BIORESOURCE COLLECTIONS

Scientific collections of the Zoological Institute of the Russian Academy of Sciences, Saint Petersburg

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Abstract

The Zoological Institute of the Russian Academy of Sciences in St Petersburg is one of the oldest biological research institutions in Russia, housing the largest zoological collections in the country, both in terms of their size (number of specimens) and global diversity. It is also one of the largest zoological depositories in the world, with over 60 million specimens in its stores. In total, the Zoological Institute holds about 260,000 animal species, about a quarter of the world's known diversity. The type collection includes several tens of hundreds of primary types, which are very important as the essential foundation for zoological nomenclature. The digitisation of scientific collections now plays an important role in ensuring the standardised accumulation and use of various data sets, as well as quick access to stored information. The digitised scientific collections of the Zoological Institute are published online for the public access. To date they have accumulated 146,695 taxa records and over 13,000 high quality images of invertebrate and vertebrate specimens and their original data labels. The Zoological Institute is not only a depository of animal specimens important for biodiversity inventories and studies, but also a unique bank of genetic resources of extant/extinct animals which can be studied using modern genetic technologies.

Keywords: zoological collections, biodiversity, taxonomy, digitization, genetic researches

Introduction

One of the main purposes of biology, as a science, is to understand and explain the similarities and differences between organisms, i.e. it is the study of biological diversity. In recent decades, there has been a significant increase in the study of biodiversity. On the pragmatic side, this research is important for the conservation of biodiversity as a renewable resource; on the scientific side, its main purpose is to study biodiversity as a specific natural phenomenon. Biological collections that are deposited in research institutions and natural history museums play a very important role in the study of biodiversity. The scientific value of biological collections lies in the fact that they contain primary (objective) information on biodiversity and allow both its empirical study and subsequent verification (Pavlinov, 2016).

Intensive development of new technologies, such as different genetic researches, CT-scan tomography, stable isotope analysis and many others, has contributed to the increasing importance of scientific natural history collections for the study of ecology, evolution and biodiversity conservation (Bi et al., 2013; Nachman, 2013; Rocha et al., 2014).

The past mass extinction of "large mammal fauna" at the end of the Quaternary (Andermann et al., 2020; Nogues-Bravo et al., 2008) and the present extinction of the modern African fauna of large mammals (Yang et al., 2005; Palko-

Citation: Abramov, A., Voyta, L., and Kijashko, P. 2022. Scientific collections of the Zoological Institute of the Russian Academy of Sciences, Saint Petersburg. Bio. Comm. 67(4): 331–339. https://doi.org/10.21638/spbu03.2022.407

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Manuscript Editor: Pavel Skutschas, Department of Vertebrate Zoology, Faculty of Biology, Saint Petersburg State University, Saint Petersburg, Russia

Received: July 22, 2022;

Revised: September 3, 2022;

Accepted: September 13, 2022.

Funding: This study was supported by Ministry of Science and Higher Education of the Russian Federation (Grant No. 075-15-2021-1069).

Ethics statement: This paper does not contain any studies involving human participants or animals performed by any of the authors.

Competing interests: The authors have declared that no competing interests exist.

poulou et al., 2018) must have been largely caused by human activity (Brooks et al., 2002; Pimm et al., 2014; Ceballos et al., 2015; Andermann et al., 2020; Hamilton et al., 2020). Landscape destruction and fragmentation of natural habitats contribute to biodiversity loss on a global scale. At present, existing international captive breeding projects for wild (non-domestic) animals have been developing new approaches for rapidly developing techniques for cryopreservation and biobanking of genetic materials (Strand et al., 2020; Hildebrandt et al., 2021). Indeed, such collections of frozen and preserved tissues of wild animals are particularly important as their availability bridges gaps in space and time, thereby optimising the genetic variability available.

Overall, zoological collections, including those of the Zoological Institute, constitute an essential tool for discovering and inventorying existing biological diversity, and for promoting scientific knowledge (Owens and Johnson, 2019). Yet, they represent a unique gene pool of existing and extinct species which can be used in research using modern genetic technologies. Furthermore, the availability of collections of parasites and various animal and plant vectors from all over the world makes natural history museums an essential source of genetic materials on infectious diseases.

Scientific collection of the Zoological Institute

The Zoological Institute of the Russian Academy of Sciences in St Petersburg (ZIN) is one of the oldest biological research institutions in Russia. The first Russian museum — Kunstkamera (= Cabinet of Curiosities) — was founded by the tsar Peter the Great in 1714. In 1832, the Zoological Museum of the Imperial Academy of Sciences was separated from the Kunstkamera as an independent academic unit with zoological research collections. A hundred years later, on 26 December 1931, the Zoological Museum was reorganized into the Zoological Institute of the Soviet Academy of Sciences (since 1991 — the Russian Academy of Sciences).

The Zoological Institute houses Russia's largest zoological collections, both in terms of number of specimens and global diversity. It is also one of the largest zoological depositories in the world, with over 60 million items of collection materials. In total, the Zoological Institute contains around 260,000 animal species, around a quarter of the world's known fauna. For many animal groups from the Northern Hemisphere this is the most representative collection in the world. There are almost all the terrestrial and aquatic animal species of Russia, of which many are represented by large series. Most of the world's vertebrate and invertebrate animal groups are available in the collections of the Zoological Institute. These consist of skins and skeletons of vertebrate animals and their parts, birds' eggs and nests, mollusk shells, animal fossils, dry insects, wet specimens of vertebrates and invertebrates preserved in ethanol or formalin, micropreparations, DNA samples or sequences.

The core collection fund of the Zoological Institute includes reference and type collections, taxidermy, regional and thematic collections, and collections under study. The main type — systematic reference collections consisting of identified specimens arranged according to modern taxonomic classification. The type collection includes several tens of hundreds of primary types, which are very important as the essential foundation for zoological nomenclature. The regional and thematic collections include the specimens used for particular scientific/practical purposes. The collections under study are represented by recently acquired materials that are not yet identified and fully catalogued. Taxidermy is used by the exhibition department of the Zoological Institute: viz. Zoological Museum, which displays nearly 30,000 specimens of all animal groups and is open to the public.

There are 18 academic departments in the Zoological Institute, specializing on different animal groups and keeping corresponding reference collections (Table).

The mammalogical collection is one of the largest in Europe, with over 230,000 specimens (Fig. 1). The majority of specimens are represented by Palaearctic species; it also contains about 800 types. Except for extant species, this collection also contains a large amount of Pleistocene mammals, including those from the so called "mammoth fauna". Yet, there is a good collection of Paleogene and Neogene mammals.

The herpetological collection originated from the Kunstkamera epoch and contains a number of Albert Seba's specimens. The main part is formed by the type specimens of E. Eichwald, E. Menetries, A. A. Strauch, J. von Bedrjaga, A. M. Nikolsky, S. F. Tzarewsky. There are types from the taxa described by I. Schneider, W. Peters, F. de Filippi, G. Boulenger, O. Boettger, F. Steindachner, F. Werner. The most representative part of the collections is represented by samples from Europe, Middle and Central Asia, the Middle East, and Southeast Asia. The collection of reptiles and amphibians from tropical Asia is one of the world's best depositories.

The bird collection contains many historically important specimens collected by F. F. Brandt, A. A. Strauch, I. G. Voznesensky, A. F. Middendorff, N. A. Severtsov, M. A Menzbier, N. M. Przewalski, P. K. Kozlov, and many other famous explorers.

The worldwide ichthyologic collection includes over 160,000 specimens of 8,700 species of marine and freshwater fishes and fishlike vertebrates, including some 1,500 types.

The insect collection originated from the 18th century and contains specimens collected by G. H. Langsdorff,

Fig. 1. The mammal depository of the ZIN's Laboratory of Theriology. (**A**) Cabinets with rodent collections. (**B**) Wooden store-boxes for keeping skins of Palaearctic large mammals. Photos by Julia A. Shemyakina.

Table. Collection sizes at the Zoological Institute of the Russian Academy of Sciences, St. Petersburg, Russia

Animal groups	Terrestrial regions									Marine regions						
	Europe	Africa	Asia Temperate	Asia Tropical	Australasia	Pacific	North America	South America	Antarctic	North Pacific	South Pacific	North Atlantic	South Atlantic	Indian	Southern	Arctic Marine
Fishes	4	2	2	3	2	3	4	2	0	5	3	4	3	3	5	4
Amphibians	4	3	5	5	3	2	3	3	1	0	0	0	0	0	0	0
Reptiles	5	3	6	6	4	2	3	3	2	1	2	0	0	2	0	0
Birds	5	3	5	4	2	3	4	4	3	0	0	0	0	0	0	0
Mammals	5	3	5	4	3	3	3	3	2	3	2	3	2	2	2	3
Insects	7	6	7	7	5	4	5	6	0	0	0	0	0	0	0	0
Arthropods	5	3	4	4	1	4	1	1	3	4	3	4	4	4	4	5
Molluscs	5	3	4	4	3	3	3	3	0	5	4	5	4	4	4	5
Other groups	5	0	4	3	0	3	1	1	3	5	4	5	4	4	4	6

Note. Ranks (number of specimens): 0 — 0; 1 — 1–10; 2 — 11–100; 3 — 101–1000; 4 — 1001–10,000; 5 — 10,000–100,000; 6 — 100,001–1,000,000; 7 — 1,000,001–10,000,000.

Fig. 2. Insect collection in the ZIN's permanent display. Photo by Pavel V. Kijashko.

R. K. Maak, G. I. Radde, N. M. Przewalski, V. I. Roborovski, P. K. Kozlov, G. N. Potanin, G. E. Groom-Grzhimailo, D. K. Glazunov, A. P. Fedtschenko, E. A. Eversmann, N. A. Zarudny, and many others. The geographical coverage includes all continents, but the richest collection is that from the Palaearctic (Fig. 2). This collection includes the majority of primary types the taxa described from the Russian Empire and the USSR.

The collection of other arthropods, including ticks, mites and fleas, originated from the 20th century. Its main part is formed by the type specimens of V. B. Dubinin, N. G. Bregetova, N. A. Filippova, S. V. Mironov, A. V. Bochkov. The crustacean collection consists of about 150,000 samples, with over 900 types. There are also collections of Pantopoda (some 3,000 samples) and Xiphosura.

The malacological collection dates back to Albert Seba's shell collection bought in Holland for the Kunstkamera in 1716. At present, this collection is the largest in Russia and one of the most representative in the world. It includes about 500,000 samples, among which 2,232 types. The geographical coverage includes almost all continents (excl. Antarctica), as well as the seas of the Arctic, Antarctic, the Far East, the Mediterranean, Black, Azov, Caspian and Aral seas, coastal waters of the Pacific, Atlantic and Indian Oceans.

The collections of annelids, bryozoans, sponges, coelenterates, echinoderms, annelids, rotifers and tunicates include about 1,200,000 samples, with 2,222 types.

There is a collection of both living cultures and dry smearses of the trypanosomatids. Its most representative part was sampled from the territory of Europe, Middle Asia, and partly Africa and South America.

The Zoological Institute keeps not only collections of extant animals. There is a large fossil collection of amphibians, ichthyosaurs, plesiosaurs, pterosaurs, dinosaurs, crocodiles, lizards, snakes, and birds. The collection of fossil turtles is one of the largest in Russia.

Digitisation of the zoological collections

In today's era of digital globalisation, digitisation of scientific collections plays an important role in ensuring the standardised accumulation and public presenta-

tion of various data sets, as well as rapid access to stored information. In the case of zoological collections, the digitization process encounters a number of difficulties, primarily related to a complex hierarchy of animal classification. At the Zoological Institute, this problem has been more or less addressed by the development and subsequent improvement of the original digital classifier "ZOOCOD" to display the taxonomic hierarchy in standard relational databases with any detail required by zoologists. Since 1992, based on this development, a zoological integrated retrieval system "ZOINT" has been created by the institute staff (https://ww.zin.ru/projects/zoointw/zoointw/zoointw.asp) (Lobanov, Sokolov, and Smirnov, 1994; Lobanov et al., 2008).

Over the past three decades, a lot of different projects based on modern information technologies have been implemented at the Zoological Institute. These include an analytical system on fleas (Siphonaptera) of the world fauna, databases of various parasites, the Information Retrieval System (IRS) "OCEAN", entomological databases, dialogue computer diagnostic systems, the IRS for fresh-water fishes of Russia, virtual collections "Protists", the IRS "Biodiversity of Russia", the IRS "Biodiversity of animals of Russia", and others.

Due to the enormous number of specimens in the collections of the Zoological Institute, their digitisation is far from complete. More recently, this work has been limited to a number of model taxa belonging to major animal groups. Priority is given to types which are reference (voucher) specimens bearing the scientific names of species and subspecies (Pugachev et al., 2019). The search for and easy access to such specimens, their correct designation and subsequent study using state-of-the-art methods is a scientific challenge of paramount importance, since any inaccuracies in taxa typification can lead to a chain of erroneous conclusions at all levels of biodiversity research and can significantly distort or even invalidate the results obtained. This is particularly relevant for old types designated in the 18th and 19th centuries, i.e. before the introduction of regulation by the International Code of Zoological Nomenclature. These type specimens have often not been adequately described and unambiguously identified, leading to serious problems in identifying taxa and correctly applying their names.

The following groups of terrestrial and aquatic animals are currently used as model groups for developing the structure and algorithms of a digital catalogue of collections: Pogonophora, Coleoptera, Lepidoptera, Siphonaptera, Hymenoptera, Diptera, Simuliidae, Ceratopogonidae, Asteroidea, Ophiuroidea, Echinoidea, Holothuroidea, Amphibia, Reptilia, and Mammalia.

The information system is based on a modular architecture and includes taxonomic, geographical, bibliographic information and high-quality digital image(s) of the specimen and its original data label. At present, the taxonomic classifier of the Zoological Institute's collection contains 146,695 taxa records of 40 taxonomic ranks, including 33,036 synonyms. More than 13,000 high-quality images of stored specimens and original data labels have been documented for Pogonophora (553 items), Coleoptera (1,134), Lepidoptera (1,451), Siphonaptera (193), Echinoidea (140), Holothuroidea (359), Amphibia (705), Reptilia (2,023) and Mammalia (869) (Ananjeva et al., 2020).

Digitised research collections are published online for public access. This information is available on a dedicated website available on the web portal of the Zoological Institute (https://www.zin.ru/collections/index_en.html). This website exists in two languages—Russian and English. The English version fully duplicates the Russian one, both in terms of data presentation and functionality. The full bilingual nature of the site significantly increases the relevance of this resource to colleagues around the world, taking the availability of information on research collections, especially the most important data on the types, to a whole new level (Pugachev et al., 2019). Website functionality is enhanced with a mechanism for exporting information on specimens. This mechanism uses the Darwin Core international standard, while full collection data can be downloaded as XML documents.

The server infrastructure at the Zoological Institute and the existing information system made it possible to use the Integrated Publishing Toolkit, a special service of the Global Biodiversity Information Center (GBIF) (http://ipt.zin.ru). This allows selective publication of data collected by the Zoological Institute on the GBIF portal (https:///www.gbif.org). To date, several datasets on the types of different animal groups have already been published there: Ophiuroidea, Polycestinae, Cosmopterigidae, Pogonophora, Bufonidae, Megophryidae, etc.

In the last decade, non-destructive imaging techniques for studying zoological collections have been developed based on modern computed micro-tomography (micro-CT) approaches (Wu and Schepartz, 2009; Ni, Flynn and Wyss, 2012; Ekdale and Racicot, 2015; Mason, 2016; Orliac and Billet, 2016). The micro-CT imaging technology allows for high-resolution images of internal and external structures of specimens without any damage (Fig. 3), making it an important tool for digitising valuable/unique zoological collections (Ball et al., 2011; Keklikoglou et al., 2019). The most important features of the micro-CT are (i) creating a virtual copy of the original specimen and correspondingly (ii) a virtual access to it via Internet. Both aspects contribute to the development of the so-called "digital collections" or "virtual museums", where "digital data are shared widely and freely around the world, while the original material

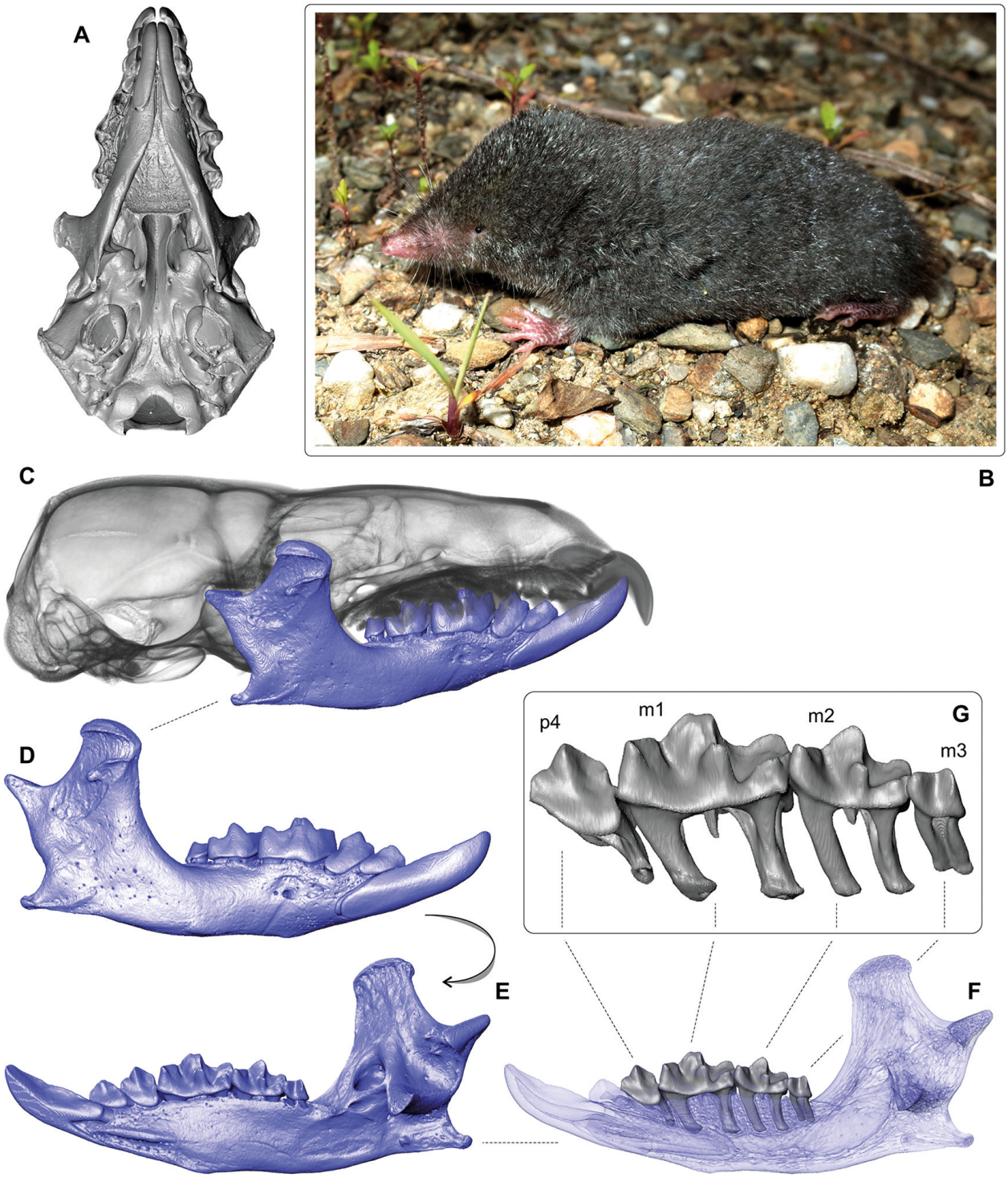

Fig. 3. Combined image of the three-dimensional skull models, lower hemimandible and lower teeth of the mole shrew *Anourosorex squamipes*, based on the micro-CT data sets. (**A**) Skull in ventral view. (**B**) Mole shrew in its natural habitat (by Alexei V. Abramov). (**C**) Skull (X-ray image) and hemimandible (the model in blue) in lateral view. (D) Right hemimandible in lateral view. (**E**) Right hemimandible in medial view. (**F**) Position of lower teeth roots in the dentary bone; hemimandible is transparent, lower teeth (p4–m3) marked with gray. (**G**) Isolated models of the lower teeth in lingual view, without scale. The micro-CT data sets were taken using the equipment of the ZIN's Core Facilities Centre "Taxon" (http://www.ckp-rf.ru/ckp/3038/).

is stored safely" (Keklikoglou et al., 2019: 3). With this trend in mind, starting in 2021, the Zoological Institute has created a three-dimensional digital store for the mammalogy collection for the first time (Voyta, Zazhigin, and Kryuchkova, 2021). This virtual depository is accessible via a Web link (https://www.zin.ru/labs/theriology/eng/research/) and is mainly based on scans obtained with equipment of the Resource Centre for X-ray Diffraction Studies of Saint Petersburg State University (Saint Petersburg, Russia).

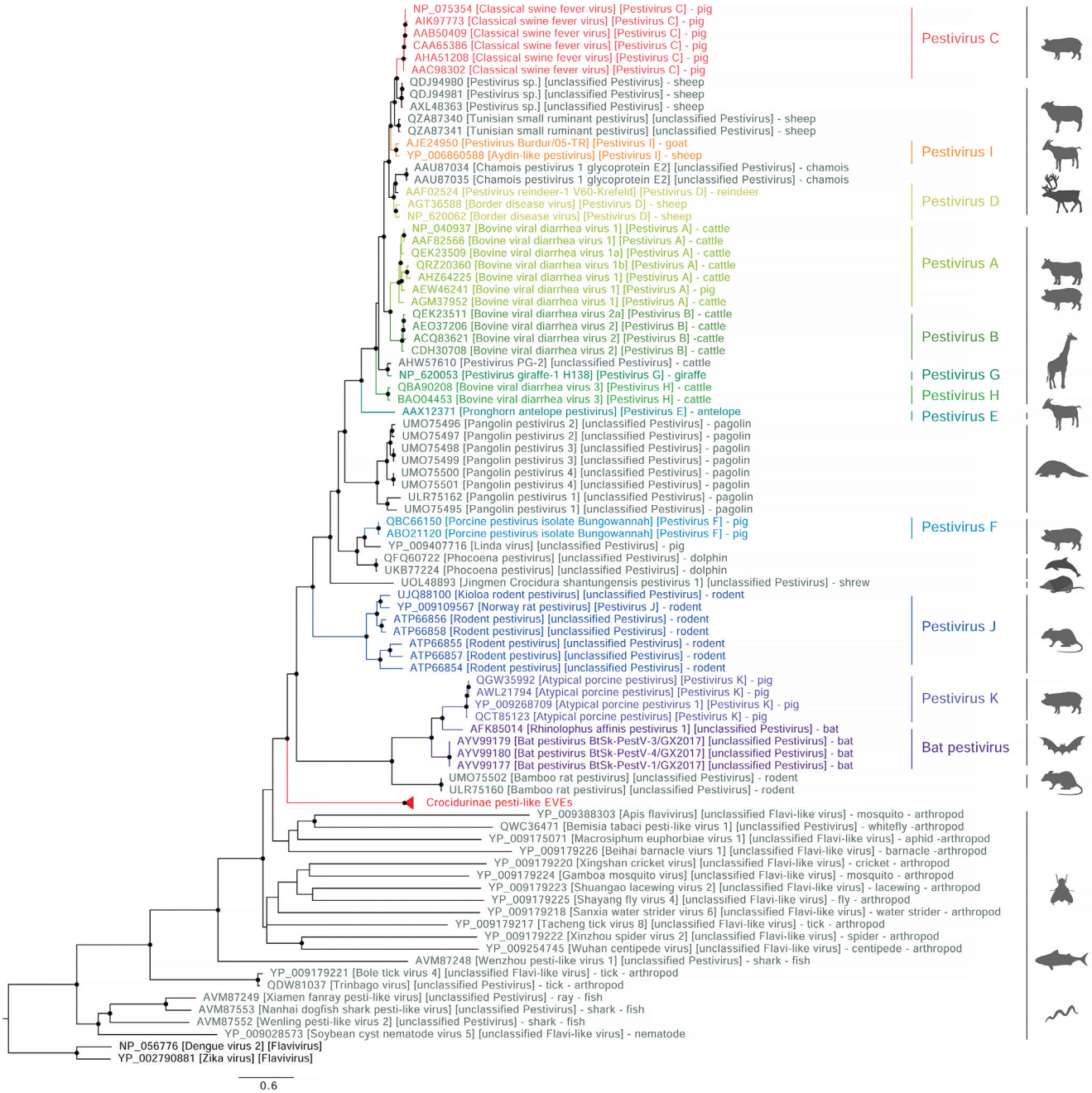

Fig. 4. Phylogenetic relationships of pesti-like EVEs with representative *Pestivirus* species and pesti-like viruses (based on aligned viral E2 and NS2-3 region). Dengue and Zika virus (*Flavivirus*) are used as outgroups. Clades are coloured according to viral species. Nodes labeled in black circles indicate the Shimodaira-Hasegawa (SH)-like branch support (%, only values > 80 % are shown). Scale bars indicate the number of amino acid substitutions per site. This study (Li et al., 2022) is based on shrew specimens (Mammala, Crocidurinae) from the ZIN's mammal collection.

Zoological collections and genetic studies

The Zoological Institute is not only a depository of animal specimens important for biodiversity inventories and studies, but also a unique bank of genetic resources of extant/extinct animals which can be studied using modern genetic technologies.

Fundamental research of the biological diversity is increasingly dependent on the developments in genomic technology. The importance of DNA sequences as key components in taxonomic, evolutionary and ecological research is steadily growing (Fig. 4). At the same time, such genetic data will be of limited value outside the phylogenetic context or without precise taxonomic assignment (= identification). Indeed, genotyping of zoological materials stored in large scientific depositories and museums is becoming extremely relevant. Genetic studies based on museum collections are essential to clarify complex taxonomic and nomenclatural questions (e.g., genotyping of type specimens). It is also an invaluable source

of the materials collected in previous centuries from geographical regions where natural habitats have been completely destroyed today, or regions which are difficult to access for various political and economic reasons. Yet, museum collections make it possible to study recently extinct populations and species, as well as endangered species, using modern genetic techniques. The collection of the Zoological Institute contains a large number of type specimens, the results of genetic analysis of which, as well as extensive materials from currently inaccessible areas of the Palaearctic, are of great importance for zoological systematics and biodiversity inventories.

The rapid improvement of genetic technologies during the last decade, including the widespread usage of high-throughput sequencing (or next-generation sequencing) methods, has significantly expanded the possibilities for studying DNA isolated both from fresh material and from historical samples and fossils. New methodological techniques allow taxonomic, phylogeographical, biogeographical and evolutionary studies to be complemented by unique historical material.

Analysis of ancient DNA polymorphism is important for describing changes in genetic diversity over long periods of time. By comparing the genetic structure of populations, it is possible to test hypotheses about the relationship between the long-term changes in environmental factors and the adaptive variability of species. Comparative analysis of modern and ancient DNA polymorphism of closely related species can help elucidate the phylogeny of supraspecific taxa, as well as help better calibrate the molecular clock.

The genetic data collection is a part of the core collection of the Zoological Institute. It is a world-class resource which supports molecular phylogenetic studies by academics from various departments of the Zoological Institute and collaborators, as well as the scientific community worldwide. It includes tens of thousands of samples housed in ultra-cold freezers, which guarantee that the samples will be usable for decades.

Acknowledgements

We are grateful to Dr Dmitri Logunov (The Manchester Museum, UK) for his helpful and constructive comments on the manuscript and for improving the English of the early draft.

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