SYNTHESYS

Synthesis of systematic resources

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Abstract

SYNTHESYS3 consortium recognises the importance of the Societal Challenges identified by the Horizon2020 programme and relevance of natural history collections for solving problems outside the traditional and conventional fields. We have reviewed 26 Use Cases backed up by documentary evidence demonstrating how the collections, expertise and services can be used to find solutions to a range of societal challenges. The Use Case review has been made available on-line in a format which allows updating and the inclusion of additional examples. It constitutes the first element for building a roadmap for the access policy of the European natural history institutions. This will enable further discussion on the prioritisation of solutions by a wider community.

1. Introduction

Natural history collections (NHC) are being seen as a source of data, specimens and samples for an increasing number of interdisciplinary research studies. These collections have been the basis for primary taxonomic, systematic, and evolutionary studies for hundreds of years and this research continues to be critically important for our understanding and conservation of life. However, an important characteristic of objects housed in NHC is that they may be used beyond the scope of the original aim. With recent advances in technology our collections may now contribute to new discoveries and research that may have not been originally envisaged by the collectors. NHC relevance for solving problems outside the traditional and conventional fields and within interdisciplinary projects is becoming increasingly recognised.

Widening the user base of the collections in order to reflect the current challenges of the Horizon 2020[1] work programme is critical for the sustainability of SYNTHESYS3 and for continuing its work. Moreover, there is a clear and urgent demand for documenting the importance of NHC for developing ESFRI projects.

The SYNTHESYS3 project aims to address the new roles arising for NHC-based institutions. These institutes have evolved from inward focused to outward looking organisations, with an impact on the current and future provision of tasks and services. One of the initial steps to identify the emerging societal challenges was the organisation of a Sustainability Workshop in Berlin in October 2015 (SYNTHESYS3 Deliverable D3.5).

Emerging new uses of NHC require a definition of major priorities and goals in order to explore new opportunities for NHC. Principal priorities may be summarized as follows:

- identification and prioritisation of potential new user groups of NHC;
- maintaining contact with priority user groups and disseminating knowledge of NHC potential among them;
- designing and co-developing collection-based services (identification services, digitization on demand, 3D print on demand, sequencing, environmental sample vouchering, isotope reference samples, collection management services, and hosting of collections);
- developing a more customer-oriented approach to service provision.

The next step was the creation of a resource which pulls together a representative set of Use Cases demonstrating how the collections, expertise and services can be used to find solutions to a range of societal challenges. Each of these Use Cases is backed up by documentary evidence. The Use Case

[1] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

review has been made available online[2] in a format which allows updating and the inclusion of additional examples.

The Use Cases resource has been used to address specific scientific communities. It constitutes the first element for building a roadmap for the access policy of the European natural history museums.

2. Methodology

Following the conclusions and recommendations of the Sustainability Workshop, we henceforth describe 26 cases how the use of NHC successfully tackles the societal challenges addressed in the European Union Framework Programme for Research and Innovation Horizon. Relevant topics are presented under the following headings within five of the seven societal challenges of H2020 (see Table 1):

- **Health, demographic change and wellbeing**
- **Food security, sustainable agriculture and forestry, marine, maritime and inland water research and the bioeconomy**
- **Climate action, environment, resource efficiency and raw materials**
- **Europe in a changing world – inclusive Innovative and reflective societies**
- **Secure societies - protecting freedom and security of Europe and its citizens**

Each Use Case is complemented by references to several similar projects. We have reviewed the type of data included in these particular studies/projects, gathered both from NHC themselves and also from other sources as well as expertise required for their processing. This data has been transferred to an on-line document and supplemented by a broader review of services we can offer to stakeholders such as companies, governmental agencies, conservation organisations and other beneficiaries, as well as relevant policies that are in place for each topic or that we can contribute to. This overview is accessible on-line at:

https://docs.google.com/spreadsheets/d/1LKsd4FqK1gJ-MQ2brgd7ZeVicFuPKu8y01Q2mNVjBak/edit?pref=2&pli=1#gid=0

These documents will be passed to CETAF to ensure its continued implementation across the European Natural History organisations.

[2] https://docs.google.com/spreadsheets/d/1LKsd4FqK1gJ-MQ2brgd7ZeVicFuPKu8y01Q2mNVjBak/edit#gid=0

Table 1: Overview of relevant topics related to the role of NHC-based research in solutions of urgent societal challenges.

Societal Challenge	**Topics**
1. Health, demographic change and wellbeing	**1.1 Emerging diseases**
	1.2 Disease vector monitoring
	1.3 Urban greening
	1.4 Biobanking for research, government, industry
	1.5 Pathogen monitoring and prediction
	1.6 New drug discovery
	1.7 Forensic and medical entomology
2. Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy	**2.1 Emerging dietary resources**
	2.2 Pest regulation
	2.3 Water and Air quality
	2.4 Deep-sea mining
	2.5 Sustainable agriculture
3. Climate action, environment, resource efficiency and raw materials	**3.1 Population assessment**
	3.2 Environment conservation, planning and monitoring
	3.3 Discovery of new sources of raw materials
	3.4 Environmental changes recorded in drill cores
	3.5 Invasive organisms monitoring
	3.6 Effects of new technologies in agriculture
	3.7 Modelling of climate change effects
	3.8 Modelling of land use change effects
	3.9 Evaluation of the risk for Extinction (Red List assessments)
	3.10 Replenishing biodiversity
4. Europe in a changing world - inclusive, innovative and reflective societies	**4.1 Data mining - citizen science**
	4.2 Increasing awareness of scientific and cultural value of natural science collections
5. Secure societies - protecting freedom and security of Europe and its citizens	**5.1 Documenting natural disasters (past and present)**
	5.2 EU border control (invasive species, pests, CITES)

1. HEALTH, DEMOGRAPHIC CHANGE AND WELLBEING

1.1 Emerging Diseases

CASE 1

Project	**Scientific Collections and Emerging Infectious Diseases**
Link to NHC	*Natural history and medical collections preserve valuable data that enhance the understanding of past and current diseases and increase our potential to predict the behaviour of future diseases and the location of future outbreaks.*
Source	http://scicoll.org/ed.html; http://scicoll.org/scicollpubs/EID_2015March.pdf
Author(s)	
Organization(s) involved	Scientific Collections International (SciColl); US Department of Health and Human Services
Abstract	Scientific collections offer a unique resource for research, both on past epidemics and current diseases. Animal- and plant-specimen collections in museums have historically provided scientists species standards and the ability to trace disease distribution patterns over time and space. Medical collections contain large strain and tissue repositories to analyse current and past diseases. For example, scientists can compare a pathogen's genome to known sequences to determine if the pathogen is new or re-emerging. With the development of new, more virulent diseases, scientific collections offer a diverse array of research material for a comprehensive understanding of particular diseases. New DNA technology can track the course of a disease over hundreds of years and across oceans and continents. A changing population and landscape present even more challenges in the scope of health care. Scientific collections can be a shared resource in a network that spans various disciplines and continents. By combining research efforts, these collections increase the potential to predict the behaviour of future diseases and the location of future outbreaks.
Data involved	- occurrence data - taxonomical data - genetic data
Skills required	- genetics - medical skills - palaeopathology

Additional resources:

1) Brooks D.R. and Hoberg E.P. (2008): Darwin's Necessary Misfit and the Sloshing Bucket: The Evolutionary Biology of Emerging Infectious Diseases. *Evolution: Education and Outreach* 1, 2-9. DOI: 10.1007/s12052-007-0022-7

2) Di Euliis D. (2015): The role of scientific collections in scientific preparedness. Emerging Infectious Diseases http://dx.doi.org/10.3201/eid2108.150423

3) Mahomoodally M.F. (2013): International Collaboration With a View to Containing Outbreak of Emerging Infectious Diseases Through Bioprospection. Chemistry for Sustainable Development in Africa, 231-247. DOI: 10.1007/978-3-642-29642-0_12

4) Smith J. and Taylor E.M. (2013): MDGs and NTDs: Reshaping the Global Health Agenda. *PLoS Neglected Tropical Diseases* 7, e2529. doi: 10.1371/journal.pntd.0002529

5) Suarez A.V. and Tsutsui N.D. (2004): The Value of Museum Collections for Research and Society. *BioScience* 54, 66-74. doi: 10.1641/0006-3568(2004

__1.2 Disease vector monitoring__

CASE 2

Project	**Schistosomiasis collection at NHM (SCAN)** SCAN: The Schistosomiasis Collection at the NHM
Link to NHC	*Schistosomiasis Collection at the Natural History Museum maintains a genetic archive of schistosome and snail samples with contextual data in order to facilitate research into this neglected tropical disease and developing control programmes.*
Source	http://scan.myspecies.info/ Emery A.M. et al. (2012): Schistosomiasis collection at NHM (SCAN). Parasites & Vectors 5, 185-185. doi: 10.1186/1756-3305-5-185
Author(s)	Emery A.M. et al.
Organization(s) involved	Natural History Museum, London (UK)
Abstract	The Natural History Museum (NHM) is developing a repository for schistosomiasis-related material, the Schistosomiasis Collection at NHM (SCAN) as part of its existing Wolfson Wellcome Biomedical Laboratory (WWBL). This is timely because a major research and evaluation effort to understand control and move towards elimination of schistosomiasis in Africa has been initiated by the Schistosomiasis Consortium for Operational Research and Evaluation (SCORE), resulting in the collection of many important biological samples, including larval schistosomes and snails. SCAN will collaborate with a number of research groups and control teams and the repository will acquire samples relevant to both immediate and future research interest. The samples collected through ongoing research and field activities, WWBL's existing collections, and other acquisitions will be maintained over the long term and made available to the global research community for approved research purposes. Goals include: 1) Consolidation of the existing NHM schistosome and snail collections and transfer of specimens into suitable long-term storage systems for DNA retrieval, 2) Long-term and stable storage of specimens collected as part of ongoing field programmes initially in Africa especially relating to the SCORE research programmes, 3) Provision of access to snail and schistosome collections for approved research activities.
Data involved	- occurrence data - disease vector data - genetic data
Skills required	- taxonomy - genetics - virology - population dynamics modelling

__Additional resources:__

1) Boissier J. et al. (in press). Outbreak of urogenital schistosomiasis in Corsica (France): an epidemiological case study. *The Lancet*. DOI: http://dx.doi.org/10.1016/S1473-3099(16)00175-4
2) Hall MJR et al. (2016): Traumatic Myiasis: A Neglected Disease in a Changing World. *Annual Review of Entomology* 61, 159-176. DOI: 10.1146/annurev-ento-010715-023655
3) Johnson P.T.J. et al. (2003): Limb deformities as an emerging parasitic disease in amphibians: Evidence from museum specimens and resurvey data. *Conservation Biology* 17, 1724–1737. DOI: 10.1111/j.1523-1739.2003.00217.x
4) Project CHOLTIC (Cholera outbreaks at Lake Tanganyika induced by climate change?) http://www.africamuseum.be/research/projects/prj_detail?prjid=450
5) VectorMap: portal provides disease maps, and mapped collection data and distribution models for arthropod disease vector species, including mosquitoes, ticks, sand flies, mites, and fleas, as well as the hosts/reservoirs of vector-borne disease pathogens. http://vectormap.si.edu

1.3 Urban greening

CASE 3

Project	**Green4Cities: Gravel Turfs – blooming park places**
Link to NHC	*Botanical collections provided information on biodiversity and ecological requirements of plants suitable for cost-efficient and climate effective urban greenery.*
Source	http://www.green4cities.com/?p=121
Author(s)	Florineth F. et al.
Organization(s) involved	Universität für Bodenkultur Wien, Institute of Soil-Bioengineering, Austria; Fachhochschule Erfurt, University of applied Life Sciences, Germany; Bavarian School of Gardening and Viticulture, Germany; Ökotechna GmbH, Austria; Böhm GmbH, Germany; Hollitzer GmbH, Austria; Marx AG, Austria; Dal Farra I. & G. GmbH, Italy; Höbn GmbH, Germany; Kalkwerk Herbsleben GmbH, Germany; Würzburger Kompostierung GmbH, Germany; Österreichischer Baustoff Recycling Verband, Austria
Abstract	The aim of the EU-funded Green Concrete project was to develop a scientifically sound recommendation for the construction of gravel turf, based on natural gravel or recycled building materials, and to clearly define such a product. 12 partners from science and industry compiled the results in a public information platform in three languages. The platform presents and demonstrates components (e.g. building materials, seed mixes etc.), building techniques (e.g. construction systems) as well as economic and ecological effects. Gravel turf represents an easy-to-install, cost-efficient and climate effective surface consolidation.
Data involved	- ecological data - taxonomical data - climatic data - physical, chemical, hydrological data
Skills required	- plant ecology - taxonomic knowledge - population analysis - climatic analysis - environmental modelling

Additional resources:

1) Qian S. et al. (in press): Biotic homogenization of China's urban greening: A meta-analysis on woody species. *Urban Forestry & Urban Greening*. DOI: 10.1016/j.ufug.2016.05.002
2) Smith J. et al. (2006): Baseline biodiversity surveys of the soil macrofauna of London's green spaces. *Urban Ecosystems* 9, 337-349. DOI: 10.1007/s11252-006-0001-8
3) Project MARSB (Mid-Atlantic Regional Seed Bank): http://www.marsb.org/
4) Nature-Based Solutions (policy topics): https://ec.europa.eu/research/environment/index.cfm?pg=nbs

1.4 Biobanking for research, government, industry

CASE 4

Project	**BopCo Barcoding Organisms of Policy Concern**
Link to NHC	*Museums and other research facilities established network focussed on supplying accurate species identifications of policy concern organisms such as endangered species protected under CITES or Invasive Alien Species (IAS).*
Source	http://bopco.myspecies.info/
Author(s)	Backeljau T., De Meyer M., Gombeer S., Van Bourgonie Y. R., Meganck K.
Organization(s) involved	Royal Belgian Institute of Natural Sciences, Royal Museum for Central Africa, Belgium; Belgian Network for DNA Barcoding; CETAF
Abstract	BopCo is an integrated service funded by the Belgian Science Policy (BELSPO) and the project represents part of the Belgian contribution to the European Research Infrastructure Consortium LifeWatch. The Royal Belgian Institute of Natural Sciences (RBINS) and the Royal Museum for Central Africa (RMCA) both house part of the team of this joint project. The BopCo project is focussed on supplying accurate species identifications of policy concern organisms and their derived products. Organisms of policy concern include endangered species protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), Invasive Alien Species (IAS), (agricultural) plant pest species, human and veterinary disease organisms and their vectors, organisms involved in food fraud, species of forensic relevance, organisms falling under the Nagoya protocol on Access and Benefit Sharing, and quarantine species. Since the enforcement of regulations relies on accurate identifications, and because visual identifications based on morphological characteristics are not always possible (e.g. processed food items), DNA barcoding technology offers an essential addition to traditional identification approaches. This molecular species identification method uses short DNA sequences as taxonomic 'barcodes' and relies on the occurrence of sequence divergence among species. More information on DNA barcoding can be found on the Barcode of Life website.
Data involved	- taxonomical data - genetic data - morphological data - conservation data
Skills required	- DNA barcoding - taxonomic knowledge - legislation

Additional resources:

1) Comtet T. et al. (2015): DNA (meta)barcoding of biological invasions: a powerful tool to elucidate invasion processes and help managing aliens. *Biological Invasions* 17, 905-922. DOI: 10.1007/s10530-015-0854-y

2) Droege G. et al (2014): The Global Genome Biodiversity Network (GGBN) Data Portal. Nucleic Acids Research. 42 (D1): D607-D612. DOI: 10.1093/nar/gkt928

3) Garmendia L. et al. (2015): Combining chemical and biological endpoints, a major challenge for twenty-first century's environmental specimen banks. *Environmental Science and Pollution Research* 22, 1631-1634. DOI: 10.1007/s11356-014-2925-5

4) Odsjö T. (2006): The environmental specimen bank, Swedish Museum of Natural History—A base for contaminant monitoring and environmental research. *Journal of Environmental Monitoring* 8, 791-794. DOI: 10.1016/0048-9697(93)90015-X

5) Barcode of Life: http://www.barcodeoflife.org/

1.5 Pathogen monitoring and prediction

CASE 5

Project	**Mapping the niche of Ebola host animals**
Link to NHC	*Field observations complemented by Natural history collection data identified most likely candidates to be reservoir species associated with Ebola transmission to humans.*
Source	http://elifesciences.org/content/3/e04395v2
Author(s)	Pigott D.M. et al.
Organization(s) involved	University of Oxford, UK; Sanaria Institute for Global Health and Tropical Medicine, USA; University of Toronto, Canada; University Health Network, Toronto, Canada; Harvard Medical School, USA; Boston Children's Hospital, USA; University of Southampton, UK; National Institutes of Health, USA; Flowminder Foundation, Sweden; Li Ka Shing Knowledge Institute, St. Michael's Hospital, Canada
Abstract	A research team from the United Kingdom, the United States and Canada mapped the areas of Africa potentially at risk from outbreaks of the Ebola virus, based on the environmental niche of bat species believed to act as reservoir hosts of the disease. While human outbreaks such as the one currently affecting West Africa are very rare, the study identified at-risk areas covering 22 countries in Central and West Africa, with a combined human population of 22 million. The research published in the eLife online journal modelled the zoonotic niche of the virus using occurrence data accessed through GBIF.org for three bat species, the hammer-headed bat (*Hypsignathus monstrosus*), little collared fruit bat (*Myonycteris torquata*) and Franquet's epauletted fruit bat (*Epomops franqueti*), identified as the most likely candidates to be reservoir species associated with transmission to humans. The authors argue that better knowledge of the areas potentially at risk from the disease will help to prioritise surveillance for Ebola virus outbreaks, and improve the diagnostic capacity in the countries identified.
Data involved	- occurrence data - taxonomical data - genetic data
Skills required	- veterinary skills - virology - taxonomic knowledge

Additional resources:

1) Barba N. et al. (2010): The need for culture collections to support plant pathogen diagnostic networks. *Research in Microbiology* 161, 470-479. DOI: 10.1016/j.resmic.2010.04.008

2) Bearchell S.J. et al. (2005): Wheat archive links long-term fungal pathogen population dynamics to air pollution. *Proceedings of the National Academy of Sciences of the United States of America* 102, 5438–5442. DOI: 10.1073/pnas.0501596102

3) Flamand C. et al. (2014): Mining local climate data to assess spatiotemporal dengue fever epidemic patterns in French Guiana. *Journal or the American Medical Informatics Association* 21, 232–240. doi: 10.1136/amiajnl-2013-002348. pmid:24549761

4) Tsangaras K. and Greenwood A.D. (2012): Museums and disease: Using tissue archive and museum samples to study pathogens. *Annals of Anatomy - Anatomischer Anzeiger* 194, 58-73. doi:10.1016/j.aanat.2011.04.003

1.6 New drug discovery

CASE 6

Project	**Recombinant Environmental Libraries Provide Access to Microbial Diversity for Drug Discovery from Natural Products**
Link to NHC	*Data from collections and newly gathered samples reveal potential value for novel natural products discovery and suggest a strategy for developing this technology into a realistic and effective drug discovery tool.*
Source	Courtois S. et al. (2003): Recombinant Environmental Libraries Provide Access to Microbial Diversity for Drug Discovery from Natural Products. Applied and Environmental Microbiology 69, 49-55. DOI: 0.1128/AEM.69.1.49-55.2003
Author(s)	Courtois S. et al
Organization(s) involved	Université Claude Bernard Lyon (France); Aventis Pharma, Centre de Recherche de Vitry-Alfortville (France); Université Paris Sud (France); Cambridge Genomics Center, Cambridge (USA)
Abstract	To further explore possible avenues for accessing microbial biodiversity for drug discovery from natural products, a 5,000-clone “shotgun” environmental DNA library was constructed and screened using an Escherichia coli-Streptomyces lividans shuttle cosmid vector and DNA inserts from microbes derived directly (without cultivation) from soil. The library was analysed by several means to assess diversity, genetic content, and expression of heterologous genes in both expression hosts. They found that the phylogenetic content of the DNA library was extremely diverse, representing mostly microorganisms that have not been described previously. The library was screened by PCR for sequences similar to parts of type I polyketide synthase genes and tested for the expression of new molecules by screening of live colonies and cell extracts. The results revealed new polyketide synthase genes in at least eight clones. In addition, at least five additional clones were confirmed by high-pressure liquid chromatography analysis and/or biological activity to produce heterologous molecules. These data reinforce the idea that exploiting previously unknown or uncultivated microorganisms for the discovery of novel natural products has potential value and, most importantly, suggest a strategy for developing this technology into a realistic and effective drug discovery tool.
Data involved	- occurrence, ecological & chemical data of the potentially interesting plants botanical data - medical data
Skills required	- taxonomic knowledge; ecological knowledge - traditional knowledge - medical skills - analytical skills

Additional resources:

1) Coley P.D. et al. (2003): Using ecological criteria to design plant collection strategies for drug discovery. Frontiers in Ecology and the Environment 8, 421-428. DOI: 10.2307/3868139

2) Gamberini C. et al. (2011): Spectral analysis of pharmaceutical formulations prepared according to ancient recipes in comparison with old museum remains. *Analytical and Bioanalytical Chemistry* 401, 1839-1846. DOI: DOI: 10.1007/s00216-011-5190-1

3) Miki E. et al. (2000): Dynamics of medicinal plants in Japan estimated by the herbarium specimens. *Journal of Japanese Botany* 75, 347–359.

4) Neimark B.D. and Wilson B. (2015): Re-mining the collections: From bioprospecting to biodiversity offsetting in Madagascar. *Geoforum* 66, 1-10. doi:10.1016/j.geoforum.2015.09.001

1.7 Forensic and medical entomology

CASE 7

Project	**Using DNA-barcoding to make the necrobiont beetle family Cholevidae accessible for forensic entomology**
Link to NHC	*DNA-Barcoding of museum and newly gathered specimens makes a specific group of necrobiont beetles available as a tool for forensic research.*
Source	Schilthuizen M. et al. (2011): Using DNA-barcoding to make the necrobiont beetle family Cholevidae accessible for forensic entomology. Forensic Science International 210, 91-95. doi:10.1016/j.forsciint.2011.02.003
Author(s)	Schilthuizen M. et al.
Organization(s) involved	Naturalis Biodiversity Center, Netherlands; Hoogeschool van Amsterdam, Netherlands; Free University Amsterdam, Netherlands;
Abstract	The beetle family Cholevidae (Coleoptera: Staphylinoidea), sometimes viewed as the subfamily Cholevinae of the Leiodidae, consists of some 1700 species worldwide. With the exception of specialized cave-dwelling species and species living in bird and mammal nests and burrows, the species are generalized soil-dwellers that, at least in temperate regions, are mostly found on vertebrate cadavers. Although they have been regularly reported from human corpses, and offer potential because of many species' peak activity in the cold season, they have not been a focus of forensic entomologists so far. This is probably due to their small size and the difficulty in identifying the adults and their larvae. In this paper, we show that DNA-barcoding can help make this group of necrobiont beetles available as a tool for forensic research. We collected 86 specimens of 20 species of the genera Catops, Fissocatops, Apocatops, Choleva, Nargus, Ptomaphagus, and Sciodrepoides from the Netherlands and France and show that a broad "barcoding gap" allows almost all species to be easily and unambiguously identified by the sequence of the "barcoding gene" cytochrome c oxidase I (COI). This opens up the possibility of adding Cholevidae to the set of insect taxa routinely used in forensic entomology.
Data involved	- taxonomical & ecological data - trait data - pathological data
Skills required	- taxonomic knowledge - insect ecology

Additional resources:

1) Gilbert M.T.P. et al. (2007): DNA Extraction from Dry Museum Beetles without Conferring External Morphological Damage. *PLoS ONE* 2, Article e272. http://dx.doi.org/10.1371/journal.pone.0000272

2) Lindgren N.S. eta al. (2015). Four Forensic Entomology Case Studies: Records and Behavioral Observations on Seldom Reported Cadaver Fauna With Notes on Relevant Previous Occurrences and Ecology. *Journal of Medical Entomology* 52, 143-150. DOI: http://dx.doi.org/10.1093/jme/tju023

3) Tuccia F. et al. (in press): A combined protocol for identification of maggots of forensic interest. *Science & Justice*. doi:10.1016/j.scijus.2016.04.001

4) Turchetto M. and Vanin S. (2004): Forensic entomology and climatic change. *Forensic Science International* 142, S207-S209. doi:10.1016/j.forsciint.2004.09.064

2. FOOD SECURITY, SUSTAINABLE AGRICULTURE AND FORESTRY, MARINE AND MARITIME AND INLAND WATER RESEARCH AND THE BIOECONOMY

2.1 Emerging dietary resources

CASE 8

Project	**Edible Insects** LINCAOCNET
Link to NHC	*Occurrence and ecological data from NH collections used to assess the impact of harvesting insects in their natural habitats on the sustainability of forests and to clarify the potential that insects offer for improving food security worldwide.*
Source	http://gbif.africamuseum.be/lincaocnet/
Author(s)	Severin Tchibozo et al.
Organization(s) involved	Royal Museum for Central Africa, Belgium; Centre de Recherche pour la Gestion de la Biodiversité, Benin; FAO
Abstract	It is estimated that insects form part of the traditional diets of at least 2 billion people. More than 1,900 species are reported to be used as food. Insects as food and feed emerge as an especially relevant issue in the twenty-first century due to the rising cost of animal protein, food and feed insecurity, environmental pressures, population growth and increasing demand for protein among the middle classes. Thus, alternative solutions to conventional livestock and feed sources are urgently needed. The consumption of insects therefore contributes positively to the environment and to health and livelihoods. In 2003 the FAO Forestry Department started to document the role of insects in traditional livelihood practices in Central Africa and to
Data involved	- occurrence, ecological & nutritional data of the potentially interesting insects - trait data - conservation data
Skills required	- entomological taxonomic knowledge - ecology - nutrition analysis

Additional resources:

1) Bedigian D. (2004): Slimy leaves and oily seeds: Distribution and use of wild relatives of sesame in Africa. *Economic Botany* 58, S3-S33. DOI: 10.1663/0013-0001(2004)58[S3:SLAOSD]2.0.CO;2

2) Hajjar R. and Hodgkin T. (2015): The use of wild relatives in crop improvement: a survey of developments over the last 20 years. *Euphytica* 156, 1-13. DOI: 10.1007/s10681-007-9363-0

3) Heywood V.H. (2011): The role of botanic gardens as resource and introduction centres in the face of global change. *Biodiversity and Conservation* 20, 221-239. DOI: 10.1007/s10531-010-9781-5

4) Project FlyHigh: https://www.luomus.fi/en/flyhigh

2.2 Pest regulation

CASE 9

Project	**Museum specimen data predict crop damage by tropical rodents**
Link to NHC	*Museum specimen data utilized to generate ecological niche models to provide predictions of geographic distributions of native rodent pest species.*
Source	Sanchez-Cordero V. and Marinez-Meyer E. (2000): Museum specimen data predict crop damage by tropical rodents. Proceedings of the National Academy of Sciences of the United States of America 97. 7077-7077. DOI: 10.1073/pnas.97.13.7074
Author(s)	Sanchez-Cordero V. and Marinez-Meyer E.
Organization(s) involved	Universidad Nacional Autonoma de Mexico, Mexico; University of Kansas, USA
Abstract	Museum collections constitute a massive store of information on biological diversity. Authors used museum specimen data to generate ecological niche models that provide predictions of geographic distributions of native rodent pest species and agricultural census data that summarize the geographic distribution of nine crops in the state of Veracruz. Mexico, as well as crop losses between planting and harvest. It is shown that crop damage is related significantly to the predicted presence of rodent species for seven of nine crops. Museum collections may thus provide important baseline information for designing land-use and agricultural pest-management programs.
Data involved	- taxonomical & ecological data - trait data - pathological data
Skills required	- taxonomic knowledge - insect ecology

Additional resources:

1) Parry H.R. et al. (2016): Plant composition modulates arthropod pest and predator abundance: Evidence for culling exotics and planting natives. *Basic and Applied Ecology* 16, 531-543. doi:10.1016/j.baae.2015.05.005
2) Stejskal V. (2015): Overview of present and past and pest-associated risks in stored food and feed products: European perspective. *Journal of Stored Products Research* 64, 122-132. doi:10.1016/j.jspr.2014.12.006
3) Thomson L.J. and Hoffmann A.A. (2010): Natural enemy responses and pest control: Importance of local vegetation. *Biological Control* 52, 160-166. doi:10.1016/j.biocontrol.2009.10.008
4) Vreysen M.J.B. et al. (2013): Tsetse flies: Their biology and control using area-wide integrated pest management approaches. *Journal of invertebrate Pathology* 112, S15-S25. doi:10.1016/j.jip.2012.07.026

2.3 Water and Air quality

CASE 10

Project	**Diatoms on herbarium macrophytes as indicators for water quality**
Link to NHC	*Diatoms can be used as sensitive indicators of water quality. Diatoms collected from herbarium specimens record changes during past century.*
Source	H. Van Dam, A. Mertens (1993): Diatoms on herbarium macrophytes as indicators for water quality. Hydrobiologia 269–270, 437–445.
Author(s)	Van Dam H. and Mertens A.
Organization(s) involved	DLO Institute for Forestry and Nature Research, Wageningen, The Netherlands
Abstract	To describe the reference situation for water quality in the eutrophicated broad area `De Nieuwkoopse Plassen' (Holland), attached diatoms from aquatic macrophytes, collected between 1934 and 1958 have been used. Recent samples for comparison were taken in 1989. The diatoms do not indicate significant changes in salinity. Eutrophication has reduced the number of rare species and increased the abundance of meso- to hyper-eutraphentic species, particularly Fragilaria berolinensis. Reduction of total phosphorus to concentrations below 0.02 mg l(-1) might be sufficient to restore the diatom assemblages of the 1930s.
Data involved	- occurrence data - ecological data - water chemistry data - climatic data
Skills required	- field mapping - marine ecology - taxonomic knowledge - analytical skills - environmental modelling

Additional resources:

1) Baddeley J.A et al. (1994): Regional and historical variation in the nitrogen content of *Racomitrium lanuginosum* in Britain in relation to atmospheric nitrogen deposition. *Environmental Pollution* 84, 189–196.
2) Barnes D.K.A. et al. (2011): Scott's collections help reveal accelerating marine life growth in Antarctica. *Current Biology* 21, R147-R148. doi:10.1016/j.cub.2011.01.033
3) Janiak A. et al. (2014): A study of the genetic variation of the aquatic fern Marsilea quadrifolia L. preserved in botanical collections in Poland and originated from natural populations in Europe. *Flora - Morphology, Distribution, Functional Ecology of Plants* 209, 655-665. doi:10.1016/j.flora.2014.08.011
4) Martins I. et al. (2006): Temporal and spatial changes in mercury concentrations in the North Atlantic as indicated by museum specimens of glacier lanternfish Benthosema glaciale (Pisces : Myctophidae). *Environmental Toxicology* 21, 528-532. DOI: 10.1002/tox.20217
5) Thompson D.R. et al. (1992): Historical changes in mercury concentrations in the marine ecosystem of the north and north-east Atlantic ocean as indicated by seabird feathers. *Journal of Applied Ecology* 29, 79–84. DOI: 10.2307/2404350
6) Report and Research Plan: Prevention, Control and Mitigation of Harmful Algal Blooms: http://www.whoi.edu/cms/files/PCM_HAB_Research_Plan%282%29_18563_23051.pdf

2.4 Deep-sea mining

CASE 11

Project	**ABBYSLINE** ABYSSLINE – A biological baseline study of the UK-1 deep-sea mining exploration claim
Link to NHC	*Field and collection study of deep-sea microfauna and macrofauna identify the risks of nodule-mining impacts on marine biodiversity.*
Source	http://abyssline.info/
Author(s)	Smith C.R. et al.
Organization(s) involved	University of Hawaii, USA; Hawaii Pacific University, USA; Natural History Museum, UK; Uni Research, Norway; National Oceanography Centre, UK; Senckenberg Institute, Germany; IRIS, Norway
Abstract	ABYSSLINE is a deep-sea benthic environmental survey of the United Kingdom's polymetallic-nodule exploration mining claim (UK-1) in the Clarion-Clipperton Zone (CCZ), eastern Pacific Ocean. The ABYSSLINE project is being conducted by a consortium of 7 non-profit academic research institutes and through a commercial arrangement with UK Seabed Resources Ltd. The project is conducting benthic biological baseline studies of relevance to the UK-1 claim areas in the CCZ in accordance with International Seabed Authority environmental guidelines. This involves collecting data on the ecology, taxonomy, connectivity and ecosystem function of the seafloor at depths of approximately 4,000 m at a range of sampling strata in the eastern CCZ (about 2200 km due south of San Diego, USA), and at reference sites more broadly distributed across the CCZ.
Data involved	- ecological data - taxonomical data - geological and geochemical data - oceanographic data
Skills required	- marine ecology - taxonomic knowledge - analytical skills

Additional resources:

1) Boschen R.E. et al. (2015): Limitations in the use of archived vent mussel samples to assess genetic connectivity among seafloor massive sulfide deposits: a case study with implications for environmental management. *Frontiers in Marine Science* 2, http://dx.doi.org/10.3389/fmars.2015.00105
2) Boschen R.E. et al. (2016): A primer for use of genetic tools in selecting and testing the suitability of set-aside sites protected from deep-sea seafloor massive sulfide mining activities. *Ocean & Coastal Management* 122, 37-48. doi:10.1016/j.ocecoaman.2016.01.007
3) Van Dover C.L. (2010): Mining seafloor massive sulphides and biodiversity: what is at risk? *ICES Journal of Marine Science* 68, 341-348. doi:10.1093/icesjms/fsq086

2.5 Sustainable agriculture

CASE 12

Project	**GBIF data fitness for use in agrobiodiversity**
Link to NHC	*Field observation and collection data survey made by GBIF significantly contributes to assessment of conservation priorities of natural resources and further actions for sustainable agriculture.*
Source	http://www.gbif.org/newsroom/news/agrobiodiversity_report
Author(s)	Arnaud E., Caszaneda-Alvarez N. P., Ganglo Cossi J., Endresen D., Jahanshiri E., Vigouroux Y.
Organization(s) involved	Global Biodiversity Information Facility; CIAT, Colombia; University of Birmingham, UK; University of Abomey-Calavi, Benin; University of Oslo, Norway; Crops for the Future, Malaysia; Institut de Recherche pour le Développement, France
Abstract	Human wellbeing and food security in a changing climate depend on productive and sustainable agriculture. For this, policies based on analyses and research results are vital to establish conservation priorities of natural resources that underpin the enhancement of sustainable food production. Therefore, data from agrobiodiversity and wider biodiversity sources are required to be available and accessible. Currently, there is a risk that agrobiodiversity and the wider biodiversity data communities remain separated with inefficient data aggregation, unless data flow pathways are harmonized. GBIF has a role to play in contributing to the convergence of the two communities. Biodiversity data in particular on wild relatives of the cultivated species will flow easier into agrobiodiversity conservation priority assessments and analysis with agrobiodiversity data integrated in GBIF. The Task Group on Data Fitness for Use in Agrobiodiversity was established by the GBIF Secretariat and Biodiversity International to help improve the fit of data related to agrobiodiversity to the variety of important uses required and requested by the community of research and policy. The task group has been looking at the key actions for creating interoperability of data on *ex situ*, *in situ* and on-farm conservation of agrobiodiversity, with a focus on plants. A survey and interviews of selected experts and ABD data practitioners were conducted to collect feedback on fitness for use and issues with GBIF-mediated data.
Data involved	- occurrence data (species distribution, genetic diversity) - taxonomical data - genetic data - morphological data - environmental data - climatic data
Skills required	- taxonomic knowledge - georeferencing

Additional resources:

1) Dias, S., Gaiji, S., 2005. EURISCO a window on Europe's plant genetic diversity: Overview of European CWR collections. Presentation given at the First International Conference on Crop Wild Relative Conservation and Use, Agrigento, Italy, September 2005 http://archive-ecpgr.cgiar.org/fileadmin/www.ecpgr.cgiar.org/Presentations/NCG_Bonn_2006/Dias_EURISCO_Overview.pdf

2) Heywood V. et al. (2007): Conservation and sustainable use of crop wild relatives. *Agriculture, Ecosystems & Environment* 121, 245-255. doi:10.1016/j.agee.2006.12.014

3) Maxted N. et al. (2007): Creation and use of a national inventory of crop wild relatives. *Biological Conservation* 140, 142-159. doi:10.1016/j.biocon.2007.08.006

3. *CLIMATE ACTION, ENVIRONMENT, RESOURCE EFFICIENCY AND RAW MATERIALS*

3.1 Population assessment

CASE 13

Project	**Are we in the midst of the sixth mass extinction? A view from the world of amphibians**
Link to NHC	*Collection and field data showed alarming extinction threats in amphibians.*
Source	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2556420/
Author(s)	Wake D.B., Vredenburg V.T.
Organization(s) involved	University of California, Berkeley, USA; San Francisco State University, USA
Abstract	Many scientists argue that we are either entering or in the midst of the sixth great mass extinction. Intense human pressure, both direct and indirect, is having profound effects on natural environments. The amphibians—frogs, salamanders, and caecilians—may be the only major group currently at risk globally. A detailed worldwide assessment and subsequent updates show that one-third or more of the 6,300 species are threatened with extinction. This trend is likely to accelerate because most amphibians occur in the tropics and have small geographic ranges that make them susceptible to extinction. The increasing pressure from habitat destruction and climate change is likely to have major impacts on narrowly adapted and distributed species. We show that salamanders on tropical mountains are particularly at risk. A new and significant threat to amphibians is a virulent, emerging infectious disease, chytridiomycosis, which appears to be globally distributed, and its effects may be exacerbated by global warming. This disease, which is caused by a fungal pathogen and implicated in serious declines and extinctions of >200 species of amphibians, poses the greatest threat to biodiversity of any known disease. Our data for frogs in the Sierra Nevada of California show that the fungus is having a devastating impact on native species, already weakened by the effects of pollution and introduced predators. A general message from amphibians is that we may have little time to stave off a potential mass extinction.
Data involved	- occurrence data - disease vectors - ecological data - chemical data - climatic data
Skills required	- field mapping - population analysis - environmental modelling - taxonomic knowledge

Additional resources:

1) Frey J.K. (2009): Distinguishing range expansions from previously undocumented populations using background data from museum records. *Diversity and Distributions* 15, 183–187. DOI: 10.1111/j.1472-4642.2008.00552.x
2) Gaubert P. et al. (2006): Natural history collections and the conservation of poorly known taxa: Ecological niche modeling in central African rainforest genets (*Genetta* spp.). *Biological Conservation* 130: 106–117. doi:10.1016/j.biocon.2005.12.006
3) Hedenäs L. et al. (2002): A herbarium-based method for estimates of temporal frequency changes: mosses in Sweden. *Biological Conservation* 105: 321-331.
4) Jeppsson T. et al. (2010): The use of historical collections to estimate population trends: A case study using Swedish longhorn beetles (Coleoptera: Cerambycidae). *Biological Conservation* 143, 1940-1950. doi:10.1016/j.biocon.2010.04.015
5) Krishtalka L. and Humphrey P.S. (2000): Can natural history museums capture the future? *BioScience* 50, 611–617. DOI:10.1641/0006-3568(2000)050[0611:CNHMCT]2.0.CO;2

6) Maguran et al. (2010): Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. *Trends in Ecology and Evolution* 25, 574-582. doi: 10.1016/j.tree.2010.06.016
7) McCarthy M. A. (1998). Identifying declining and threatened species with museum data. *Biological Conservation* 83, 9–17. doi:10.1016/S0006-3207(97)00048-7

3.2 Environment conservation, planning and monitoring

CASE 14

Project	**Contribution of natural history collection data to biodiversity assessment in national parks**
Link to NHC	*Collections have been used to assess the population dynamics and effects of conservation efforts before and after establishment of NP.*
Source	O'Connell A.F.J. et al. (2004): Contribution of natural history collection data to biodiversity assessment in national parks. Conservation Biology 18, 1254–1261. DOI: 10.1111/j.1523-1739.2004.00034.x-i1
Author(s)	O'Connell A.F.J., Gilbert A.T., Hatfield J.S.
Organization(s) involved	US Geological Survey
Abstract	There has been mounting interest in the use of museum and herbaria collections to assess biodiversity; information is often difficult to locate and access, however, and few recommendations are available for effectively using natural history collections. As part of an effort to inventory vertebrates and vascular plants in U. S. national parks, we searched manually and by computer for specimens originating within or adjacent to 14 parks throughout the northeastern United States. We compared the number of specimens located to collection size to determine whether there was any effect on detection rate of specimens. We evaluated the importance of park characteristics (e.g., age since establishment, size, theme [natural vs. cultural]) for influencing the number of specimens found in a collection. We located >31,000 specimens and compiled associated records (hereafter referred to as specimens) from 78 collections; >9000 specimens were park-significant, originating either within park boundaries or in the local township where the park was located. We found >2000 specimens by means of manual searches, which cost $0.001-0.15 per specimen searched and $0.81-151.95 per specimen found. Collection effort appeared relatively uniform between 1890 and 1980, with low periods corresponding to significant sociopolitical events. Detection rates for specimens were inversely related to collection size. Although specimens were most often located in collections within the region of interest, specimens can be found anywhere, particularly in large collections international in scope, suggesting that global searches will be necessary to evaluate historical biodiversity. Park characteristics indicated that more collecting effort occurred within or adjacent to larger parks established for natural resources than in smaller historical sites. Because many institutions have not yet established electronic databases for collections, manual searches can be useful for retrieving specimens. Our results show that thorough, systematic searching of natural history collections for park-significant specimens can provide a historical perspective on biodiversity for park managers.
Data involved	- occurrence data - ecological data
Skills required	- field mapping - environmental modelling - taxonomic knowledge

Additional resources:

1) Guralnick R. and Van Cleve J. (2005): Strengths and weaknesses of museum and national survey data sets for predicting regional species richness: Comparative and combined approaches. *Diversity and Distributions* 11, 349–359. DOI: 10.1111/j.1366-9516.2005.00164.x
2) Johnson et al. (2011): Climate Change and Biosphere Response: Unlocking the Collections Vault. *Bioscience* 61, 147-153. DOI: 10.1525/bio.2011.61.2.10
3) Lister et al. (2011): Natural history collections as sources of long-term datasets. *Trends in Ecology and Evolution* 26, 153-154. doi:10.1016/j.tree.2010.12.009
4) Poulíčková A. et al. (2013): Tracing decadal environmental change in ombrotrophic bogs using diatoms from herbarium collections and transfer functions. *Environmental Pollution* 179, 201-209. doi:10.1016/j.envpol.2013.04.007
5) Roy M.S. et al. (1994): The use of museum specimens to reconstruct the genetic-variability and relationships of extinct populations. *Experientia* 50, 551–557. DOI: 10.1007/BF01921724
6) Schaffer et al. (1998): The role of natural history collections in documenting species declines. *Trends in Ecology and Evolution* 13, 27-30. doi:10.1016/S0169-5347(97)01177-4
7) Schwemmer P. et al. (2011): Effects of ship traffic on seabirds in offshore waters: implications for marine conservation and spatial planning. *Ecological Applications* 21, 1851-1860. DOI: 10.1890/10-0615.1

3.3 Discovery of new sources of raw materials

CASE 15

Project	**CO_2SolStock**
Link to NHC	*Biological and geological collections may be used as a reference points to past CO_2 trapping mechanisms in rocks.*
Source	http://www.co2solstock.org/
Author(s)	Zaoui C., Chapelle G., Valayer PJ.
Organization(s) involved	University of Edinburgh, UK; Universidad de Granada, Spain; Université de Lausanne, Switzerland; Technishe Universiteit Delft, Netherlands; Biomim-Greenloop S.A.; Université de Neuchatel, Switzerland
Abstract	Climate change linked to intensive fossil fuels use and production of CO_2 is increasingly considered as the most important challenge facing mankind for this century. This project investigates on sustainable bio-inspired solutions for carbon sequestration as an alternative or complementary way to existing Carbon Capture and Storage (CCS) techniques. The explored biological CO_2 sequestration opportunity is the biomineralization of carbon by microorganisms, in particular the natural properties of some bacteria to combine calcium and CO_2 to produce calcareous rocks. A technology involving this carbonatation process is considered sustainable and environmentally safe, as the CO_2 is captured in a stable mineral structure. Moreover, the project includes the aspects of economic use of the produced calcium carbonate as e.g. a building material.
Data involved	- geological data - biological data (microorganisms) - geochemical data
Skills required	- analytical skills - Geochemistry knowledge - environmental modelling

Additional resources:

1) Antonelli F.et al. (2014): Petrographic characterization and provenance determination of the white marbles used in the Roman sculptures of Forum Sempronii (Fossombrone, Marche, Italy). *Applied Physics A* 115, 1033-1040. DOI: 10.1007/s00339-013-7938-2
2) Flűgel E. and Flűgel C. (1997): Applied microfacies analysis: Provenance studies of Roman mosaic stones. *Facies* 37, 1-48.
3) Van der Werf I.D. et al. (2016): A multi-analytical approach for the assessment of the provenience of geological amber: the collection of the Earth Sciences Museum of Bari (Italy). *Environmental Science and Pollution Research*, 1-15. DOI: 10.1007/s11356-016-6963-z

3.4 Environmental changes recorded in drill cores

CASE 16

Project	**The Hominin Sites and Paleolakes Drilling Project**
Link to NHC	*Field observations complemented by fossil collection studies reveal response of human evolution to past environmental changes.*
Source	http://geology.rutgers.edu/images/Cohen_et_al_2016_Drilling.pdf
Author(s)	Cohen A. et al.
Organization(s) involved	University of Arizona, USA; Arizona State University, USA; Addis Ababa University, Ethiopia; National Museum of Natural History, USA; Berkley Geochronology Center, USA; Rutgers University, USA; Yale University, USA; University of Michigan, USA; University of Aberystwyth, UK; Binghampton University, USA; University of Minnesota, USA; University of Nairobi, Kenya; Hong Kong Baptist University, Hong Kong; University of Saskatchewan, Canada; University of Cologne, Germany; Université de Rennes, France; University of Potsdam, Germany; University of South Florida, USA; Brown University, USA; Jomo Kenyatta University of Agriculture and Technology, USA; National Museums of Kenya, Kenya; Georgia State University, USA; Hamilton College, USA; University of Tubingen, Germany; National Oil Corporation of Kenya, Kenya; Tata Chemicals, Kenya; Syracuse University, USA; George Washington University, USA; University of St. Andrews, UK; Utrecht University, Netherlands; University of New Mexico, USA; ConocoPhillips, USA;
Abstract	The role that climate and environmental history may have played in influencing human evolution has been the focus of considerable interest and controversy among paleoanthropologists for decades. Prior attempts to understand the environmental history side of this equation have centered around the study of outcrop sediments and fossils adjacent to where fossil hominins (ancestors or close relatives of modern humans) are found, or from the study of deep sea drill cores. However, outcrop sediments are often highly weathered and thus are unsuitable for some types of paleoclimatic records, and deep sea core records come from long distances away from the actual fossil and stone tool remains. The Hominin Sites and Paleolakes Drilling Project (HSPDP) was developed to address these issues. The project has focused its efforts on the eastern African Rift Valley, where much of the evidence for early hominins has been recovered. We have collected about 2 km of sediment drill core from six basins in Kenya and Ethiopia, in lake deposits immediately adjacent to important fossil hominin and archaeological sites. Collectively these cores cover in time many of the key transitions and critical intervals in human evolutionary history over the last 4 Ma, such as the earliest stone tools, the origin of our own genus Homo, and the earliest anatomically modern Homo sapiens . Here we document the initial field, physical property, and core description results of the 2012–2014 HSPDP coring campaign.
Data involved	- sedimentological data - geochronological data - palaeoanthropological data - paleontological data - geochemical and geophysical data - ecological data
Skills required	- field mapping - sedimentology and stratigraphy - dating - palynology - geochemistry - environmental modelling

Additional resources:

1) Ariztegui D. et al. (2015): Present and future of subsurface biosphere studies in lacustrine sediments through scientific drilling. *International Journal of Earth Sciences* 104, 1655–1665. DOI: 10.1007/s00531-015-1148-4
2) Franců E. et al (2010): Historical Changes in Levels of Organic Pollutants in Sediment Cores from Brno Reservoir, Czech Republic. *Water, Air & Soil Pollution* 209, 81-91. DOI: 10.1007/s11270-009-0182-x
3) Gabrieli J. and Barbante C. (2014): The Alps in the age of the Anthropocene: the impact of human activities on the cryosphere recorded in the Colle Gnifetti glacier. *Rendiconti Lincei* 25, 71-83. doi:10.1007/s12210-014-0292-2
4) Valero-Garcés B.L. and Moreno A. (2011): Iberian lacustrine sediment records: responses to past and recent global changes in the Mediterranean region. *Journal of Paleolimnology* 46, 319-325. DOI: 10.1007/s10933-011-9559-0
5) Wilke T. et al. (in press): Scientific drilling projects in ancient lakes: Integrating geological and biological histories. *Global and Planetary Change*. doi:10.1016/j.gloplacha.2016.05.005

3.5 Invasive organisms monitoring

CASE 17

Project	**Detecting range shifts from historical species occurrences: New perspectives on old data**
Link to NHC	*Occurrence data from museum collections significantly contribute to create models for non-native species invasions.*
Source	Tingley MW, Beissinger SR. 2009. Detecting range shifts from historical species occurrences: New perspectives on old data. *Trends in Ecology and Evolution* 24: 626–633. doi:10.1016/j.tree.2009.05.009
Author(s)	Tingley MW, Beissinger SR.
Organization(s) involved	University of California, Berkeley, USA
Abstract	The difficulty of making valid comparisons between historical and contemporary data is an obstacle to documenting range change in relation to environmental modifications. Recent statistical advances use occupancy modelling to estimate simultaneously the probability of detection and the probability of occupancy, and enable unbiased comparisons between historical and modern data; however, they require repeated surveys at the same locations within a time period. We present two models for explicitly comparing occupancy between historical and modern eras, and discuss methods to measure range change. We suggest that keepers of historical data have crucial roles in curating and aiding accessibility to data, and we recommend that collectors of contemporary specimen data organize their sampling efforts to include repeated surveys to estimate detection probabilities.
Data involved	- occurrence data - ecological data
Skills required	- field mapping - behavioural ecology - data mining - population dynamics modelling

Additional resources:

1) Di Febbraro M. et al. (2013): The Use of Climatic Niches in Screening Procedures for Introduced Species to Evaluate Risk of Spread: A Case with the American Eastern Grey Squirrel. *PLoS ONE* 8, e66559. http://dx.doi.org/10.1371/journal.pone.0066559
2) Essl F. et al. (2009): Changes in the spatio-temporal patterns and habitat preferences of Ambrosia artemisiifolia during its invasion of Austria. *Preslia* 81, 119–133.
3) Fuentes N. et al. (2008): Alien plants in Chile: inferring invasion periods from herbarium records. *Biological Invasions* 10, 649-657. DOI: 10.1007/s10530-007-9159-0

4) Lavoie C. (2013): Biological collections in an ever changing world: Herbaria as tools for biogeographical and environmental studies. *Perspectives in Plant Ecology, Evolution and Systematics* 15, 68-76. doi:10.1016/j.ppees.2012.10.002
5) Zarzoso-Lacoste D. et al. (2016): Improving morphological diet studies with molecular ecology: An application for invasive mammal predation on island birds. *Biological Conservation* 193, 134-142. doi:10.1016/j.biocon.2015.11.018

3.6 Effects of new technologies in agriculture

CASE 18

Project	**Project Baseline** Project Baseline – A time capsule of seeds
Link to NHC	*Project to create a seed collection that stores and maintains genetic structure of recent plant populations and supports their future conservation.*
Source	http://baselineseedbank.org/
Author(s)	Etterson, J. R., Franks S. J., Mazer S. J., Shaw R. G., Weis A. E.
Organization(s) involved	University of Minnesota Duluth, USA; Fordham University, USA; University of California, Santa Barbara, USA; University of Toronto, Canada; USDA National Center for Genetic Resources Preservation, USA
Abstract	We live in an era of rapid change, yet little is known about the evolutionary responses of wild plants to environmental perturbations. Project Baseline collections is designed to maintain the genetic structure of populations within samples to be most useful to researchers utilizing the resurrection approach. This approach is a powerful way to observe evolution in action in the wild, and provide insight into how plant populations evolve in response to stressors such as climate change and invasive species. Seeds are collected and stored separately by maternal plant from up to 200 individuals per population. After collection, seeds are cleaned and shipped to the USDA National Center for Genetic Resources Preservation for long-term storage.
Data involved	- occurrence data - taxonomical data - genetic data - morphological data - climatic data - conservation data
Skills required	- taxonomic knowledge - DNA barcoding - population ecology, population analysis

Additional resources:

1) Boundy-Mills K. (2012): Yeast culture collections of the world: meeting the needs of industrial researchers. *Journal of Industrial Microbiology & Biotechnology* 39, 673-680. DOI: 10.1007/s10295-011-1078-5
2) Koizumi A. et al. (2009): Past, present, and future of environmental specimen banks. *Environmental Health and Preventive Medicine* 14, 307-318. DOI: 10.1007/s12199-009-0101-1
3) Pascher K. et al. (2011): Setup, efforts and practical experiences of a monitoring program for genetically modified plants - an Austrian case study for oilseed rape and maize. *Environmental Sciences Europe* 23, DOI: 10.1186/2190-4715-23-12.
4) Thomas M. et al. (2011): Seed exchanges, a key to analyze crop diversity dynamics in farmer-led on-farm conservation. *Genetic Resources and Crop Evolution* 58, 321-338. DOI: 10.1007/s10722-011-9662-0

3.7 Modelling of climate change effects

CASE 19

Project	**Will Arctic mammals benefit from climate change?**
Link to NHC	*Occurrence data from museum collections used to create a model for range shifts of Arctic mammals in response to current climate change and its impact on ecosystems structure.*
Source	Hof A. et al. (2012): Future Climate Change Will Favour Non-Specialist Mammals in the (Sub)Arctics. PLoS ONE 7, e52574. http://dx.doi.org/10.1371/journal.pone.0052574
Author(s)	Hof A.R., Janson R., Nilsson C.
Organization(s) involved	Umea University, Sweden; Swedish University of Agricultural Sciences, Sweden
Abstract	Authors modelled future distributions for mammal species currently resident in the far North of Europe, as well as some potential colonizers from further South. Occurrence records for 61 species were gathered from national databases in Norway, Sweden and Finland, and from the GBIF data portal. The results, based on climate scenarios for 2080, indicated that 43 out of the 61 species studied would expand and shift their ranges, mainly to the north-east, assuming they were fully able to disperse to suitable areas. If the ability to disperse is severely limited, for example due to roads or industrial developments, most mammal species would lose range, but none is projected to become extinct due to climate change. The study also predicts that the climate in Arctic and subarctic Europe will become suitable for ten more mammalian species, including eight bat species, and that the region is thus likely to become richer in mammal species. This may have unexpected consequences, such as a the coexistence of large predators threatening populations of prey species – for example, both the grey wolf and brown bear are projected to expand their range and affect the population of European roe deer. The authors suggest that the reason for the relative stability of mammal species presence under projected climate might be that Arctic regions have experienced large climatic shifts in the past, filtering out sensitive and range-restricted species.
Data involved	- occurrence data - taxonomical data - genetic data
Skills required	- taxonomic knowledge - georeferencing - ecological knowledge - population analysis and modelling

Additional resources:

1) Denys L. (2009): Palaeolimnology without a core: 153 years of diatoms and cultural environmental change in a shallow lowland lake (Belgium). *Fottea* 9, 317–332. http://fottea.czechphycology.cz/pdfs/fot/2009/02/15.pdf
2) Ensslin A. et al. (2015): Fitness, decline and adaptation to novel environments in ex situ plant collections: Current knowledge and future perspectives. *Biological Conservation* 192, 394-401. doi:10.1016/j.biocon.2015.10.012
3) Loiselle B.A. et al. (2008): Predicting species distributions from herbarium collections: does climate bias in collection sampling influence model outcomes. *Journal of Biogeography* 35, 105–116. DOI: 10.1111/j.1365-2699.2007.01779.x
4) Primack D. et al. (2004): Herbarium specimens demonstrate earlier flowering times in response to warming in Boston. *American Journal of Botany* 91: 1260–1264. DOI: 10.3732/ajb.91.8.1260
5) Purvis O.W. et al. (2007): Multi-element composition of historical lichen collections and bark samples, indicators of changing atmospheric conditions. *Atmospheric Environment* 41, 72-80. doi:10.1016/j.atmosenv.2006.08.040

3.8 Modelling of land use change effects

CASE 20

Project	**Species vulnerability to environmental change: Insights from land use legacies**
Link to NHC	*Occurrence data from museum collections combined with historical records and modern day survey provide clues to understand response of species to land use changes and anticipate their responses to further environmental changes.*
Source	http://www.reeis.usda.gov/web/crisprojectpages/0229197-species-vulnerability-to-environmental-change-insights-from-land-use-legacies.html
Author(s)	Rowe R.
Organization(s) involved	University of New Hampshire, Durham, USA
Abstract	Biologists and natural resource managers require reliable forecasts as to which species are most resilient and most vulnerable. To address this question of the unique land-use history of New England was reviewed based on examination of small mammal populations recorded in museum collections and their responses to reforestation and warming over the past century. This historical perspective was coupled with modern day surveys in forests at different successional stages (i.e., young vs. old forest-habitats), experiencing different degrees of disturbance or management, and in different landscape contexts (i.e., isolated patches of varied sizes vs. continuous forest). These data will be used to understand the association between species life-history traits (e.g., body size and diet) and their disturbance tolerances.
Data involved	- occurrence data - ecological data - climatological data - historical records
Skills required	- field mapping - taxonomic knowledge - population analysis - environmental modelling

Additional resources:

1) Glavan M. et al. (2013): Finding options to improve catchment water quality - Lessons learned from historical land use situations in a Mediterranean catchment in Slovenia. *Ecological Modelling* 261-262, 58-73. doi:10.1016/j.ecolmodel.2013.04.004

2) Lotze H.K. et al. (2011): Historical Changes in Marine Resources, Food-web Structure and Ecosystem Functioning in the Adriatic Sea, Mediterranean. *Ecosystems* 14, 198-222. doi:10.1007/s10021-010-9404-8

3) Skaloš J. et al. (2011): Using old military survey maps and orthophotograph maps to analyse long-term land cover changes – Case study (Czech Republic). *Applied Geography* 31, 426-438. doi:10.1016/j.apgeog.2010.10.004

4) Raška P. et al. (2016): The late Little Ice Age landslide calamity in North Bohemia: Triggers, impacts and post-landslide development reconstructed from documentary data (case study of the Kozí vrch Hill landslide). *Geomorphology* 255, 95-107. doi:10.1016/j.geomorph.2015.12.009

3.9 Evaluation of the risk for Extinction (Red List assessments)

CASE 21

Project	**Defining a role for herbarium data in Red List assessments**
Link to NHC	*Herbarium data of endangered species are vital to assess population profiles and trends necessary to design further conservation efforts.*
Source	Willis F. et al. (2003). Defining a role for herbarium data in Red List assessments: A case study of Plectranthus from eastern and southern tropical Africa. Biodiversity and Conservation 12, 1537–1552. DOI: 10.1023/A:1023679329093
Author(s)	Willis F., Moat J., Paton A.
Organization(s) involved	Royal Botanical Gardens Kew, UK
Abstract	Red Lists are widely used to indicate species at risk of extinction. Specimen sheets in herbaria provide an important source of data relevant for Red List assessments. The aims of this study are to establish which data can be sourced from specimen information to satisfy IUCN Red Data List criteria and to identify the specific criteria that can be used. Red List parameters are measured within a Geographical Information System (GIS), as this provides an objective and repeatable methodology which is less subjective than manual methods. Data used to explore this were gathered during the course of preparing a monograph on Plectranthus (Lamiaceae). Criteria relating to distribution (extent of occurrence, area of occupancy and fragmentation) and population profile (projected continuing decline and number of subpopulations) proved most suitable for assigning categories of threat. Estimates of mature individuals, generation length, population size, population reduction, extreme fluctuation and number of locations could not be derived from herbarium material without making inconsistent subjective decisions. In addition to comprehensively databased specimen information, extensive field knowledge is required to produce better estimates for assessing extinction risk. In order to enhance the usefulness of specimen information in the future, improvements in recording additional botanical data at the time of collection would be beneficial. Overall, herbaria provide a useful starting point for conservation-related work and can help to guide future work.
Data involved	- occurrence data - ecological data - climatological data - historical records
Skills required	- field mapping - taxonomic knowledge - population analysis - environmental modelling

Additional resources:

1) Casas-Marce M. et al. (2012): The Value of Hidden Scientific Resources: Preserved Animal Specimens from Private Collections and Small Museums. *BioScience* 62, 1077-1082. DOI: 10.1525/bio.2012.62.12.9
2) Cooper J.E. et al. (1998): Reference collections: Their importance and relevance to modern zoo management and conservation biology. Dodo – Journal of the Wildlife Preservation Trusts 34, 159-166.
3) Habel J.C. et al. (2009): Unprecedented long-term genetic monomorphism in an endangered relict butterfly species. *Conservation Genetics* 10, 1659-1665. DOI: 10.1007/s10592-008-9744-5
4) Roberts D.L. and Solow A.R. (2008): The Effect of the Convention on International Trade in Endangered Species on Scientific Collections. *Proceeding s of the Royal Society B - Biological Sciences* 275, 987-989. DOI: 10.1098/rspb.2007.1683

3.10 Replenishing biodiversity

CASE 22

Project	**Ex situ seed collections will benefit from considering spatial sampling design and species' reproductive biology**
Link to NHC	*This study evaluates sampling methods for seed collections to better represent biodiversity and conservation potential.*
Source	Hoban S. and Strand A. (2015): Ex situ seed collections will benefit from considering spatial sampling design and species' reproductive biology. Biological Conservation 187, 182-191. doi:10.1016/j.biocon.2015.04.023
Author(s)	Hoban S. and Strand A.
Organization(s) involved	University of Tennessee, USA; College of Charleston, USA
Abstract	Collecting seed from natural plant populations is a key tool for conservation, ecological restoration, assisted migration, studying plant mating systems, and crop breeding. Many collections rely on simple, broadly-applied rules-of-thumb for minimum sample sizes, regardless of species' natural history, and are likely inadequate for obtaining sufficient genetic representation. There is a current paucity of information about how various logistical and biological factors influence seed sampling outcomes. Here we use simulated and empirical data to, for the first time, quantitatively evaluate the degree to which collection effectiveness is influenced by spatial arrangement, sampling intensity, and species' reproductive biology. We clearly and quantitatively demonstrate that collections with spatially limited or biased sampling arrangements, or collections from species with high selfing or low dispersal, will need substantially more samples than are commonly recommended, or else will fail to reach the targeted genetic diversity. We also show that the marginal gain from sampling additional maternal plants will nearly always exceed that of additional seeds. Lastly we show that random sampling outperforms "easy access" and "transect" sampling by 70% and 30%, respectively. Overall, we conclude that collection guidelines tailored to particular taxa will help facilitate optimal sampling design.
Data involved	- occurrence data - taxonomical data - genetic data - morphological data - climatic data - conservation data
Skills required	- taxonomic knowledge - DNA barcoding - population ecology, population analysis

Additional resources:

1) Cibrian-Jaramillo, A. *et al. (2013):* What is the conservation value of a plant in a botanic garden? Using indicators to improve management of ex situ collections. *Botanical Review* 79, 559–577. DOI 10.1007/s12229-013-9120-0
2) Maunder M. et al. (2001): The conservation value of botanic garden palm collections. Biological Conservation 98, 259-271. [doi:10.1016/S0006-3207(00)00160-9](doi:10.1016/S0006-3207(00)00160-9)
3) Pyke G.H. and Ehrlich P.R. (2010): Biological collections and ecological/environmental research: a review, some observations and a look to the future. *Biological Reviews* 85, 247-266. doi:10.1111/j.1469-185X.2009.00098.x
4) Tanksley, S.D. and McCouch, S.R. (1997): Seed banks and molecular maps: Unlocking genetic potential from the wild. *Science* 277, 1063–1066. DOI: 10.1126/science.277.5329.1063

4. EUROPE IN A CHANGING WORLD - INCLUSIVE, INNOVATIVE AND REFLECTIVE SOCIETIES

4.1 Data mining - citizen science

CASE 23

Project	**Notes from Nature**
Link to NHC	*Volunteers make Natural history collections data available to researchers to address key environmental issues such as climate change or emerging wildlife and human diseases.*
Source	https://www.notesfromnature.org/
Author(s)	
Organization(s) involved	Natural History Museum, London, UK; Museum of Natural History, University of Colorado, USA; Appalachian State University, USA; CalBug, USA; Vizzuality; National Science Foundation
Abstract	Natural history collections document where species and populations exist now and where they existed decades and centuries before, so they hold irreplaceable information necessary for uncovering the patterns of changes in species distributions and ecosystem composition over time. Scientists use such data and information in order to address key environmental issues such as the impacts of climate change and how diseases affect wildlife and humans. For the information held in these collections to be used to its full potential there must be better digital access to these data. Most natural history collections are housed in museum repositories, where they are not easily available to citizens and researchers. Only a small fraction of all natural history specimens is available digitally over the Internet, while the vast majority remains locked away from view in an inflexible, limited format. The Notes from Nature transcription project is a citizen science platform built to address this problem by digitizing the world's biological collections one record at a time.
Data involved	- all kinds of data that are stored in or associated with NHC - trait data - occurrence data - ecological data
Skills required	- taxonomic knowledge - morphology - georeferencing - data mining - data management

Additional resources:

1) Auer T. et al. (2011): HerbariaViz: A web-based client–server interface for mapping and exploring flora observation data. *Ecological Informatics* 6, 93-110. doi:10.1016/j.ecoinf.2010.09.001

2) Battistini A. et al. (2013): Web data mining for automatic inventory of geohazards at national scale. *Applied Geography* 43, 147-158. doi:10.1016/j.apgeog.2013.06.012

3) Meirelles W.C.L. and Zárate L.E. (2015): Data mining in the reduction of the number of places of experiments for plant cultivates. *Computers and Electronics in Agriculture* 113, 136-147, doi:10.1016/j.compag.2015.02.006

4) Project Europeana: http://www.europeana.eu/portal/

4.2 Increasing awareness of scientific and cultural value of natural science collections

CASE 24

Project	**NatSCA On-line Collections and Publications**
Link to NHC	*NatSCA's mission is to promote and support natural science collections as a base of our understanding of past populations, their current distributions and future trends.*
Source	http://www.natsca.org
Author(s)	
Organization(s) involved	Natural Sciences Collections Association (NatSCA)
Abstract	The Natural Sciences Collections Association (NatSCA) is a UK based membership organisation and charity run by volunteers from the membership. NatSCA's mission is to promote and support natural science collections, the institutions that house them and the people that work with them, in order to improve collections care, understanding, accessibility and enjoyment for all.
Data involved	- collection management data - occurrence data
Skills required	- data mining - communication skills

Additional resources:

1) Cook J.A. et al. (2014): Natural History Collections as Emerging Resources for Innovative Education. *BioScience* 64, 725-734. DOI: 10.1093/biosci/biu096
2) MacFadden B.J. (2008): Evolution, museums and society. *Trends in Evolution and Ecology* 23, 589-591. doi:10.1016/j.tree.2008.06.006
3) Scoble M.J. (2000): Costs and benefits of Web access to museum data. *Trend in Ecology and Evolution* 15, 374. doi:10.1016/S0169-5347(00)01895-4
4) Sunderland M.E. (2013): Computerizing natural history collections. *Endeavour* 37, 150-161. doi:10.1016/j.endeavour.2013.04.001
5) Matter of Life and Death: Natural Science Collections: Why Keep Them and Why Fund Them? A Report Published by the Natural Sciences Collections Association in the UK http://www.spnhc.org/media/assets/AMatterOfLifeAndDeath.pdf

5. SECURE SOCIETIES - PROTECTING FREEDOM AND SECURITY OF EUROPE AND ITS CITIZENS

5.1 Documenting natural disasters (past and present)

CASE 25

Project	**Storegga Slide and related tsunami**
Link to NHC	*Geological collections store information on rapid environmental changes related to this natural disaster.*
Source	http://bora.uib.no/bitstream/handle/1956/729/Bondevik-al-03-EOS.pdf;jsessionid=DC8CB66967CA2BA881690D37A2511EFA.bora-uib_worker?sequence=1 Fruergaard M. et al. (2015): Tsunami propagation over a wide, shallow continental shelf caused by the Storegga slide, southeastern North Sea, Denmark. Geology 43, 1047-1050. DOI: 10.1130/G37151.1
Author(s)	Bondevik et al., Fruergaard M. et al.
Organization(s) involved	University of Tromsø, Norway; University of Bergen, Norway; Coventry University, UK; University of Caen, France; University of Copenhagen, Denmark; Geological Survey of Denmark and Greenland, Denmark
Abstract	The large Storegga slide, which occurred on the Norwegian Atlantic shelf ~8,150 yrs ago, triggered a tsunami that has been identified in sediment deposits along the coasts of Greenland, Norway, the Faroe Islands, the Shetland Islands, Scotland, and the northernmost coasts of England, but hitherto not along the southeastern shores of the North Sea. It has generally been assumed that the shallow continental shelf of the North Sea attenuated and dissipated the energy of the tsunami before it reached those coastlines. Combination of various methods has been applied to sediment cores to identify tsunami deposits on the barrier island of Rømø located on the southwestern North Sea coast of Denmark. Tsunami sediments were deposited in a freshwater paleolake that is located ~16 m below present-day mean sea level. The tsunami sediment run-up was between 1.5 m and 5.5 m above the contemporaneous sea level. Our results demonstrate that the Storegga slide tsunami propagated across the wide (>500 km) and relatively shallow (depth <95 m) continental shelf of the North Sea and resulted in run-up along adjacent coastlines. In contradiction to earlier theoretical studies, the coastline of the southeastern North Sea cannot be regarded as being sheltered from impacts of North Atlantic tsunami incidents.
Data involved	- geological data - stratigraphical data - radiometric data - ecological data
Skills required	- sedimentology and stratigraphy - dating - palynology - geochemistry - environmental modelling

Additional resources:

1) Becker A. and Davenport C.A. (2003): Rockfalls triggered by the AD 1356 Basle Earthquake. *Terra Nova* 15, 258–264. DOI: 10.1046/j.1365-3121.2003.00496.x
2) Courtillot V. (2005): New evidence for massive pollution and mortality in Europe in 1783–1784 may have bearing on global change and mass extinctions. *Comptes Rendus Geoscience* 337, 635-637. doi:10.1016/j.crte.2005.03.001
3) Monecke K. et al. (2004): The record of historic earthquakes in lake sediments of Central Switzerland. *Tectonophysics* 394, 21-40. doi:10.1016/j.tecto.2004.07.053
4) Riede F. (2013): Towards a science of past disasters. *Natural Hazards* 71, 335-362. DOI: 10.1007/s11069-013-0913-6

5.2 EU border control (invasive species, pests, CITES)

CASE 26

Project	**Temporal and interspecific variation in rates of spread for insect species invading Europe during the last 200 years**
Link to NHC	*Occurrence data from museum collections revealed patterns and timing of insect invasion in Europe during the last two centuries.*
Source	Roques A. et al. (2016): Temporal and interspecific variation in rates of spread for insect species invading Europe during the last 200 years. *Biological Invasions* 18, 908-920. DOI: 10.1007/s10530-016-1080-y
Author(s)	Roques A. et al.
Organization(s) involved	Institut National de la Recherche Agronomique (INRA), Orleans, France; University College London, UK; University of Pretoria, South Africa; Czech Academy of Sciences, Pruhonice, Czech Republic; Charles University, Prague, Czech Republic; Stellenbosch University, Matieland, South Africa; United States Forest Service, Morgantown, USA; University of Canberra, Australia
Abstract	Globalization is triggering an increase in the establishment of alien insects in Europe, with several species having substantial ecological and economic impacts. Authors investigated long-term changes in rates of species spread following establishment. They used the total area of countries invaded by 1171 insect species for which the date of first record in Europe is known, to estimate their current range radius. They estimated initial rates of radial spread and compared them among different groups of insects for all years (1800-2014) and for a subset of more recent decades (1950-2014). Accidentally introduced species spread faster than intentionally introduced species. Considering the whole period 1800-2014, spread patterns also differ between feeding guilds, with decreasing spread rates over residence time in herbivores but not in detritivores or parasitic species. These decreases for herbivorous species appeared mainly in those associated with herbaceous plants and crops rather than woody plants. Initial spread rate was significantly greater for species detected after 1990, roughly 3-4 times higher than for species that arrived earlier. Authors hypothesize that the political changes in Europe following the collapse of the Iron Curtain in 1989, and the further dismantling of customs checkpoints within an enlarged European Union (EU) have facilitated the faster spread of alien insect species.
Data involved	- occurrence data - ecological data
Skills required	- field mapping - behavioural ecology - data mining - population dynamics modelling

Additional resources:

1) Jansen S. (2000): Chemical-warfare techniques for insect control: insect 'pests' in Germany before and after World War I. *Endeavour* 24, 28-33. doi:10.1016/S0160-9327(99)01261-2
2) Ravensberg W.J. (2011): A roadmap to the successful development and commercialization of microbial pest control products for control of arthropods. *Progress in Biological Control*, vol 10. Springer, Dordrecht, The Netherlands.
3) Renner S.C. et al. (2012): Import and export of biological samples from tropical countries–considerations and guidelines for research teams. *Organisms, Diversity & Evolution* 12, 81-98. DOI 10.1007/s13127-012-0076-4

3. Results
The Use Cases documented here show that NHC are an important resource in finding solutions for a large number of societal challenges. Their power to provide a deep historical context sits alongside their importance as a source of biodiversity data documenting the effects of current climate change and related environmental responses to it. NHC-based institutes as well as other related research organisations possess relevant data (i.e., collections), expertise and skills (such as taxonomic knowledge, analytical skills, DNA barcoding, population and behavioural ecology, environmental modelling and georeferencing, field mapping, phytochemistry, geochemistry and palynology) as well as analytical facilities. Additional data and skills are provided by interdisciplinary collaboration, particularly for chemical, medical and climatic data.

By collaborating with industry and public authorities to face emerging societal challenges, NHC institutions are able to provide a number of services, such as disease vector monitoring and prediction, population modelling and biodiversity data assessment, environment impact assessment (EIA), forensic services and seed banking, biotechnology assessment and climate change and invasive species modelling. These services may be focused on medical and veterinary companies, public health officials, emergency and urban planners, FAI policies on food security, CITES, local and national water resources managements, national and international conservation policy makers or governmental parties.

NHC have always been research driven and the research community will remain the core users. However, this community has also increasingly evolved from inward focused collection of researchers focused on taxonomic and systematic issues, to a more outward focused set of researchers who exploit this taxonomic and systematic data to address challenges of greater societal relevance. This is partly driven by changing economic circumstances that have resulted in challenges for natural history institutes. Cost-benefit-analyses and new financial and intellectual business models, for example, are being introduced to overcome these challenges. Therefore, collaboration and joint efforts of natural history institutes are essential.

In particular, new user groups that increase the relevance of NHC have been key to increasing demand for NHC. This requires a shift in thinking towards a benefit-based approach. Key questions for NHC holding institutions when acquiring new collections are:

- *Who can use and benefit from the collections?*
- *How can the access and use by new user groups be facilitated?*

Institutes housing NHC are facing complex challenges both to clarify their needs to sustain the collections as well as to discover the needs of the users.

4. Strategy
Two principal strategies can be employed to achieve the aforementioned goals. The first of these is the application for individual short to mid-term projects under the Framework Programme H2020. This includes applications that build on the success of the SYNTHESYS programme, to support new type of access to collections within 'SYNTHESYS4' or similar projects. These activities might be tailored to address specific user groups' needs and selected societal challenge topics. A second possibility is preparation of an ESFRI project. Placing European NHC infrastructure within ESFRI creates the potential for better reflecting the priorities and needs for the user community that rely on this NHC infrastructure and provide a mechanism to better coordinate European efforts around NHC's.

5. Timeline

The documented need for better support for NHC institutions to deliver their goals and develop a common strategy serves as a starting point for engaging new uses for collections and developing new roles that better exploit the potential of these institutions. This procedure requires a timeline and milestones. This is suggested below (Figure 1).

Figure 1: Timeline for European NHC activities.

ACTIONS	2016	2017	2018	2018-2024	2024-
M1: S3 Symposium at SPNCH	■				
M2: S3 Deliverable European Roadmap	■				
M3: Open Call for H2020 projects, application for S4		■			
M4: ESFRI proposal submission		■			
M5: Start of Preparatory Phase for ESFRI			■		
M6: Preparatory Phase for ESFRI				■	
M7: Start of Operational Phase of ESFRI					■

Milestone 1 (2016): SYNTHESYS3 symposium at SPNCH and GGBN conferences (06/2016) organised in cooperation with MfN in Berlin. It provided base for planning of potential 'SYNTHESYS4' project in context of the present European Road Map. Important discussions on new societal challenges and their implementation with leading experts in the field.
Funding from SYNTHESYS3 (confirmed).

Milestone 2 (2016): SYNTHESYS3 Deliverable D3.6 European Road Map (06/2016): document providing evidence for need of NHC support. This document will be used for definition of new goals for projects in frames of CETAF consortium.
Funding from SYNTHESYS3 (confirmed).

Milestone 3 (2017): Open Call for H2020 projects, application for 'SYNTHESYS4'. The present and selected new partners will prepare a largely modified concept of SYNTHESYS project based on digitisation on demand and new models of scientist mobility. The project will see increasing use of non-destructive methods and broad use of digitised NH collections.
Funding from H2020 (not yet secured).

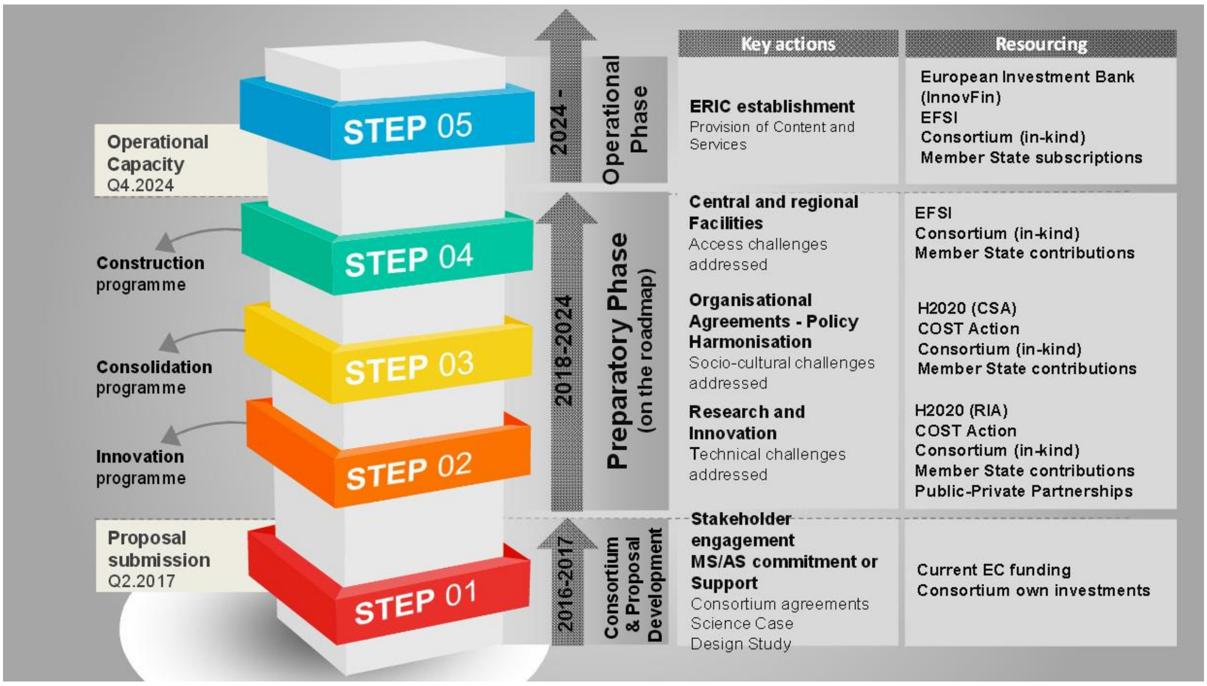
Milestone 4 (2017): Q2 submission of ESFRI proposal. This proposal has its own preparatory time line (Figure 2). The proposal will include preparation of unified portal of European natural history collections, new mobility scheme, and development of NH collection standards, competencies, staff development and training.
Funding from COST (not yet secured) and members of the ESFRI consortium (confirmed).

Milestone 5 (2018): start of Preparatory Phase for ESFRI. The major goal will include to incorporate as many NH institutions from EU member states as possible to deliver the preparatory activities set out in the ESFRI proposal. The European Road Map will be used aid in the delivery of this activity, with the financial aid of the COST scheme and member states.
Funding from COST (not yet secured) and member state contributors (not yet secured).

Milestone 6 (2024): end of Preparatory Phase for ESFRI. At this stage all necessary activities will be switched to start the operational phase of the consortium including detailed definition of major goals and major tasks. Ongoing political lobbying in all involved EU member states will be necessary.
Funding by member state contributors and consortium members (not yet secured).

Milestone 7 (2024): beginning of operational phase of ESFRI. The ESFRI consortium including ideally all the major European NH museums will begin to develop its activities according to the plan. The process of formation of ESFRI consortium is expected to be gradual and will depend on results of political negotiations in individual EU member states.
Funding by member state contributors and consortium members (not yet secured).

Figure 2: Timeline for ESFRI activities (by D. Koureas).



6. Conclusions

We have identified a number of topics relevant to the H2020 societal challenges. We have provided a set of 26 Use Cases which include robust documentary evidence that NHC-based research can provide solutions to major societal challenges. Furthermore we have identified potential user groups (collaborators and beneficiaries) who would be stakeholders within this research. We have also outlined a timeline and milestones for further actions to sustain these activities of European natural history collections.