UK museum workers agreed UK museum collections could support are marked in **bold**.

Which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?	**% of respondents who thought UK museum collections could support individual questions**	
	Biodiversity workers	**UK museum workers**
Ecosystem function and services		
Do critical thresholds exist at which the loss of species diversity, or the loss of particular species, disrupts ecosystem functions and services, and how can these thresholds be predicted?	61%	57%
How can ecosystems be managed to increase protection of humans and biodiversity from extreme events?	54%	48%
How, where, and when has biodiversity loss affected human welfare?	61%	59%
How does soil biodiversity contribute to the extent and persistence of ecosystem services, including agricultural productivity?	52%	43%
Impact of climate change on biodiversity and ecosystems		
What impact will the melting of polar ice and a reduction in permafrost have on the human use of high-latitude ecosystems, and how will these changes in human use affect biodiversity?	47%	58%
Which elements of biodiversity in which locations are most vulnerable to climate change, including extreme events?	82%	81%
How is the resilience of ecosystems to climate change affected by human activities and interventions?	64%	52%
How will climate change, together with other environmental stressors, alter the distribution and prevalence of diseases of wild species?	64%	73%

Which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?	% of respondents who thought UK museum collections could support individual questions	
	Biodiversity workers	UK museum workers
Impact of climate change on biodiversity and ecosystems (cont.)		
How will human responses to climate change (e.g., changes in agriculture, resource conflicts, and migration) affect biodiversity?	63%	69%
How might biodiversity policies and management practices be modified and implemented to accommodate climate change?	51%	52%
How, where, and to what extent can natural and seminatural ecosystems contribute to climate change adaptation and mitigation?	52%	52%
How does biodiversity shape social resilience to the effects of climate change?	51%	29%
Impacts of technological change on biodiversity		
How do the type, location, and associated mitigation measures of renewable energy technologies affect biodiversity?	51%	70%
What are the direct and indirect impacts of genetically modified organisms on biodiversity?	59%	68%
What are the implications for land use and biodiversity of the new and emerging “bioeconomy” markets (crops for pharmaceuticals, plastics, adhesives, etc.)?	62%	58%

Which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?	% of respondents who thought UK museum collections could support individual questions	
	Biodiversity workers	UK museum workers
Protected areas and biodiversity		
How effective are different types of protected areas (e.g., strict nature reserves, hunting reserves, and national parks) at conserving biodiversity and providing ecosystem services?	74%	91%
How does the management of protected areas affect conservation beyond the boundaries of the protected area, such as through the displacement of human populations, hunting, or fishing?	55%	50%
Ecosystem management and restoration: impacts on biodiversity		
What was the condition of ecosystems before significant human disruption, and how can this knowledge be used to improve current and future management?	72%	87%
What, and where, are the significant opportunities for large-scale ecosystem restoration that benefits biodiversity and human well-being?	55%	54%
How can ecosystem management systems be designed to better emulate natural processes, notably natural disturbance regimes, and to what extent does this improve conservation effectiveness?	55%	41%
What spatial pattern of human settlement (e.g., clustered vs. dispersed) has the least impact on biodiversity?	61%	64%

Which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?	**% of respondents who thought UK museum collections could support individual questions**	
	Biodiversity workers	**UK museum workers**
Ecosystem management and restoration: impacts on biodiversity (cont.)		
What is the contribution of areas that are intensively managed for production of commodities (such as food, timber, or biofuels) to conservation of biodiversity at the landscape scale?	48%	51%
Terrestrial ecosystems		
Under what conditions can agricultural intensification contribute to conserving overall biodiversity by reducing pressure to convert natural ecosystems?	44%	63%
What are the impacts (on and off site) on agricultural returns and biodiversity of “biodiversity-friendly” agricultural practices, such as organic, minimum tillage, and agroenvironment schemes?	44%	63%
Under what circumstances can afforestation, reforestation, and reduced emissions from deforestation and degradation (REDD) benefit biodiversity conservation, reduce emissions, and provide sustainable livelihoods?	35%	59%
How are arid and semiarid ecosystems affected by the interaction of multiple stressors such as grazing by domestic livestock, soil erosion, and drought?	56%	54%
What are the contributions of urban nature reserves and other green amenity spaces, such as golf courses, to biodiversity conservation, and how can these be enhanced?	59%	83%

Which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?	% of respondents who thought UK museum collections could support individual questions	
	Biodiversity workers	UK museum workers
Marine ecosystems		
How will ocean acidification affect marine biodiversity and ecosystem function, and what measures could mitigate these effects?	75%	71%
What are the ecological, social, and economic impacts resulting from the expansion of freshwater and marine aquaculture?	44%	56%
What management actions are most effective for ensuring the long-term survival of coral reefs in response to the combined impacts of climate change and other existing stressors	50%	39%
How does the effectiveness of marine protected areas vary with biological, physical, and social factors and with connectivity to other protected areas?	60%	68%
What will be the impacts of climate change on phytoplankton and oceanic productivity, and what will be the feedbacks of these impacts on the climate?	54%	51%
How will multiple stressors, especially fishing, pollution, sea temperature fluctuations, acidification, and diseases, interact to affect marine ecosystems?	69%	56%
Which mechanisms are most effective at conserving biodiversity in ocean areas occurring outside the legal jurisdiction of any single country?	52%	39%

Which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?	**% of respondents who thought UK museum collections could support individual questions**	
	Biodiversity workers	**UK museum workers**
Freshwater ecosystems		
How can freshwater biodiversity and ecosystem service values best be incorporated in the design of water-provisioning schemes for direct human use and food production?	52%	43%
Which aquatic species and communities are most vulnerable to human impacts, and how would their degradation affect the provision of ecosystem services?	79%	90%
Where will the impacts of global climate change on hydrology be most extreme, and how might they affect freshwater species and the ability of wetlands and inland waters to deliver ecosystem services?	60%	67%
How does investment in restoration of wetlands and riparian areas compare with construction of dams and flood defences in providing cost-effective improvements in flood management and the storage and retention of water for domestic, industrial and agricultural use?	40%	55%
Species management		
What information is required to enable responsible authorities to decide when and how to manage non-native species?	60%	65%
What is the relative effectiveness of different methods for facilitating movement of a species among disjunct patches of its habitat?	44%	53%

Which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?	**% of respondents who thought UK museum collections could support individual questions**	
	Biodiversity workers	**UK museum workers**
Species management (cont.)		
What are the ecosystem impacts of efforts to conserve charismatic, flagship, or umbrella species?	63%	56%
What are the likely risks, costs, and benefits of reintroducing and translocating species as a response to climate change?	53%	63%
Nature conservation organisational systems and processes		
How do the characteristics of the organizations (e.g., government vs. nongovernment) and their funding (e.g., amount and duration of funds) shape the effectiveness of conservation interventions?	53%	32%
What is the effectiveness of the different mechanisms used to foster the evaluation and dissemination of conservation interventions?	58%	32%
How effective are the different strategies devised to integrate scientific knowledge into conservation policy and practice?	63%	39%
How effective are the different mechanisms used to promote data sharing and collaboration among individuals, conservationists, and conservation organizations?	77%	55%

Which of the 100 questions do biodiversity workers and UK museum workers think UK museum collections could support?	% of respondents who thought UK museum collections could support individual questions	
	Biodiversity workers	UK museum workers
Societal context and change, and its impacts on species/habitats		
What are the impacts on biodiversity of shifting patterns and trends in human demography, economic activity, consumption, and technology?	50%	59%
What is the relationship between individuals learning about environmental problems and their conservation attitudes, knowledge, beliefs, and behaviors?	53%	45%
What are the impacts of increasing human dissociation from nature on the conservation of biodiversity?	54%	52%
What are the effects of changes in human patterns of food consumption on biodiversity (e.g., shift from bushmeat to domestic meat and from fish to plant-based protein), and how are such human patterns of food consumption shaped by education programs, financial incentives, and other policy instruments?	51%	50%
Impact of nature conservation interventions		
What have been the impacts on biodiversity of the Convention on Biological Diversity 2020 targets, and what objectives, mechanism, time frame, and means of measurement would be most effective for future targets?	50%	44%
What has been the effect of environmental impact assessments on biodiversity conservation?	59%	58%
What mechanisms best promote the use of local ideas and knowledge in conservation programs in ways that enhance biodiversity outcomes?	59%	44%

There was a fairly strong agreement between biodiversity workers and UK museum workers as to which of the 100 questions they thought UK museum collection could support. There were 31 questions 50% or more members of both groups thought museum collections could support, and 49 questions neither group thought museum collections could support. These 31 questions can be thought of as a strategic direction for biodiversity workers and UK museum workers, to develop use of collections to support biodiversity research, policy and site/species management.

As most respondents to the museum survey were curators working with natural history collections, the high level of agreement can be taken as strong evidence of the value of natural history curators for making effective use of natural history collections.

However, it is worth noting that differences of opinion between the two groups of respondents are worth exploring further, as they suggest additional uses for collections that are not currently being considered by the other group.

THERE WERE 31 QUESTIONS 50% OR MORE MEMBERS OF BOTH GROUPS THOUGHT MUSEUM COLLECTIONS COULD SUPPORT

Museum collections and ecosystem services

"Both nature and nature's contributions to people are vital for human existence and good quality of life" (IPBES 2019)

The Millennium Ecosystem Assessment (2005) defined ecosystem services as benefits people obtain from ecosystems

Museum collections, and natural history museums more generally, are key resources for understanding and conserving a range of ecosystem services, notably (1) those provided by biodiversity (e.g pollination), (2) for studying impacts of humans on biodiversity in relation to a wide range of ecosystem services (e.g. agriculture) and (3) directly supporting cultural ecosystem services, through promoting understanding, appreciation and conservation of nature, and promoting sustainable lifestyles.

MUSEUM COLLECTIONS, AND NATURAL HISTORY MUSEUMS MORE GENERALLY, ARE KEY RESOURCES FOR UNDERSTANDING AND CONSERVING A RANGE OF ECOSYSTEM SERVICES

Services that can be readily understood through natural history collections are marked in green.

Provisioning services: benefits obtained by people from products obtained from ecosystems

- **Fisheries, wild fisheries**
- **Aquaculture**
- **Agriculture**
- **Forestry**
- **Genetic material**
- **Harvested wild foods/ Hunting/ Non-wood forest products (honey, mushrooms, berries)**
- **Livestock grazing**
- **Material extraction (e.g. coral, shells, resin, rubber, grass, rattan)**
- **Medicinal resources from nature**
- **Water (water supply and quantity)**

Regulating services: benefits obtained by people from nature's regulation of ecosystem processes

- **Pest and disease regulation**
- **Pollination and crop pollination**
- Carbon uptake and storage
- Coastal protection and flood regulation
- Flood protection, regulation and prevention
- Regulation of chemical composition of the atmosphere
- Erosion control (e.g stabilising sand dunes, river banks)
- Soil stabilisation (e.g. landslide prevention, avalanche protection)
- Sediment retention, regulation, delivery
- Seasonal water yield and regulation of this through the year
- **Water purification**

Cultural services: nonmaterial benefits people obtain from ecosystems

- **Cultural heritage, inspiration, community benefits**
- **Health, mental and physical**
- **Peace and stability**
- **Knowledge assets and education**
- **Recreation, tourism**
- **Spiritual values, sacred sites**
- Scenic quality
- **Wilderness and iconic values**

Supporting services: services that make other services possible

- **Nutrient cycling**
- **Primary production**
- Soil formation
- **Space/habitat**

Reference:
Neugarten, RA *et al.* (2018). *Tools for measuring, modelling, and valuing ecosystem services: Guidance for Key Biodiversity Areas, natural World Heritage Sites, and protected areas.*
https://portals.iucn.org/library/sites/library/files/documents/PAG-028-En.pdf

Museum collections and ecosystem services: *An example*

The link between pollinators, pollination, crops, and human food and nutrition is especially clearly understood. This will serve as an example of how museums can support ecosystem services and function.

Museums are key tools for studying pollinator diversity and pollinator declines

Bees are widely, and popularly, understood to be important to human society, pollinating a wide range of essential crops, and providing honey. Declines in bee numbers are also widely reported in the mass media in the UK, Europe and the US.

Pollinators, including bees, are in decline worldwide.[5] In Europe (including the UK) 70% of bumblebee species are classified as threatened or with declining populations by the IUCN.[6]

"Estimates of pollinator declines are lacking for most countries worldwide. The use of historical collection data may be the most effective tool for filling these gaps… There is immense potential for museum specimens to play a central role in assessing the extent of the global pollination crisis."

“THERE IS IMMENSE POTENTIAL FOR MUSEUM SPECIMENS TO PLAY A CENTRAL ROLE IN ASSESSING THE EXTENT OF THE GLOBAL POLLINATION CRISIS”

Reference: Bartomeus, I, JR Stavert, D Ward and O Aguado (2018). Historical collections as a tool for assessing the global pollination crisis. *Phil. Trans. Roy. Soc. (B)* 374: 20170389.

Bees preserved in museum collections:

- Are a crucial source of information of the distribution of bee species, both their current distribution and status and long-term population trends. They can fill knowledge gaps.[7]

- Are a source of genetic material, and have been used to illustrate changes in genetic diversity. For example, Honey Bees in museums demonstrate strong changes in terms of which genetic strains are most common in California.[8]

- Are a source of pollen samples collected by bumble bees over time. These have been used to illustrate changes in habitat diversity/quality over time in Belgium, the Netherlands and the UK. Declines in pollen diversity were more pronounced in pollen samples taken from declining bumble species. The researchers noted that “natural history collections can play an important role in improving our understanding of the ecological mechanisms driving species population change.”[9] (Kleijn 2008)

- Have been used to study the impacts of climate change on a solitary bee and an orchid it pollinates. The bee and orchid were shown to respond differently to temperature increases, and pollination of the orchid will likely decrease, threatening its survival. Researchers noted “a significant potential for co-evolved plant-pollinator relationships to be disrupted by climatic warming.”[10] (Robbirt *et al*. 2014)

- Where digitization of museum specimen data has been completed, the data provide a rich source of information, allowing assessment of the current status and long-term trends of bee populations.[11]

- However, huge collections and associated data are not yet available on GBIF, the main data aggregator of biodiversity data. This is a serious impediment to making use of collections for research purposes.

[5] Potts, SG *et al*. (2016) IPBES: summary for policymakers of the assessment report of the IPBES on pollinators, pollination and food production. https://www.ipbes.net/system/tdf/spm_deliverable_3a_pollination_20170222.pdf?file=1&type=node&id=15248

[6] Nieto, A *et al*. (2014). European red list of bees. http://ec.europa.eu/environment/nature/conservation/species/redlist/downloads/European_bees.pdf

[7] Colla, SR, F Gadallah, L Richardson, D Wagner and L Gall (2012). Assessing declines of North American bumble bees (*Bombus* spp.) using museum specimens. *Biol. Cons.* 21: 3585-95.

[8] Cridland, JM, SR Ramirez, CA Dean, A Sciligo and ND Tsutsui (2017). Genome sequencing of museum specimens reveals rapid changes in the genetic composition of Honey Bees in California. *Genome Biol. Evol.* 10(2): 458-72.

[9] Kleijn, D and I Raemakers (2007). A retrospective analysis of pollen host plant use by stable and declining bumble bee species. *Ecology* 89(7): 1811-23.

[10] Robbirt, KM, DL Roberts, ML Hutchings and AJ Davy (2014). Potential disruption of pollination in a sexually deceptive orchid by climatic change. *Current Biol.* 24: 2845-9.

[11] Bartomeus, I, Ascher JS, Gibbs J, Danforth BN, Wagner DL, Hedtke SM, Winfree R (2013). Historical changes in northeastern US bee pollinators related to shared ecological traits. *Proc. Natl Acad. Sci. USA* 110, 4656-60.

Morales, CL, Arbetman MP, Cameron SA and Aizen MA (2013). Rapid ecological replacement of a native bumble bee by invasive species. *Front. Ecol. Environ.* 11, 529-34.

70% OF BUMBLEBEE SPECIES ARE CLASSIFIED AS THREATENED OR WITH DECLINING POPULATIONS BY THE IUCN

Museum collections as tools for studying climate change

CLIMATE CHANGE IS ALREADY DISRUPTING A WIDE RANGE OF BIOLOGICAL AND ENVIRONMENTAL PROCESSES

The impacts of human-induced climate change are increasingly obvious, with increases in mean global temperature; more extreme weather; rising sea levels; and declines in ice at the poles, in glaciers and on mountains. Climate change is already disrupting a wide range of biological and environmental processes, at a wide variety of levels, from individuals to species, communities, ecosystems and biomes

Genetics: there is growing evidence that changes in phenology and morphology are the result of selection for particular traits, causing changes in gene frequency. Genetic diversity in some species (e.g. Chipmunks in the US and Garden Tiger Moths in the UK) has declined, and has been linked to the impacts of climate change.

Morphology: climate change has already been linked to reductions in body size in many animals, for examples birds, amphibians and fish; to changes in coloration due to selection for particular colour morphs in Tawny Owls; and mismatches in coloration in animals that change colour seasonally.

CLIMATE CHANGE IS PREDICTED TO ALTER MANY HABITATS GLOBALLY, WITH SERIOUS IMPLICATIONS FOR CODEPENDENT SPECIES AND BIOLOGICAL COMMUNITIES

Phenology: climate change has been linked to shifts in the timing of many biological events, for example migration times; growing season and flowering time in plants; and emergence time of insects. Shifts in timing are overwhelmingly in the direction expected from climate change.

Distribution: rapid and major changes in the distribution of marine, freshwater and terrestrial species are already being observed around the world. Across land and aquatic ecosystems, species have expanded the edge of their range by 17km per decade on average. Marine species have expanded by 72km per decade. For example, Japanese corals have shifted their range by up to 14km per year for around 80 years. In many places, warm-adapted species are expanding, while cold-adapted species are retreating, both polewards and to higher altitudes. Climate change is predicted to alter many habitats globally, with serious implications for codependent species and biological communities, and people who depend upon them. Over the past 40 years, maximum range shifts vary from 200km (butterflies) to 1,000km (marine crustacea).

Population dynamics: large, often rapid, changes in abundance have been recorded for many species in recent decades. Many changes have been linked to climate change. Coral bleaching and die-off is a well-known example. In the Arctic, the Ivory Gull has declined by 80% in Canada since the 1980s; as this species relies on sea ice, which is declining, climate change is thought to play a part in this decline.

Interspecific relationships: species are dependent on other species for food and habitat, or, in the case of plants, for pollination and seed dispersal. Responses to climate change are not necessarily the same for different species, leading to mismatches. For example, this is already being seen in many bird species that are dependent on caterpillars to feed their young, leading to reduced breeding success, or shifts to poorer-quality habitat.

LARGE, OFTEN RAPID, CHANGES IN ABUNDANCE HAVE BEEN RECORDED FOR MANY SPECIES IN RECENT DECADES

Museum collections can support an understanding of a wide range of biological consequences of climate change, for example:

Morphology: a major area that museum collections can support, for example changes in body size, shape, coloration, impacts of ocean acidification, annual and seasonal growth.

Genetics: changes in genetic diversity over time, changes in hybridisation and hybrid zones, changes in landscape-scale genetic patterns.

Physiology: disease susceptibility linked to climate change in plants and animals, e.g. the link between climate change and chytrid fungus in amphibians has been explored by studying chytrid presence/absence in historical specimens of amphibians in collections.

Phenology: another major area that museum collections can support, for example timing of migration, flower and seed production, emergence time of insects, from information on specimen labels and examination of specimens.

Population dynamics, e.g. recruitment, age structure, sex ratio, abundance: yet another area museums can support, for example through the understanding of changes in population age structure over time.

Distribution, e.g. habitat quantity, range size, range localisation: museums are an irreplaceable resource for understanding the distribution of animals and plants. Changes in distribution over time can often be well-exemplified from collections.

Interspecific relationships, e.g. synchronisation of timing, novel interactions (predation, competition), community composition, changes in paratism and vector-borne disease. Museum collections can help explore e.g. the spread of disease agents over time. Changes in parasitisation of small birds by Cuckoos has been linked to timing mismatches and decline of Cuckoos. Shifts in community composition of birds, crustacea, butterflies and amphibians have all been linked to climate change.

Productivity (biomass, primary productivity): growth at different times can be studied readily from museum collections, and linked to productivity.

MUSEUM COLLECTIONS CAN SUPPORT AN UNDERSTANDING OF A WIDE RANGE OF BIOLOGICAL CONSEQUENCES OF CLIMATE CHANGE

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Kharouba, HM, JMM Lewthwaite, R Guralnick, JT Kerr and M Vellend (2018) Using insect natural history collections to study global change impacts: challenges and opportunities. *Phil. Trans. Roy. Soc. (B)* 374: 20170405.

Parmesan, C and G Yohe (2003). A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(2 Jan): 37-42.

Pecl, G. *et al.* (2017). Biodiversity redistribution under climate change: impacts on ecosystems and human wellbeing. *Science* 355(6332): 1-9.

Scheffers, BR *et al.* (2016). The broad footprint of climate change from genes to biomes to people. *Science* 355(6313): aaf7671. https://doi.org/10.1126/science.aaf7671

Museums are the original Big Data

Museums are storehouses of vast quantities of information about biodiversity, both as specimens and as data associated with specimens. They are the original Big Data.

Museums are an enormously important source of data on biodiversity.

"For many areas of the world and for the majority of species, museum data are the best available data describing distributions... conserving biodiversity requires knowledge of the distribution of species and museum data must play an important role in this process."

(Newbold 2010)

"Specimens stored in museums represent the most complete record describing both occurrence and distribution for most of the 1.5 million described species"

(Callinger 2015)

"Digital natural history collections provide unprecedented opportunities for collaboration across disciplines and among institutions, including those in the tropics, which have historically had limited access to specimens held in museums throughout North America and Europe. This is perhaps best exemplified by the Reflora project of Brazil, which has sought to repatriate its collections from institutions outside of their country via digitization. Thus, digitization has the potential to diversify hypothesis testing by promoting cultural diversity in science and by providing unique, vast datasets at reduced costs to researchers regardless of location"

(Meineke *et al.* 2018)

Museum data can be used to contribute to species distribution models. Models have a very widespread usage in conservation ecology, guiding species conservation and identifying conservation hotspots. Species distribution models can be used to model impacts of environmental changes, such as climate change, on particular species or ecological communities.

Limitations of museum data

1. **Errors:** one of the great advantages of museum collections is that they can be re-checked for e.g. identifications. This is especially useful as the taxonomy of many groups is fluid, as is the taxonomy of many species/subspecies of conservation priority. Errors of collection locality, or collection date from the use of different calendars, may require careful checking. With no specimens, there can be no rechecking.

2. **Bias:** records in museum data are often biased, with four main types of bias: spatial, environmental, temporal and taxonomic. UK museums are particularly rich in material from the 19th and early 20th centuries, and in material from former British colonies. UK museums contain a globally important record of biodiversity in Africa, South Asia, Australia and New Zealand. Temporal bias is often associated with the activity of key experts and collectors. Taxonomic bias means that larger, more obvious vertebrates, invertebrates and plants were the focus of collecting. Museums should address taxonomic bias in collections, as well as continuing e.g. time series that their collections record.

3. **Discoverability:** vast amounts of data on museum specimens remain to be digitized, or incorporated into online data aggregators such as GBIF or, for data on UK biodiversity, the National Biodiversity Network (NBN). In the UK, the Joint Nature Conservation Committee states "making sure that data sources are accessible and available is critical if conservation is to be effective." [12] JNCC makes use of data from GBIF and NBN, meaning that data in UK museums are not contributing towards the work of JNCC.[13]

“MAKING SURE THAT DATA SOURCES ARE ACCESSIBLE AND AVAILABLE IS CRITICAL IF CONSERVATION IS TO BE EFFECTIVE”

References:
Callinger, KM (2015). A functional group analysis of change in the abundance and distribution of 207 plant species across 115 years in north-central North America. *Biological Conservation* 24: 2439-57.

Newbold, T (2010). Applications and limitations of museum data for conservation and ecology, with particular attention to species distribution models. *Progress in Physical Geography* 34(1): 3-22.

Meineke, EK *et al.* (2018). Biological collections for understanding biodiversity in the Anthropocene. *Phil. Trans. Roy. Soc. (B)* 374: 20170386.

[12] Joint Nature Conservation Committee: Data sources, http://jncc.defra.gov.uk/default.aspx?page=5319

[13] The best available resource for searching UK natural history collections is http://fenscore.natsca.org/

Museum collections are windows on evolutionary processes

Museum collections are windows on evolutionary processes

Natural history collections can be used to study evolution directly. Studies using museums have demonstrated significant changes in genotype and phenotype over relatively short time scales, in response to environmental (including human-induced) change.

To give some examples:

- Black-tailed Godwits have smaller ornamental feather (feathers that are involved in mate selection) than they used to, and this has been linked to habitat quality.
- Flowering times of many plants have shifted over the last century.
- Museum collections reveal changes in genetic diversity in populations over time.
- Density of pores on leaves (stomata) has declined by 40% in some species, and this has been suggested to be linked to climate change in some way.
- The classic example of genetic change over time is the Peppered Moth, which adapted to be black in industrial areas of Britain (and elsewhere). Recent genetic work on 19th century museum specimens has shown that the black mutant may have appeared only once, and that there was very strong selection for the black moth.
- American salamanders are smaller than they used to be.
- The colour of Tawny Owls has changed over the last century in Finland, so that grey owls are less common than previously. This has been linked to declines in snow cover and temperature increases.
- Some Australian birds, and a variety of other types of animals, have declined in body size, with a suggested link to increasing global temperatures.
- Birds and moths have developed longer wings in more fragmented habitats, although it is unclear if this is down to phenotypic plasticity or genetic change.
- 25 species of rodent demonstrate rapid change in skull shape and body size.

Reference:
Holmes, MW *et al.* (2017). Natural history collections as windows on evolutionary processes. *Molecular Ecology* 25(4): 864-81.

Research based on natural history collections benefits science and society

Research based on natural history collections benefits science and society

Biodiversity and society are heavily entangled, and people rely on biodiversity as biodiversity depends on people; biodiversity also impacts human health in many ways. Suarez and Tsutsui (2004) noted how natural history collections in museums make "innumerable contributions to science and society in areas as divergent as homeland security, public health and safety, monitoring of environmental change, and traditional taxonomy and systematics." Museum collections make key contributions to understanding the origin and spread of human diseases. For example, the Spanish Flu of 1918 killed 20-40 million people worldwide. Analysis of bird specimens from 1918 in the Smithsonian Institution showed that the virus responsible for the Spanish Flu was more similar to the strain that affects pigs than birds.

Other studies have helped reconstruct the evolution of the virus over time, helping support the development of a vaccine. "Using museum specimens in this way safeguards society by allowing researchers to define natural reservoirs of disease and focus containment measures on appropriate populations".

Environmental contamination represents a serious health and ecological problem. Analysis of preserved birds in the Swedish Museum of Natural History has shown that mercury pollution increased during the 1940s and 50s, probably due to industry. Eggshells of birds in museums in the UK and US demonstrated poisoning from agricultural chemicals in the second half of the twentieth century, and museum collections showed that sexual abnormalities in frogs in the US increased after use of a particular herbicide.

Reference:
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Museums fit for the future

"Natural history museums must define and capture their future. To do so, whether freestanding or university-based, they need to enact their mission of understanding the life of the planet to inform its stewardship. They need to expand their collections and systematics enterprise to encompass the 90 percent of biological diversity that awaits discovery, documentation, description, and comprehension. As a community, they need to erect an informatics infrastructure to deploy their vast collection of information on the planet's known biological diversity and transform this information into knowledge for science and society. They need to engage the public with this knowledge into becoming the biodiversity conscience of the nation. They need to educate their students to be proficient in the ecology and behavior of organizations as well as the ecology and systematics of organisms. And they need to adopt practices of management and leadership that can enable their complex organizational ecosystems to meet these challenges with foresight, collaboration, adaptability, and excellence.

Our natural history museums are sentinel observatories of life on Earth, peering over its past 3.8 billion years and assaying its present condition. Now it is time for them to be stewards of its future."

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Museums for natural futures

Since Leonard Krishtalka and Philip Humphrey made these remarks, the state of nature has declined in many ways. Drivers of global environmental change, operating separately and together, have accelerated. If anything, museums and museum collections are needed now more than ever to help conserve global biodiversity.

Ensuring the ongoing usefulness of UK natural history collections

The ongoing usefulness of collections is threatened for five main reasons. These are (with suggestions for how to address them):

1. Collections are not as visible or accessible as they could be: faced with enormous numbers of specimens, the task of digitising and networking collections is monumental. There is little appetite for funding basic documentation of collections, although this lies at the heart of making collections and collections-related information available. **Stronger support for basic care of collections and sharing collections information is needed, within museums and across the museum sector.**

2. Museum funding cuts have meant that there are less natural-history-trained curators in museums than there used to be, and they have wider ranges of responsibilities than previously. **Ensuring collections have appropriate levels of staffing, with skills to facilitate the effective use of collections, should be a key priority for museums and museum funders.**

3. There is relatively little contact between researchers and museums, or between conservation research policy workers and museum policy workers. **Building common purpose between nature conservation and museum sectors should be a priority, to ensure that museum policy development, and associated funding, contribute effectively to the achievement of environmental policies and agendas such as the CBD.**

4. There is no overarching strategy for museum collection development linked to current and developing research agendas, or local or global challenges. **Collections need to continue to be developed to ensure that time series studies can be made, and that specimens are preserved and information curated so that they are useful. This would help support the Sustainable Development Goals, through achieving effective connections between policies, funding, and preservation of natural heritage (both in museums and in the environment).**

5. Collections need to be developed in new ways, to be able to address current and future research questions that would support the conservation and management of biodiversity. **Museum workers need to work in concert with biodiversity workers, to ensure collections can meet biodiversity workers' needs in an ongoing way.**

Funding streams that help liberate museum data to e.g. National Biodiversity Network and GBIF would pay great dividends, supporting researchers in the UK and globally, and promoting much greater use of UK museum collections. Such an initiative would simultaneously deliver digital, open research, and wider public access agendas, and support developing countries. In the US, for example, the National Science Foundation has funded iDigBio (Integrated Digitized Biocollections, https://www.idigbio.org/portal/), with over 114 million occurrence records representing 3-400 million specimens. A similar scheme in the UK would be a very welcome development.

Biodiversity workers can benefit greatly from the unique resources offered by museums, and museums can benefit greatly from ensuring their collections and other resources make their maximum impact. A stronger synergy between the two sectors would create significant benefits for biodiversity. It just requires closer integration between the two sectors.

BIODIVERSITY WORKERS CAN BENEFIT GREATLY FROM THE UNIQUE RESOURCES OFFERED BY MUSEUMS, AND MUSEUMS CAN BENEFIT GREATLY FROM ENSURING THEIR COLLECTIONS AND OTHER RESOURCES MAKE THEIR MAXIMUM IMPACT

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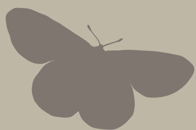

CURATING TOMORROW

BRITISH ECOLOGICAL SOCIETY

MANCHESTER MUSEUM

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