Marine Biodiversity
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SENCKENBERG

REVIEW

200 years of marine research at Senckenberg: selected highlights

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Abstract
A history of the Marine Zoology Department at the Senckenberg Society for the Study of Nature (Senckenbergische Naturforschende Gesellschaft) has not yet been published. Still, there is no lack of documentation of research activities at the Senckenberg Research Institute and Natural History Museum. Marine zoology studies began with Eduard Rüppell (1794–1884) after his admission to the Senckenberg Society in 1818, one year after its foundation, and his collections of fishes, molluscans and crustaceans from the Mediterranean made in 1820. During the nineteenth century, further progress in marine zoology studies was slow and serious interest in the study of marine organisms expanded significantly only during the twentieth century after the foundation of the marine station at Wilhelmshaven in 1928. The amount of marine biology and geology literature originating from researchers associated with the Senckenberg has become overwhelming and the dwarfs once standing on the shoulder of giants have become giants themselves. In this article, we present the Marine Zoology Department, its sections and assess the most important researchers associated with the Senckenberg Research Institute including the founders of the sections and their place in two centuries of history since the foundation of the Senckenberg Society in 1817.

Keywords Senckenberg · history · marine research · expeditions

Introduction

The cornerstone of marine science at Senckenberg Research Institute in Frankfurt/Main was set by Eduard Rüppell (1794–1884) (Fig. 1a, b). In his unfinished autobiography, probably written in the late 1840s, Rüppell noted that the death of a (harbour or monk) seal at the biannual Frankfurt Fair had inspired Frankfurt's citizens to found an association of naturalists. He furthermore argued that Johann Georg Neuburg (1757–1830), a prominent Frankfurt physician, who felt sorry

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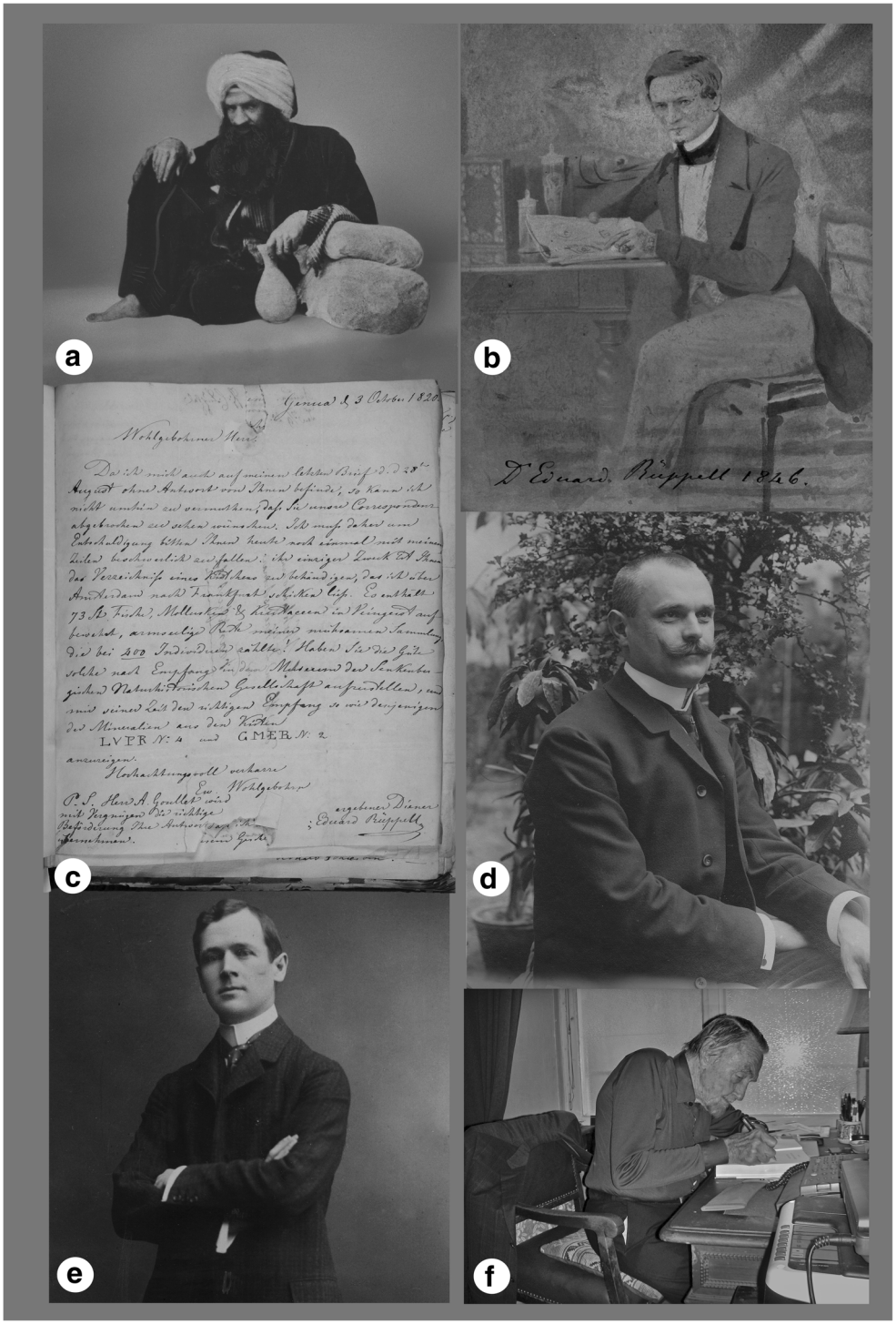


Fig. 1 Selected portraits (and a letter) of scientists who were influential for the Senckenberg Research Institute and natural History Museum of Nature Senckenberg). A, B Eduard Rüppell, first Red Sea Explorer in local Arab dress, c. 1840; C Letter of Rüppell to Jacob Cretzschmar dated October 3rd, 1820, Archive of the SGN Frankfurt); D Römer; E Otto zur Strassen; F Hans Hass

to see the rare specimens decaying because the city lacked a suitable institution to house them, proposed the establishment of a natural history society. Subsequently, Neuburg became the first director of the Senckenberg Society and Rüppell buttressed the authenticity of this account by insisting that he had heard the story from Neuburg personally (Sakurai 2013, translated from Mertens 1949). Judging from the current structure of the Marine Zoology Department at the Senckenberg (comprising research sections on fishes and various phyla of marine invertebrates), the origin of marine zoology at the Senckenberg Museum goes back to Eduard Rüppell's collecting expeditions (Sakurai 2013). What we know is that Rüppell, who in 1818 was nominated as one of the founders of the Senckenberg Society, started to collect marine animals shortly thereafter. In 1820, Eduard Rüppell was staying in Genova to study under the auspices of the geodesist and

astronomer Franz Xaver von Zach (1754–1832) – the same teacher who had trained Alexander von Humboldt (1769–1859) in the field of astronomical navigation. Rüppell fell in love with animals from the bottom of the sea and when collecting a variety of fish, mollusc and crustacean species in the Gulf of Naples, his scientific interests shifted from archaeology and mineralogy to zoology (Mertens 1949): "…countless remains of my Mediterranean collection, at least 200 individuals…", as he wrote on October 3rd 1820 to Philipp J. Cretzschmar (1786–1845) (Fig. 1c), a member of the foundation committee of the Senckenberg Natural History Society whose director he became in 1817 for almost 30 years. Accordingly, October 3rd 1820 can be seen as the birthday of Senckenberg's Marine Zoology at a time when the first Senckenberg Museum at the "Eschenheimer Tor" had not yet opened its gates. Despite his interest and scientific work on marine organisms, he became head of Senckenberg's Ichthyology Section only in 1847 (Mollenhauer and Ziegler 1992). Though he collected most of the taxa he came across, he concentrated his efforts on molluscs and crustaceans while neglecting sessile and colonial organisms (Mertens 1949) and his respective scientific preferences shaped the collection and research priorities of the Senckenberg Society for the next one and a half centuries. However, this is not surprising as by about 1860, every second biological object was either collected, or organised by Rüppell (Sakurai 2013). By that time, Rüppell had already left the Senckenberg Society (1859) for good, following internal disarrays over Rüppell's performance as the second Director of the Senckenberg Society (Schäfer and Kramer 1967). The remaining decades of his long life, he dedicated almost exclusively to numismatics.

Today, three of the five Marine Zoology sections in Frankfurt are strongly influenced by Eduard Rüppell's legacy in the collections of fish, molluscs and crustaceans. Sponges and worms, despite having been collected by Rüppell, and bryozoans were not a research priority during the nineteenth century. Since the sixties and seventies, however, with the expansion of Senckenberg facilities and research activities, the new section Marine Invertebrates was established including the Cnidaria and Porifera, the Polychaeta, and the Bryozoa (Marine Evertebrates I-III). The Marine Station "Senckenberg am Meer" was founded in 1928 by Rudolf Richter (1881–1957) primarily as a marine field station for the study of actuogeological and palaeontological processes in Wilhelmshaven. Marine biodiversity in the North Sea became a specific focus starting in the seventies and got further accentuated by the establishment of the German Centre of Marine Biodiversity (DZMB) as a second department.

In July 2017, 200 years after the Senckenberg Society was founded, the marine collections, libraries, and offices moved to a newly renovated building on the Senckenberg campus, the Arthur von Weinberg building.

In the following, we present a brief outline of selected highlights of marine biological activities at the Senckenberg Research Institute as they unfolded in time. We will start with a group that was so important to Rüppell, that he did not include it in his Atlas of the fauna of Northern Africa, but dedicated a monograph to this taxon: Crustacea.

Crustacea

The section Crustacea was founded in 1841 at the Senckenberg Research Institute in Frankfurt. Yet, research dates back even further due to the very early explorations of Eduard Rüppell, who published his first work on this taxon in 1830 on 24 crab species from the Red Sea (Rüppell 1830) (Fig. 2a). But even before that, in the 1820s, Rüppell conducted his first expedition to Egypt (Mertens 1949) and it is likely that he also collected marine animals at that time. However, we do not have written proof for this, and the first handwritten record of a crustacean deposited at the Senckenberg collection dates back to 1826 to *Ashtoret lunaris* (Forskål, 1775), a specimen collected by Rüppell in the Red Sea. Several carcinologists followed Rüppell, for example Richard Bott (1900–1980) who was very active in research of freshwater crabs and crayfish between 1948 and 1974 (Türkay 1975). Later Michael Türkay (1948–2015), who came as a young student to Senckenberg, worked on decapods from the deep sea and oriental regions, but also from the North Sea and the Mediterranean from 1974 until to his death (Sonnewald and Apel 2016). Türkay always kept tight connections to "Senckenberg am Meer" in Wilhelmshaven, where he ran the summer field courses of the "Senckenbergschule" each year for young museum technicians. The good relationship of the latter with Japanese scientists (among others: T. & K. Sakai, K. Matsuzawa) led to a series of huge donations of Japanese crustaceans, likely one of the world's largest collection of Japanese crabs outside of Japan. Selected highlights of this century are substantial monographs on crayfish and freshwater crabs by Bott (Bott 1955; Türkay 1974, 1975) and extensive work on deep-sea decapods from the Red Sea (Türkay 1986), as well as various publications on long-term monitoring of the Dogger Bank in the North Sea (e.g. Türkay 1991, 1992; Türkay and Kröncke 2004; Sonnewald and Türkay 2010, 2012a, b, c). Traditionally, many guest researchers temporarily work and worked in the crustacean section or work up material from countless expeditions using various research vessels (e.g. Fig. 3). For example, Reza Naderloo (University of Teheran) often collaborated with Türkay and conducted many outstanding studies on the decapod fauna of the Persian Gulf region (e.g. Naderloo and Apel 2014; Naderloo and Schubart 2010; Naderloo et al. 2011), culminating in an atlas of crabs of the Persian Gulf (Naderloo 2017). Extensive material from his studies is deposited in the crustacean collection.

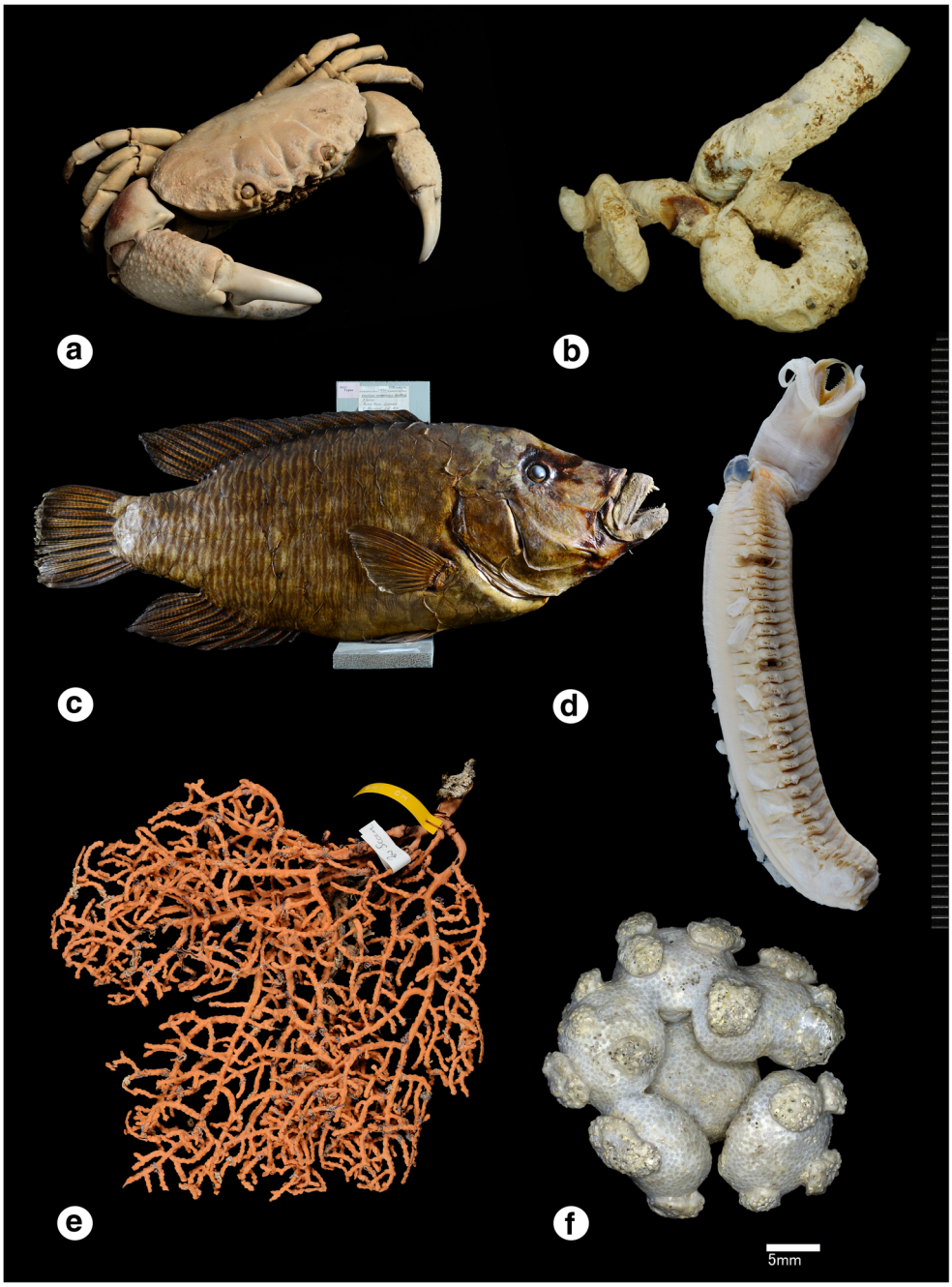


Fig. 2 Selected marine organisms collected by Rüppell and subsequent scientists at Senckenberg. A *Lidia tenax* Rüppell, 1830 (SMF 1485); B *Thylacodes inopertus* (Leuckart in Rüppell and Leuckart, 1828); C; holotype of the Napoleon Wrasse *Cheilinus undulates* Rüppell, 1835; D *Polyodontes gulo* (Grube, 1855), SMF (2609); E *Astrogorgia begata* Grasshoff, 1999 (paratype, SMF-No. 6763. Photo Sven Tränkner); F Cyclostome bryozoan *Bueltenopora hustedti* (Voigt, 1924). Neotype, SMF 26189

Since April 2017, the section is being led by Angelika Brandt, who has worked for more than 21 years in the crustacean department of the Zoological Museum of the University of Hamburg. Brandt collaborated with the Senckenberg Research Institute since she had been a member of the foundation committee of the German Centre of Marine Biodiversity Research in Wilhelmshaven and Hamburg (DZMB) as a section of Senckenberg Research Institute (see chapter 9). Her work focuses on the systematics, ecology and evolution of peracarid crustaceans with focus on Isopoda from deep-sea and polar habitats. In the framework of the Census of the Marine Life, she was involved in the Antarctic and deep-sea field projects CAML (Census of the Diversity of Antarctic Marine Life) and CeDAMar (Census of the Diversity of Abyssal Marine Life). Her work documented high biodiversity of Southern Ocean deep-sea invertebrates (e.g. Brandt et al. 2007). In recent years, her research interest concentrated in the identification of drivers of evolution in the deep sea, such as dispersal barriers (Brandt et al. 2017; Riehl et al. 2017), as well as on advancing deep-sea sampling methodologies (Brandt et al. 2016). She plans to continue deep-sea research (currently in the Northwest Pacific and Southern Ocean) but continues laying focus on the Red and Arabian seas as well as the North Sea and Baltic Sea.

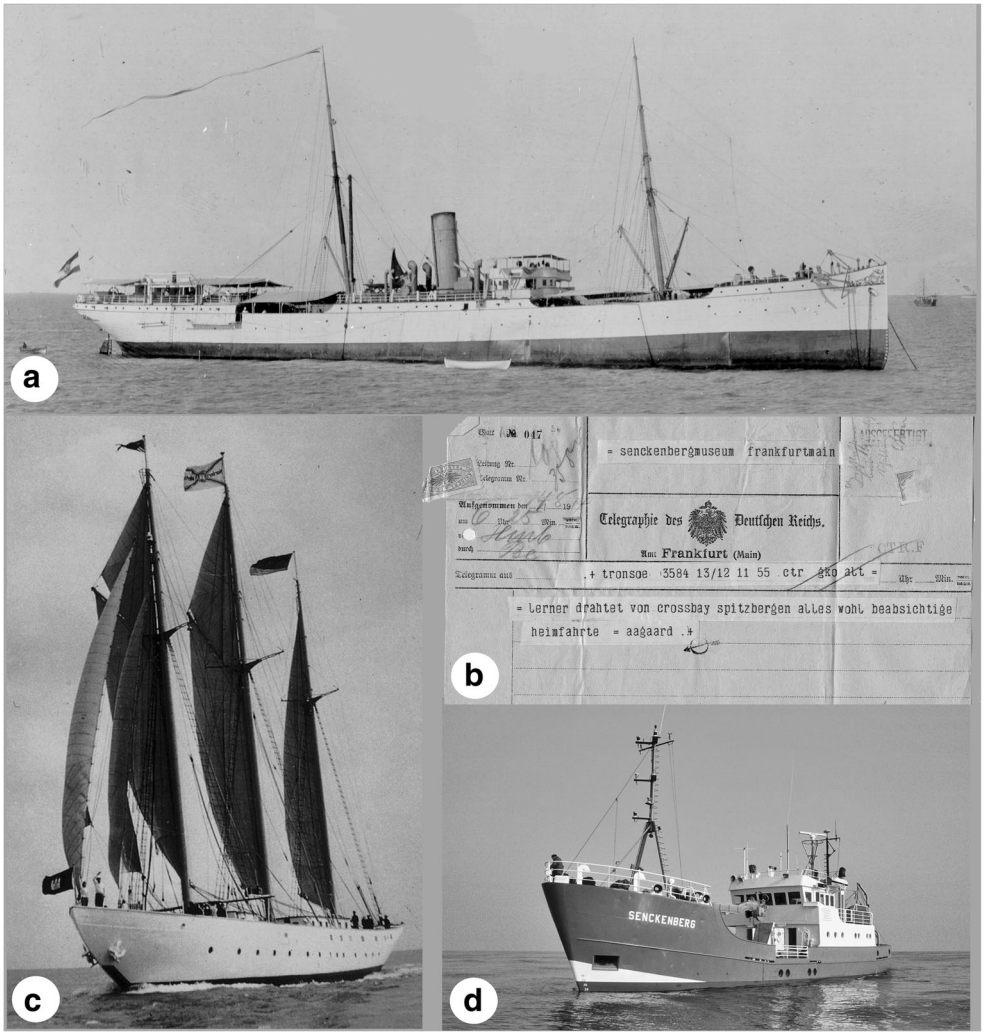


Fig. 3 Marine exploration at Senckenberg, a few examples. A Valdivia; B Telegram from the research vessel Valdivia to the Senckenberg Research Institute, Frankfurt; C Xarifa (The 3-mastedschooner "Xarifa", which was built in 1927, became a world renowned research vessel when Hans Hass and his team used it for their explorations of the Red Sea and Indian Ocean in 1957–1958); D Senckenberg

Today, the collection houses more than 50,000 catalogued series containing about 480,000 individuals from 5724 different species, comprising 1671 types (including 534 holotypes) from all aquatic realms, but also covering terrestrial crustaceans as well.

Malacology

The traditional focus of Senckenberg's malacological research in the middle of the nineteenth century was the study of terrestrial and limnic molluscs and to date the international importance of the collection mainly results from these early priorities. However, in the nineteenth century, and again since the 1960s, marine molluscs were also investigated. Once again, it was Rüppell, who intensively collected marine molluscs during his numerous research trips to Italy and the Red Sea and has thus laid the foundations of the marine collections (Fig. 2b). Rüppell worked on the nudibranchs of the Red Sea (Rüppell and Leuckart 1828–1830), described snails living in corals (e.g. Rüppell 1834) from the Red Sea as well as cephalopods from the Mediterranean (Rüppell 1844).

From the 1860s, the versatile Wilhelm Kobelt (1840–1916) devoted himself to exploring European marine molluscs and brought extensive collections of Mediterranean marine molluscs to the Senckenberg Museum during his numerous journeys to the Mediterranean (Kobelt 1886–1888). Important publications resulted from his work such as the catalogue of European marine molluscs (Kobelt 1886–1888), as well as his "Iconography of the shelled European marine molluscs" (1883–1908). Between 1874 and 1898, Kobelt also worked on numerous species and families of marine molluscs for the famous "New systematic Conchylien-Cabinet von Martini & Chemnitz." Moreover, Oskar Boettger (1844–1910) focused on small species and, among others, described numerous species of marine molluscs from little-known or difficult families from the Philippines (Boettger 1887, 1893, 1895, 1896).

Since 1870, the Senckenberg Society financed and supported expeditions from the so-called Rüppell Foundation, some also with a malacological focus, such as the expeditions of Theodor A. Verkrüzen starting 1871 to Newfoundland and

northern Norway (1874, 1876), the 1894 Moluccas expedition of Willy Georg Kükenthal (1861–1922) and the journey of Hugo Merton (1879–1940) to the Aru and Kei Islands (1908), from which numerous new species were described. The marine molluscs of the Hanseatic South Sea Expedition (1909), in which the Senckenberg custodian E. Wolf participated, as well as those of Merton's expedition were worked up by Caesar-Rudolf Boettger (1888–1976) in the years 1915 and 1916 (Boettger 1915, 1916). All these species are still part of the malacological collection. In the following decades of the last century, less attention was paid to the marine molluscs. However, the treatment of the gastropods for the handbook of palaeozoology by Wilhelm Wenz (1886–1945) and Adolf Zilch (1911–2006) is outstanding and for decades remained the only compilation of all genera of recent gastropods (Wenz 1938–1944, Zilch 1959–1960). Marine malacology received a new impetus when in the 1960s Senckenberg researchers studied the material obtained by the expeditions of the research vessel *Meteor* and marine research at Senckenberg gained new significance (see chapter 5). Gotthard Richter (retired 1989) was the first who devoted himself to the taxonomy of planktonic molluscs at Senckenberg, especially the Atlantidae, and the ontogeny and larval development of marine gastropods (e.g. Richter 1961, 1974, 1993, Richter and Thorson 1975). In 1978 and 1979, the Senckenberg Research Institute organised expeditions to the Cape Verde Archipelago (Cosel 1982) and from 1977 onwards expeditions of the research vessels *Sonne*, *Valdivia* and *Meteor*, as well as participation in various projects in the Arabian region brought rich material from those regions to Frankfurt. In 1977, Ronald Janssen became head of the malacological section and since then he studies and publishes on recent molluscs, mainly from the Arabian seas and hydrothermal biotopes (e.g. Janssen and Taviani 2015; Krylova and Janssen 2006). One highlight of his work (Janssen 1993) was the re-discovery of the types of Wilhelm B. R. H. Dunker's work on the marine molluscan fauna from Japan (Dunker 1859, 1861). Currently, the Malacology section is involved in the Red Sea Biodiversity Project.

Ichthyology

Since Eduard Rüppell, Senckenberg's first curator of fishes, ichthyological research focuses on the seas surrounding the Arabian Peninsula. In 1817, Rüppell visited the region for the first time and subsequently published the first comprehensive monographs of Red Sea fishes, describing 320 species, of which almost 100 were new to science (Rüppell 1828–1830, 1835–1838) (Fig. 2c holotype of *Cheilinus undulatus* collected by Eduard Rüppell).

Wolfgang Klausewitz (born 1922), curator of ichthyology from 1954 to 1987, contributed significantly to our knowledge of taxonomy, systematics and biogeography of Red Sea fishes. In 1957–1958, he participated in the legendary *Xarifa* research cruise to the Red Sea and southern Asia led by Hans Hass, where he introduced SCUBA diving to ichthyological research and for the first time described and figured reef fish assemblages in their natural habitat along reef transects (Figs 1f and 3c). Later, several expeditions with RV Meteor to the Red Sea and Indian Ocean further enlarged the fish collections first laid by Eduard Rüppell.

Since Klausewitz, conservation is an additional research focus. From 1991 to 1996, following the first Gulf War, which resulted in the largest oil spill in history, Senckenberg curator Friedhelm Krupp led a multinational, multidisciplinary EU-funded team of about 80 marine scientists, who studied the effects of the oil spill on marine ecosystems and species, developed methods to restore the affected coastline to pre-war conditions and established a 2300 km^2 Marine Protected Area (Krupp et al. 1996).

Between 1997 and 2002, Krupp took the lead in an UN-funded project, studying the marine biodiversity and fisheries of Socotra, the second largest island of the Western Indian Ocean. Project activities included satellite mapping of all coastal and shallow marine habitats, biodiversity inventories, fish population studies and socio-economic surveys. The number of fish species known from Socotra increased from 57 before the project to >730 today, with similar increase in our knowledge of marine invertebrate diversity. Based on the research output, UNESCO declared Socotra a Man & Biosphere Reserve and a Natural World Heritage Site, the first and only one in the Arabian Peninsula (Zajonz et al. 2016).

A monograph with detailed descriptions of all fish species occurring in the Red Sea above 200 m water depth has recently been compiled (Randall et al. in press).

Marine biology at "Senckenberg am Meer" in Wilhelmshaven

The marine station "Senckenberg am Meer" (SAM) in Wilhelmshaven was founded in 1928 by Rudolf Richter (1881–1957). It was the first field station worldwide for the study of recent geological and palaeontological processes aiming for a better understanding of the fossil record. After World War II, actuopalontology and actuogeology developed as attractive topics to study the "animal–sediment relationship" (Sanders 1958; Schäfer 1962; Reineck and Singh 1973), and SAM became a well-reputed institute for marine research and a technical platform for student training.

In 1970, during the main personal and scientific expansion of the marine station, systematic zoology became included in the portfolio of SAM with Jürgen Dörjes becoming the head

of the Marine Biology section. His research focused on the diversity of meiofauna and macrofauna communities of depositional systems in the Wadden Sea and the North Sea as well as in Mediterranean, US and Taiwanese coastal systems. In 1970, he started to study the epifauna community in the Jade Bight and in 1978, the infauna community off the island of Norderney on monthly scale (Dörjes et al. 1986; Dörjes 1992a, b). Both long-term studies were maintained by Ingrid Kröncke, who became head of the Marine Biology section in 1992. She established four additional long-term studies on infauna as well as epifauna on large spatial scale covering the southeastern North Sea, the Dogger Bank and several "boxes" in the entire North Sea, which are sampled on seasonal or annual scale. Today, all long-term studies are compiled as Senckenberg's LTER (Long-term ecological research) North Sea Benthos Observatory (Fig. 4).

LTER is essential for the understanding of the natural variability of species composition, dominance structure and functional diversity of marine communities. Only LTER allows disentangling effects of natural environmental and climate drivers from those caused by human activities. These long-term data revealed climate-driven changes in the biodiversity of in- and epifauna communities of the southeastern North Sea. For instance, increases in the abundance of warm-temperate species and decreases in abundances of cold-temperate species were observed (Kröncke 2011, Kröncke et al. 2013a, b, Schückel and Kröncke 2013, Meyer et al. 2016). Changes in traits and benthic food webs could also be addressed to increase in North Sea sea-surface temperature (Neumann et al. 2016, Weinelt et al. 2016). The data on large spatial scale were used to draw maps for the present spatial distribution of in- and epifauna communities in the southeastern North Sea, also using habitat model approaches (Kröncke et al. 2011; Neumann et al. 2017). Combined benthic and hydroaustic approaches, as well as species distribution model approaches allowed full coverage distribution analyses of benthic communities as well as predictions for future distribution (2050 or 2100) of benthic species in the Jade Bight or North Sea (Singer et al. 2016; Holler et al. 2017; Gutperlet et al. 2016; Neumann et al. 2016, 2017). The species-distribution model predicted that 65% of the modelled North Sea in- and epifauna species will shift their ranges northwards until 2100 due to increasing bottom water temperature (Weinert et al. 2016; Singer et al. 2016). The LTER North Sea Benthos Observatory, whose data contributed to many joint projects, is a collaborative project with most of the North Sea and Baltic Sea marine research institutes contributing; it received funding from EU, BMBF, DFG, VW Foundation among others. Additionally, the Marine Biology section participated also in the DIVA (**DIV**ersity of the **A**byssal Atlantic) expeditions in the southeastern Atlantic deep-sea and the LEVAR (Levantine Basin Biodiversity Variability) expedition in the eastern Mediterranean deep sea. There, the diversity of infauna communities was studied on higher taxonomic level in relation to environmental parameters such as food supply and sediments (Kröncke and Türkay 2003; Kröncke et al. 2003, 2013a, b).

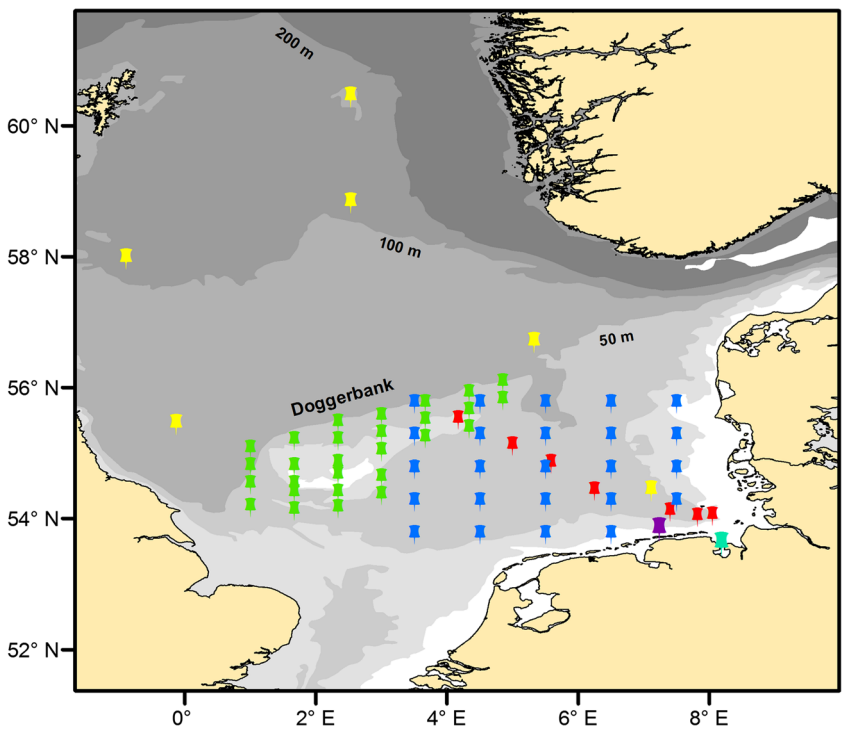


Fig. 4 Senckenberg's LTER North Sea Benthos Observatory

Polychaeta: section marine invertebrates II

While Crustacea and Mollusca are among the oldest sections at Senckenberg, it was only in 1966 and 1971 that two additional curator positions were assigned to the large number of other marine invertebrate taxa. From 1971 to 1989, the section "Marine Invertebrates II" with its first head Gotthard Richter focused on marine planktonic molluscs. In 1990, Dieter Fiege became the new head, and the section took over responsibility for the collections of Echinodermata and "worms" comprising important specimens from the German Deep-Sea Expedition (1898–1899), the Red Sea and Indonesia, as well as significant collections of Plathelminthes from South America and Annelida from worldwide collections. Research is currently focused on the systematics and diversity of Polychaeta — a dominant faunal element in many marine habitats.

Like for other marine taxa, the foundations of Senckenberg's marine invertebrate collections were laid by Eduard Rüppell. In the early nineteenth century, he travelled to Egypt, the Sinai Peninsula and along the Red Sea and returned with the first polychaete worms to Frankfurt. The first polychaete described from this material is the acoetid *Polyodontes gulo* (Grube, 1855) (Fig. 2d). Senckenberg's collection of polychaetes has grown substantially since 1990 based on numerous research projects and participation in expeditions in both hemispheres covering coastal areas to the deep-sea. Currently the collection comprises about 20.000 digitally catalogued lots of species from all over the world including over 100 name-bearing types, as well as several thousand lots of unidentified specimens from all oceans awaiting identification and description of hitherto unknown species. With regard to numbers of specimens and taxa, the collections from the North Sea, Mediterranean Sea, Red Sea, Persian Gulf and South China Sea are of international importance. Taxonomic groups best represented are the Aphroditoidea (scale worms), Glyceridae, Eunicida, Terebellomorpha, and Serpulidae. The collection's international significance is strengthened by the deposition of the unique collection of Serpulidae identified by Helmut Zibrowius (Marseille) and more recently by the collection of Wilfried Westheide (Osnabrück). Covering all aspects of polychaete research, the section library is an important tool with more than 15,000 references at hand including the libraries of Gesa Hartmann-Schröder (Hamburg) and Volker Storch (Heidelberg). Likewise, Gesa Hartmann-Schröder's comprehensive catalogue of polychaete taxa is kept up to date in the section.

Highlights of the research are a series of revisions of the Aphroditiformia (scale worms) covering the Arabian Peninsula, the Northeast Atlantic, and the Mediterranean Sea (e.g., Barnich and Fiege 2003, 2009; Wehe 2006, 2007; Núñez et al. 2015a, b). Research focused also on the Serpulidae, Magelonidae, and a worldwide revision of the Glyceridae (Böggemann 2002). A revision and phylogeny of the Polygordiidae includes also molecular techniques (Lehmacher et al. 2016) and a scientifically very fruitful collaboration on the Japanese fauna of the Ampharetidae led to the description of 24 new taxa, all well illustrated by the skilful drawings of the late Minoru Imajima (Tokyo) (Imajima et al. 2012, 2013; Reuscher et al. 2015a, b). The collection of deep-sea polychaetes during participation in a cruise with RV *Meteor* (Expedition DIVA I) to the deep eastern South Atlantic resulted in the analysis of biodiversity and distributional patterns of Polychaeta in the deep South Atlantic (Fiege et al. 2010). It will serve as a base for an upcoming comparison with more recent collections from the deep Pacific. Recent research on the Polygordiidae and Sternaspidae led to contributions to the online edition of the Handbook of Zoology (Ramey-Balci et al. 2013; Fiege 2016). To date, altogether seven genera including 67 species have been described. Last but not least, a special exhibition "Bristle worms – dazzling inhabitants of the Sea" was created for the first time and presented at the Senckenberg Museum and several other German museums, as well as in Luxembourg in order to introduce these colourful and diverse animals to the general public (Barnich and Fiege 2000).

Bryozoa: section marine invertebrates III

Bryozoa, a phylum described in 1831 by the corresponding member of the Senckenberg Society, Christian Gottfried Ehrenberg (1795–1876), on the basis of collections off the Egyptian coast, represent the last major phylum of calcifying invertebrates to appear in the fossil record after the Cambrian explosion (McKinney and Jackson 1989). Likewise, they were last to enter Senckenberg collections as a section (aside from sponges) (Fig. 2f). Eduard Rüppell, who collected nearly every biological object available to him during his expeditions to Arabia and North Africa (including corals, sponges and ascidians) overlooked bryozoans. This is somewhat puzzling and may or may not be a result of his ambivalent relationship to Ehrenberg. Bryozoan research at the Senckenberg started as late as 1999 when the respective research section was founded under the name Marine Invertebrates III, on the grounds of one of the most significant donations the Senckenberg society ever received from one single person: The collection of Late Cretaceous and Cainozoic bryozoans of Ehrhard Voigt (1905–2004) from the University of Hamburg.

Voigt was a geoscientist. He became an appointed professor and executive director of the State Department of Geology at the University of Hamburg in 1939 and served these functions until his retirement in 1975. He was a member of the German Academy of Sciences (Leopoldina) and of several geoscientific societies and made major contributions in reconstructing and shaping geoscientific research after World War II. Voigt's main research areas were the study of glacial drifts and of fossil Bryozoa from the Late Cretaceous and the

Early Palaeogene. This group of colonial, predominantly marine invertebrates is one of the most common fossils found in Chalk sediments of Europe and Central Asia. Voigt began his studies on bryozoans already as a young teenager after finding his first fossil Bryozoa in his parents' garden. His passion and commitment for fossil bryozoans are peerless. As a pupil, Voigt wrote his first publications on Bryozoa (e.g. Voigt 1924). After his first collection was completely destroyed in 1943, Voigt re-built a new collection that is one of the most comprehensive fossil collections ever collected by a single researcher (Martha 2014). It comprises about 300,000 samples of Bryozoa, mainly from the Late Cretaceous and the Palaeocene of Western and Northern Europe. Voigt studied material from this collection until his death, the last first-author publication being authored at the age of 94 years. After Voigt's death, the bryozoan collection, as well as his literary remains (correspondence, manuscripts, notes, file cards and others) were bequeathed to Senckenberg by testamentary will and moved from Hamburg to Frankfurt. The bryozoan collection of Voigt is of invaluable importance for bryozoan research and temperate carbonates in a greenhouse world. Over 20,000 specimens (approximately 7.5%) of Voigt's bryozoan collection were recently digitised and a catalogue illustrating over 250 types from the Voigt collection was produced within a DFG project.

Immediately after the bryozoan section had been founded at Senckenberg, Heinrich Ristedt (1936–2017), then palaeontologist at the University of Bonn, donated his bryozoan collection to the Senckenberg, comprising about 15,000 objects (meanwhile 80% of them digitised) and covering a considerable geographical range mostly from the Indo-Pacific realm, including the Mediterranean and also Antarctic specimens. Expanding the Ristedt collection, a central focus in the section's activities under lead of Joachim Scholz have been conducted in Japan (e.g. Kaselowsky 2004; Kaselowsky et al. 2005; Gerdes et al. 2005; Spencer Jones et al. 2011). Later, research was conducted in various museums, keeping collections from the North Sea (Bitschofsky et al. 2011; Bitschofsky 2013), and this will be continued. Some recent activities are aiming towards the understanding of internal skeletal structures of bryozoans, using advanced techniques such as EBSD (Benedix et al. 2016) and MicroCT (Fedorov et al. 2017), in collaboration with, for instance, the Zoological State Collection in Munich and the Macquarie University in Sydney.

Porifera and Cnidaria: section marine invertebrates I

To date, the collections of Marine Evertebrates I comprise 16,987 electronically catalogued series (10,611 Cnidaria, 4916 Porifera, 867 Tunicata and 93 Ctenophora, according to SeSam October 2017). Internationally significant is especially the collection of Cnidaria.

Some of the first cnidarians and sponges partly described by K. G. F. Rudolf Leuckart (1822–1898) in the nineteenth century had been already collected by Eduard Rüppell during his expeditions to the Mediterranean and Red seas. In 1886, with support from Senckenberg, the famous zoologist Willy Kükenthal participated in an expedition to the South China Sea and the Moluccas, expanding the Senckenberg collections to 177 series, almost exclusively types of cnidarians and especially sponges, which were mostly described by Johannes Thiele (1860–1935). Investigation of the deep sea started in 1898–99 with the first German deep-sea expedition (*Valdivia* Expedition), in which also the Senckenberg Research Institute participated. The expedition leader was the Frankfurt zoologist Carl Friedrich Chun (1852–1914), a friend and corresponding member of the Senckenberg Natural History Society, who brought important historical collections of cnidarians, tunicates and sponges to the Senckenberg Research Institute. From this expedition, a syntype of a very spectacular glass-sponge species with a giant root spicule is described: *Monorhaphis chuni* Schulze, 1904. The foundation of SAM in Wilhelmshaven by Rudolf Richter (1883–1962) in 1928 was the beginning of Senckenberg's still ongoing long-term ecological studies in the German sector of the North Sea. One of the main research areas is the Doggerbank, from which our collection contains numerous sponges, partly identified and published from more than 30 years of regular monitoring.

In 1964, Wilhelm Schäfer took part in the maiden journey of RV *Meteor* to the Red Sea (International Indian Ocean Expedition), where he studied subfossil coral reefs in raised terraces on the Farasan islands in the southern Red Sea. Another Member of the group on Farasan islands was Wolfgang Klausewitz who investigated the recent fish fauna around the archipelago. Later, Michael Türkay carried out expeditions on a regularly basis to the Mediterranean and the Red Sea, from where the collections, over the years, have received rich material of corals and sponges most of which is still under investigation using morphological and molecular methods.

In 1966, soon after Wilhelm Schäfer (1961–1978) had been appointed as director of Senckenberg Research Institute and Natural History Museum in Frankfurt, the section Marine Invertebrates became established, with Manfred Grasshoff as its first curator. In 1967, Grasshoff took part in the first East Atlantic seamounts expedition with RV *Meteor*. In 1975, he participated in the RV *Meteor* Northwest African upwelling program together with a young assistant, Michael Türkay. Later on, he took part in an expedition by the French research vessel *Marion Dufresne* to the southern part of the Indian Ocean ridge. Grasshoff specialised on Octocorallia (Fig. 2e), and during his more than 30 years of intensive research at Senckenberg he identified and partly described more than

1200 octocorals, many of which became part of and enhanced the significance of Senckenberg's Cnidaria collection, as well as those in Paris among others.

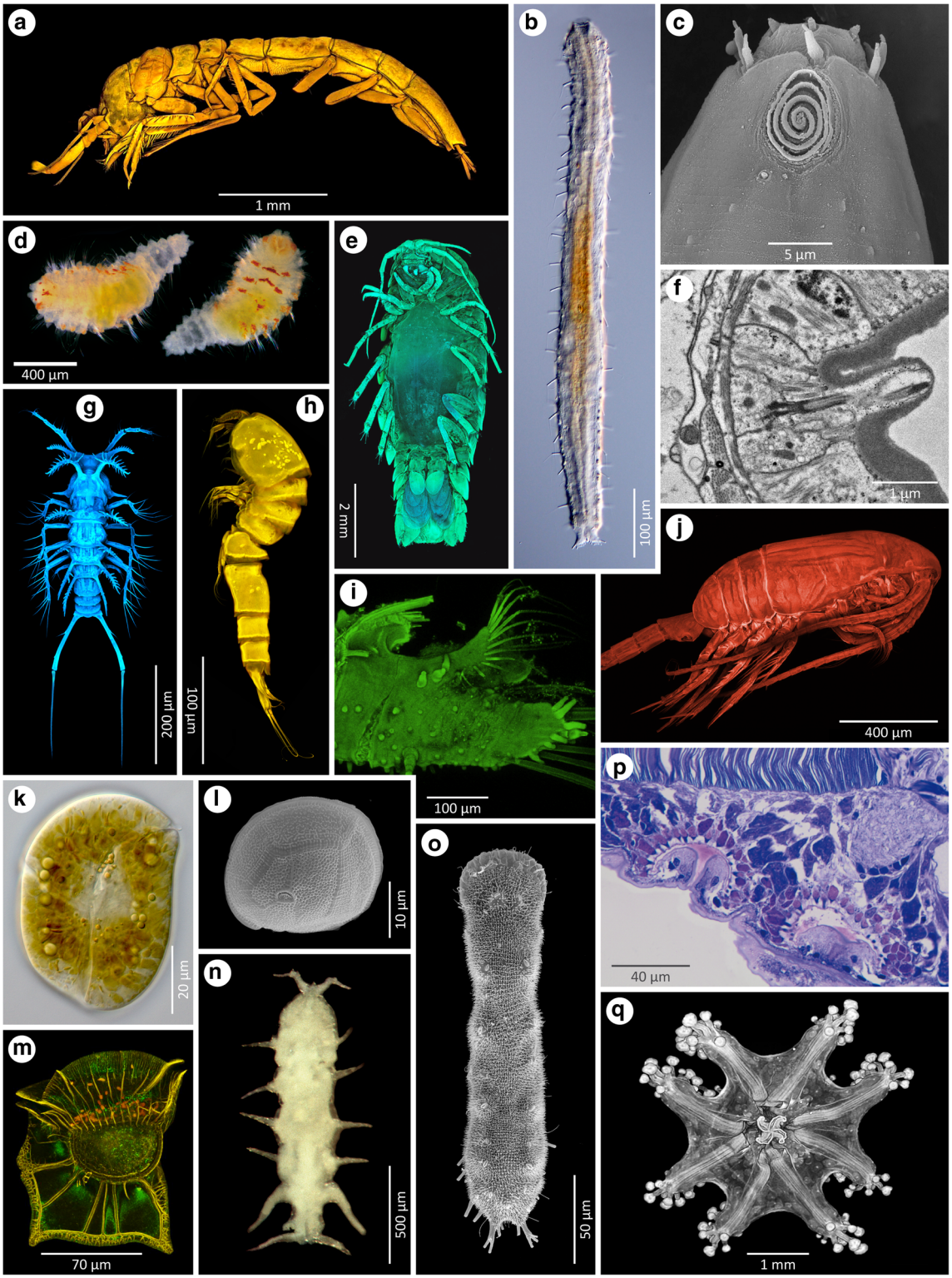
In 2001, Dorte Janussen took over the section Marine Invertebrates I and introduced the Porifera research at Senckenberg with focus on deep-sea and polar sponges (Göcke and Janussen 2013). From 2002—2008, she was involved in the Antarctic Deep-Sea Biodiversity (ANDEEP) and Pelago-Benthic System Coupling (SYSTCO) projects under leadership of Angelika Brandt, which brought important new insights in the hitherto barely studied deep-sea basins of the Antarctic Weddell Sea. Later, expeditions with RV *Polarstern* focused on the disintegrating shelf-ice shelves at the Antarctic Peninsula and re-colonisation of iceberg scars by sponges and other benthic animals, a research topic highly significant for the assessment of ecological implications in case of continuing global warming and reduction of the polar ice caps. Together with Pedro Martinez (DZMB) and others, Janussen is currently involved in research projects on deep-sea sponges focussing on the biodiversity of manganese nodule fields in the Central Pacific Clarion Clipperton Fracture Zone. Her main concerns are the ecological role and significance of sponges, as well as their cultural heritage as a source of inspiration for human technology, art and design.

The German centre of marine biodiversity research (DZMB)

In 2001, the DZMB was established as a second department of "Senckenberg am Meer". Preceding persistent activities of the marine zoologists Horst Kurt Schminke, Michael Türkay, Johann-Wolfgang Wägele, and Angelika Brandt resulted in approval of their idea to build a central scientific service facility dedicated to the management of biological samples of German maritime expeditions (George et al. 2016). The German Science Council finally recommended the foundation of the DZMB [originating from the former taxonomic workgroup (TAG) of the Biologische Anstalt Helgoland (BAH)] and its integration as a department of the Senckenberg Research Institute and Natural History Museum with two locations, one in Wilhelmshaven and one in Hamburg. The original task of the DZMB was the management of marine expeditions, provision of necessary infrastructure (sampling gears, storage capacity, appropriate lab facilities and equipment, technical, regulatory and scientific knowledge) and the realisation of comprehensive technical, as well as scientific processing of the numerous marine biological samples. Apart from this core business, the scientific spectrum of the DZMB has expanded considerably during the past decade and covers diversity, distribution and evolution of marine organisms. The concept of the DZMB is currently realised as a combination of scientific service, science, and applied research. These tasks closely connect and bridge the Marine Zoology departments and working groups at Senckenberg including the DZMB and influence future developments as outlined below. In addition, the new section "Marine Botany" opened in 2008 at the DZMB with the main focus laid on marine phytoplankton. The collection houses the world's largest Dinophyta type collection with about 60 types.

Taxonomy and biodiversity research The DZMB houses taxonomic experts for several marine groups. The rich and numerous biological samples of the expedition programs (Tab. 1, electronic supplement) yield material for the erection of eight new families, 31 new genera, 338 new species and at least 59 re-described taxa of eukaryotic marine organisms that were described by scientists of the DZMB and other German institutes (e.g., Zoological Museum Hamburg) since 2001 in the framework of the CoML (Census of the Marine Life), an international mega-project involving more than 2000 researchers from 80 nations, with the CeDAMar (Census of the Diversity of Abyssal Marine Life) project. Taxonomic and integrative taxonomic studies, investigations with an evolutionary-systematic focus and surveys on marine diversity and ecology span a wide systematic range from unicellular and multicellular clades (Fig. 5). The current taxonomic coverage of the DZMB includes, but is not limited to, the Dinophyta (e.g., Adl et al. 2012; Hoppenrath 2017; Hoppenrath et al. 2014, 2017; Kretzschmar et al. 2017; Zinßmeister et al. 2017), Cnidaria (e.g., Holst et al. 2016; Laakmann and Holst 2014; Holst and Laakmann 2014), Gastrotricha (e.g., Hochberg et al. 2014; Kieneke et al. 2015; Kieneke and Nikoukar 2017; Rothe et al. 2011), Nematoda (e.g., Miljutina and Miljutin 2012, 2015), Kinorhyncha (e.g.,

Fig. 5 A brief glimpse on the taxa studied by scientists of the DZMB. A ▶ Lateral view of *Ketosoma ruehlemanni* (Isopoda). B Ventral view of *Turbanella hyalina* (Gastrotricha). C Anterior end of *Paracanthonchus mamubiae* (Nematoda) with spiral amphids (sensory organs). D *Glandulospio orestes* (Polychaeta). Left: dorsal view, right: ventral view. E Ventral view of *Lucayalana troglexuma* (Isopoda). F Cross section of a pharyngeal ciliary receptor cell of *Neodasys chaetonotoideus* (Gastrotricha). G Dorsal view of *Dendropsyllus* sp. H Lateral view of *Emertonia andeep* (G-H: Harpacticoida). I Parapodium of *Pholoe longa* (Polychaeta). J Lateral view of *Pseudocalanus elongatus* (Calanoida). K Sand-dwelling dinoflagellate *Togula britann*ica. L Toxic dinoflagellate *Gambierdiscus lapillus*. M Pelagic dinoflagellate *Ornithocercus quadratus* (K-M: Dinophyta). N Ectoparasitic copepod *Abyssotaurus vermiambatus* (Cyclopoida). O Dorsal view of *Tetranchyroderma suecicum* (Gastrotricha). P Cross section of ventral epidermal glands of *Microspio granulata* (Polychaeta). Q Oral view of the stauromedusa *Craterolophus convolvulus* (Cnidaria). A, E, G-J, M: Maximum intensity projections of confocal image stacks of stained specimens (false colours). B, K: Light microscopic images (differential interference contrast). C, L, O: Scanning electron microscope images. F: Transmission electron microscope image. N: Light microscopic image (dark field illumination). P: Semithin cross-section viewed with light microscopy. Q: Volume rendering of a μCT-dataset



Ostmann et al. 2012), Polychaeta (e.g., Meißner and Götting 2015; Meißner et al. 2014, 2016), Halacarida (e.g., Bartsch 2003, 2004), harpacticoid Copepoda (e.g., Candás et al. 2013; George 2017; George and Gheerardyn 2015; George et al. 2014; Gheerardyn and Veit-Köhler 2009; Veit-Köhler 2004; Veit-Köhler et al. 2013), calanoid Copepoda (e.g., Markhaseva et al. 2008; Renz and Markhaseva 2015), cyclopoid Copepoda (e.g., Brenke et al. 2017; Martínez Arbizu 2006), Tantulocarida (e.g., Martínez Arbizu and Petrunina 2017; Mohrbeck et al. 2010), Cumacea (e.g., Mühlenhardt-Siegel 2005a, b, c), and Isopoda (e.g., Brix et al. 2014a; Bruce et al. 2017; Kaiser et al. 2017).

Deep sea One of the major concerns of the DZMB is the exploration of biodiversity, structure, and ecological demands of abyssal communities, or their genetic connectivity across underwater topographic structures on the abyssal plains in the world oceans. Basis for this research is the material obtained during major expedition programs across the Atlantic Ocean and adjacent seas such as ANDEEP, DIVA, LEVAR, or IceAGE (e.g., Brandt et al. 2007; Brix et al. 2014b; George and Brökeland 2009, Martinez Arbizu and Brix 2008: Tab. 1, electronic supplement, Fig. 6).

Seamounts Several DZMB-attended and organised expeditions of the last years enabled sampling on diverse seamounts and oceanic archipelagos of the northern subtropical Atlantic Ocean and the eastern Mediterranean Sea such as OASIS, DIVA-3, POS384, M71/1, M79/3, M83/2, MSM14/1, GROMET, MAPS, and PS101 (see supplementary Table 1) in order to test the potential importance of seamounts for the long-distance dispersal of meio- (George 2013) and macrofauna (e.g., Meißner et al. 2014).

The sailors

The 200-year history of the Senckenberg Society is subdivided in two periods of more or less equal length and considerable overlap in time. Within the first century, acquisition of collections was the result of the genuine interests and ambitions of self-educated citizen scientists. They acted on their own, although coordinating their expeditions with the directors of the society.

Most of the early researchers where physicians like Cretzschmar, or merchants like Rüppell, they were self-funded and proud of it. Frankfurt was one of only four imperial cities to survive the Napoleonic wars with its sovereignty intact, and the Senckenberg collections were considered to be the patriotic effort of the citizens of Frankfurt (Sakurai 2013).

The second half of Senckenberg's existence belonged to a different and larger world, and changes correlate with a rising spirit of national unity. This was very much the case in 1865 during an assemblage meeting of geographers from the various German states ("Versammlung Deutscher Meister und Freunde der Erdkunde") in Frankfurt, with Rüppell attending. The participants suggested coordinated efforts of German states in the exploration of (1) Africa, (2) the Arctic and (3) the Oceans in general (Runge 2015). The age of the great autodidacts slowly faded and when Rüppell died in 1884, very few attended his funeral. As for marine research, Senckenberg scientists became an integrated part of naval expeditions shared by many institutions. Among these countless voyages, which cannot all be referred to as in recent years many expeditions with the RVs *Meteor*, *Sonne*, *Polarstern* and others have been performed by Senckenberg scientists, three historical ones are selected here as examples.

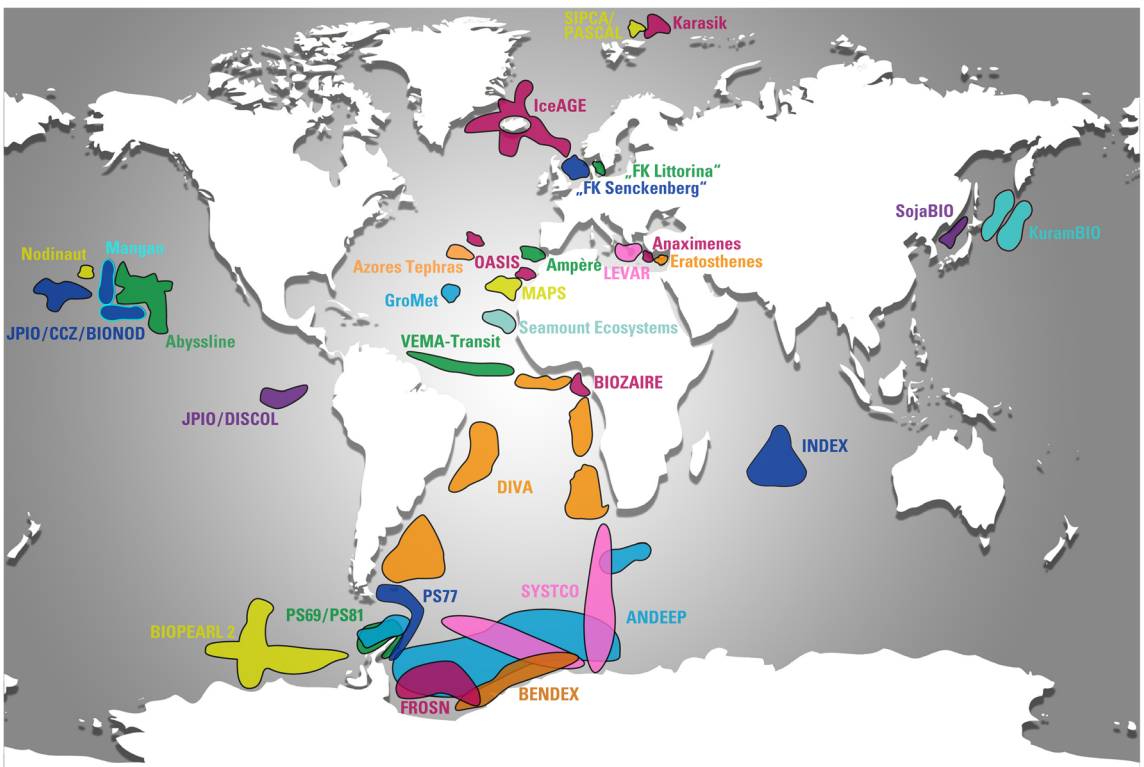


Fig. 6 Main operational areas of scientists and technicians of the German Centre for Marine Biodiversity Research (DZMB) led expeditions (see supplementary Table 1 for details)

In 1898/99, the Helgoland Expedition, named after the research vessel, explored the Barents Sea, Spitzbergen, and Bear Island (Berger 2007). The research team was led by Fritz Römer (1866–1909) (Fig. 1d), who became curator at Senckenberg in 1900 and director in 1907. He was the first Senckenberg staff member to be paid a salary on a regular base. The expedition itself was initiated and organised by Theodor Lerner (1866—1931), a multi-talent and adventurer. He died in Frankfurt, and parts of his estate are housed in the archive of the Senckenberg Society.

Likewise in 1898–99, the German *Valdivia* Expedition with the RV was to change the course of marine zoology at the Senckenberg Research Institute. The *Valdivia* Expedition was the first German expedition to explore the deep sea and organised by Carl Chun (1852–1914), who was born in Höchst am Main near Frankfurt. Chun became deeply influenced by the Senckenberg Society in his childhood. With the *Valdivia* Expedition he focused on the Eastern Atlantic, as well as the Southern and Indian oceans. During this voyage, photographs were taken by Fritz Winter (1878–1917), the son of Wilhelm Winter (1844–1900), who was director of the Senckenberg Museum from 1892 to 1894. Otto zur Strassen (1869–1961) (Fig. 1e), who succeeded Fritz Römer as director of the Senckenberg Society in 1909, was a member of the scientific crew (for further details, see Palla 2016, Martha et al. in press).

Finally, in 1957–1958, the second *Xarifa* Expedition, organised and funded by the Austrian diving pioneer Hans Hass (1919–2013) (Fig. 1f), explored reef habitats in the Red Sea and the Indian Ocean. During this expedition, Wolfgang Klausewitz (born 1922), head of the fish section from 1954 to 1987, studied the biology and taxonomy of fishes (Klausewitz 2009).

All three expeditions represent the advances of Senckenberg's marine zoology from the home base at Frankfurt perspective into three international field areas of marine research: The polar realms, the deep sea and the tropical seas with the Red Sea as top research priority. All these areas are still in the focus of the present-day marine research at Senckenberg and many of these expeditions of the recent past were organised by the DZMB or the Zoological Museum Hamburg (by Brandt).

Future horizons

Senckenberg in the digital world

Senckenberg developed its own open-access database as a collection management system, Senckenberg Sammlungen (SeSam) in order to increase the publicity use and availability of the collections to the scientific community and the public. SeSam currently contains about 6% digitalized geographic records of the total collection (Türkay et al. 2011). A new database is currently under development, AQUiLA, and a new search portal (https://search.senckenberg.de/aquila-public-search/) has already been launched enabling simultaneous full-text search in all collections. Data available in SeSam/AQUiLA are linked to GBIF and the Ocean Biogeographic Information System (OBIS) enabling users to extract all the information for each species and also to create species distribution maps and biogeographic studies.

So far a total of 21,459 distribution records from all marine collections belonging to 3081 taxa, 2466 species, 93 orders, 28 classes and 10 phyla of marine organisms have been submitted to the OBIS (Ocean Biogeographic Information System) through the EurOBIS node. Considering all distribution records, 97% of the taxa matched the accepted taxa in WoRMS (World Register of Marine Species) and 99% were lower than the family level. The geographic extension of the available data had a worldwide coverage (Latitude −77.730 to 88.781; Longitude −177.733 to 179.000). European waters, the Gulf of Aden, and Antarctic waters (from −30° to −85° Longitude) have the highest number of distribution records and species richness reported by the Senckenberg Research Institute and Natural History Museum (Fig. 7).

Service: expeditions and sample management

Since its foundation, the staff members of the DZMB contributed to 62 major expeditions (16 in its own management, participation in a further 46, see Supplementary Tables 1, 2 in the electronic supplement). These campaigns yielded a total amount of 8764 sorted samples from 46 expeditions. More than 6.1 million specimens were identified to higher taxon level (Tab. 2, electronic supplement). Of those, more than 1.3 million specimens were further processed and are available on request via the Meteor material archive. About 338,000 specimens identified to family or higher taxon level are handed over to experts as loan, and almost 163,000 specimens were achieved in "final storage" in different museum collections (www.material-archiv.de/en/repository). The Centre of Excellence for Dinophyte Taxonomy (CEDiT) was founded in July 2005 as a scientific service unit. It provides online taxonomic information and aids for the identification of taxa (http://www.dinophyta.org).

Applied research: monitoring of biotopes under anthropogenic impact

Manganese nodule areas and hydrothermal vent sites The abyssal Central Pacific between the Clarion and Clipperton Fracture Zones (CCZ) is an area prospected for deep-sea mining because of the high abundance of polymetallic nodules on the deep seafloor. The raised interest in the exploitation of this area raises questions on the impact on the mostly unknown resident fauna. Assessing species diversity and determining processes underlying current species distributions are

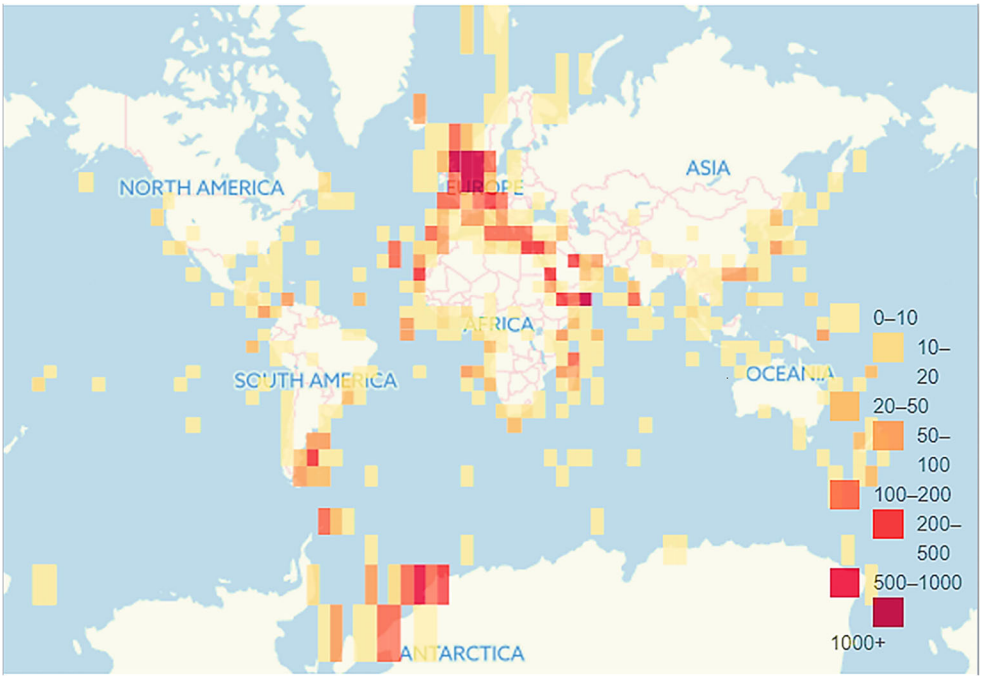


Fig. 7 The number of distribution records per each 1-degree latitude-longitude cell extracted from the Senckenberg collection management system (SeSam) dataset into EurOBIS, the map has been created using data mapper in OBIS website

prerequisites for a sustainable conservation planning and prediction of faunal responses to mining activities. Since 2004, the DZMB participated in several cruises to the CCZ in order to deliver this badly needed knowledge base (expeditions Nodinaut 2004, Mangan 2010, 2013, 2014, 2017, BioNod 2012, FLUM2015, JPIO 2016, see Fig. 6 Supplementary Table 1) and Indian Ocean (INDEX). Mining of manganese nodules is expected to begin within the next one or two decades, thus, a rapid characterisation of the nodule fauna is required (Janssen et al. 2015; Gollner et al. 2017).

Helgoland zooplankton time series A time series monitoring zooplankton diversity and abundance at Helgoland Roads (54° 11' N, 7° 54′ E) is conducted in cooperation between the Alfred Wegener Institute and the DZMB. The frequent sampling (three times per week) started in 1974 and enables detailed analyses of plankton population dynamics over decades. This rich and still growing database allows comprehensive analyses on ecosystem states and changes. Impacts of climate or human activities on marine communities can thereby be monitored and assessed (e.g., Boersma et al. 2015; Greve et al. 2004). The Helgoland Roads zooplankton time series is included in different international initiatives, such as the International Group for Marine Ecological Time Series, which seeks to integrate a suite of time-series stations in order to gain a holistic view on changes within different ocean regions. Furthermore, it contributes to the Zooplankton Status Report (e.g., O'Brien et al. 2013), a comparative analysis of zooplankton time series from national monitoring programs in the ICES (International Council for the Exploration of the Sea).

The future role of the Senckenberg research institute in marine research and the Anthropocene

As archives of biodiversity that comprise the name-bearing types as well as reference collections, natural history museums such as Senckenberg represent the essential and sustainable fundament of all biological research.

In the Anthropocene, nature is altered through fisheries, waste disposal and oil drilling, and anthropogenic induced climate change is proceeding at an alarming and accelerating rate. In this decade, large-scale mining activities will occur in depths down to the abyss (Vanreusel et al. 2016). These activities bear the prospect of a decreasing biodiversity with consequences for mankind ultimately unknown. For the conservation of our natural environment, ecological and evolutionary relationships need to be studied. Therefore, collections of biological objects like those housed by the Senckenberg play a pivotal role.

Probably one of the most prominent current problems is climate change triggering an increase in the average sea-surface temperature (Collins et al. 2013). Ocean warming will result in the reduction of dissolved oxygen altering marine ecosystems. The variety of resulting stressors is expected to reduce the upper ocean's metabolic index by about 20% globally and by *c.* 50% in northern high-latitude regions, forcing poleward and vertical contraction of metabolically viable habitats and species ranges in this century (Deutsch et al. 2015). This will affect the fauna of the continental shelf and upper slope first, but eventually the whole ocean down to the abyss will warm, with projections of up to 0.1 °C per decade on average for the deep oceans (Purkey and Johnson 2012). While latitudinal

range shifts have been already observed for shallow-water marine crustaceans in response to climate change (Neumann et al. 2013), shifts in depth ranges are also likely (Brown and Thatje 2015) and can already be modelled for deep-sea species (see below). Research collections play a vital role in the process of determining such range shifts or habitat changes.

As the only type of institution focussing on the sustainable preservation of specimen collections (biodiversity) and collection-based research, such as taxonomy, natural history museums have the synergistic potential to maintain and develop these unique tasks while embracing the new developments of the future. The full potential of research collections should be used to address the pressing questions of the twenty-first century and beyond. Increasingly complex methodologies are and will be employed in the future as a response to the challenges imposed by complex natural histories and ecologies. Since their foundation, the Senckenberg natural history collections have been used by morphologists, anatomists and taxonomists to investigate evolutionary processes and to describe biological diversity. They continue to be used for this purpose as indeed systematic biology is a discipline rooted in collections (Wen et al. 2015). As biological archives, natural history collections also offer great opportunities for (historical) biogeography, as well as genetic research in taxonomy, conservation, systematics and population biology besides modelling future biogeographic scenarios. They allow assays of past populations, including those of extinct species, giving context to present patterns of genetic variation and direct measures of evolutionary processes (Burrell et al. 2015). These are furthermore integral to mankind's efforts to educate society about biodiversity and conservation (Wen et al. 2015).

Recent advances in DNA sequencing technology have made genomic studies from museum specimens possible (Burrell et al. 2015) promising a deeper understanding of systematics, phylogeny and phylogeography. However, these advances in molecular analyses prompted Senckenberg to establish and to develop infrastructure to archive tissue or DNA samples (e.g., tissue collections in Dresden and Frankfurt) from newly collected specimens. For example, from 2010 to 2016, the BMBF-funded (German Federal Ministry for Education and Research) junior research working group "Molecular Taxonomy of Marine Organisms" promoted the development and integration of new methods such as Next-Generation-Sequencing, FISH (fluorescence in situ hybridization method), or MALDI-TOF (Matrix-Assisted Laser Desorption/Ionisation Time-of-Flight mass spectrometry) for taxonomic purposes (e.g., Hofmann et al. 2015; Laakmann et al. 2013; Mohrbeck et al. 2015). State-of-the-art conservation and analyses of "molecules" (e.g. DNA, RNA and protein) and phenotypes allows integrative research and addresses timely questions. For instance, parallel investigation of morphology and genetic profiles of deep-sea invertebrates allows not only to discover new species, but also to explore their genetics to understand population dynamics and connectivity (e.g., Gollner et al. 2016; Riehl et al. 2017). Understanding deep-sea biodiversity and respective connectivity patterns is of urgent need for conservation issues, for instance in the context of deep-sea mining activities. Furthermore, integrative studies on taxonomy, phenotype and molecules allow the understanding of the evolutionary significance of interspecies hybridization, for example as an evolutionary precondition to colonise habitats under changing environmental conditions (e.g. lowering salinity or ocean acidification) (Stuckas et al. 2017).

Digitalization of the collections, specimens, as well as metadata, is one of the major tasks of the future Senckenberg Research Institute. The increasingly available information about the diversity, taxonomy and historical distributions of species worldwide promises exciting research possibilities from aspects of ecological and evolutionary theory, to applications in conservation, fisheries and human health (Graham et al. 2004). The application of confocal Laser Scanning Microscopy (cLSM) and micro-computed tomography (μCT), for example, allows for the non-destructive digitalization and investigation of the morphology of valuable type specimens (Michels 2007; Faulwetter et al. 2013; Fernández et al. 2014; Brix et al. 2015). Furthermore, non-invasive methods, also for genetic research, will have to be developed. In this context, one of the keys to useful online data continues to be the taxonomic accuracy (Graham et al. 2004). It stresses the fact that taxonomy as a profession remains essential in the future of collection-based research.

Worldwide, natural history museums suffer from a trend of decline in funding and a loss in public and political appreciation for the collections. Nevertheless, these collections are becoming increasingly valuable thanks to newly developed techniques and databases (Kemp 2015). One of the primary tasks to oppose this decline has to be bringing collection-based research back into the spotlight, continue and increase taxonomic effort, further field campaigns, especially to the deep oceans, which are still not well understood.

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Compliance with ethical standards

Ethical approval This article does not contain any studies with animals performed by any of the authors.

Conflict of interest The authors declare that they have no conflict of interest.

Field study Not applicable.

Registration of new species, scientific names, and genetic/genomic data Not applicable.

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