The biology subject group

IB FRIIS AND TOBIAS WANG[1]

The status of biology in the Academy

Today, biology includes a highly diverse range of subjects, which describe, analyze, and develop explanatory models for all empirical knowledge about living organisms. Biology spans the smallest components of life in the form of molecules and the microscopic components of cells; the form and function of individual organisms, which are classified in a taxonomy of different species, genera, families, orders, classes, phyla, and kingdoms; to the interplay of all living organisms in local, regional, or global ecological systems. At the universities, the biological subjects belong to natural sciences faculties, and are primarily concerned with the study of healthy organisms, while the diseases of animals and humans as well as medicines belong to the health sciences faculties, which also carry out research and teaching on healthy organisms, however.

The designation 'biology' is relatively new in the formal structure of the Academy. During the discussions of new by-laws in 1909, it was proposed for the first time to divide the members of the class of the natural sciences and mathematics into subject groups (including zoology, botany, and physiology), but the word 'biology' would not be used in the by-laws until 1916, when the class of the natural sciences and mathematics was divided into two subjects groups: One group was comprised of "the scientists who primarily cultivate subjects derived from the animal and plant kingdom ... this group is designated the biology group. The other group consists of the other members of the class." The Academy's publication series *Biologiske Meddelelser* (Biological communications), which began publication in 1917, marked the arrival of the word 'biology' in the Academy's publications, and *Biologiske Skrifter* (Biological writings) came later.

1. Ib Friis has written about the biological members of the Academy up to World War II and about some subjects up to the present time. Tobias Wang has written about biological members within a group of experimental subjects, which expanded significantly after the World War II.

The Academy's biologists in the earliest period

As a consequence of the encounter with increasing numbers of new plants and animals from outside Europe in the 18th century, there arose a need for taxonomies, which could explain how the many new organisms could be classified. The Swedish medical doctor and natural historian Carl Nilson Linnaeus (ennobled as Carl von Linné) established systematic taxonomies of all of the plant and animal species known at the time.

In the mid-1700s, around the time at which the Academy was founded, the recognition of a need for new botanical and zoological knowledge dawned in Denmark, and some of the earliest members elected were the medical doctors Christian Gottlieb Kratzenstein and Christian Friis Rottbøll, who were influenced by Linnaeus. Many of the Academy's members in the 1700s who were interested in zoology and botany were theologians, medical doctors, or economists, because botany and zoology were not yet independent university subjects. And so the founding of Naturhistorieselskabet (the Society for Natural History) as a private institution in 1789 was a significant event. A number of the members of Royal Danish Academy of Sciences and Letters were active in the society, especially Peter Christian Abildgaard. He was educated as a medical doctor and, as was typically at the time, engaged both in basic research and applied science. During the cattle plague of 1762, he was sent to France by royal decree to study the disease, and he was later instrumental in the establishment of a veterinary college in Copenhagen where he worked together with Erik Viborg, among others. Their scientific works were wide-ranging and touched on a long row of modern scientific fields. Although the Academy was not responsible for the production of the work *Flora Danica*, which began in 1761 by royal decree, all of the project's later scientific participants would become members of the Academy. Martin Vahl became affiliated with the Society for Natural History as a professor, and his contribution was so decisive that the society was disbanded after his death in 1804. Vahl wrote a number of important works of systematic botany, both on the flora of Den-mark, which then included Norway, Schleswig-Holstein, the Faroe Islands and Greenland, and the plant life of distant lands. Danish researchers were interested in both, and it is characteristic that collecting natural objects was an important objective of the scientific expeditions of the period. This also applied to the travels of Eggert Ólafsson and Bjarni Pálsson in

Iceland from 1752 to 1757, which were supervised by the Academy.

Several of the Academy's members produced groundbreaking research across the spectrum of biology in the 18th century. For example, Otto Fabricius (the fauna of Greenland), Otto Friederich Müller (microscopic animals), and Johan Christian Fabricius (the classification of insects). Members of the Academy such as Morten Thrane Brünnich, Johan Christian Reinhardt and Gregers Wad were also involved in building the national scientific collections of plants and animals in Denmark.

The Academy's biologists in the period approx. 1800-1880

To a high degree, biology is characterized by gradual development and increasing specialization. This makes it difficult to identify precise periods in the history of the subject group in the Academy. But around 1880, something new happens, represented by names such as Charles Darwin and Louis Pasteur.

Zoology

The first new member of the Academy to be interested in zoology in the 1800s was Ludvig Levin Jacobson, a very productive and internationally recognized comparative anatomist, who worked as a medical doctor and surgeon throughout his life.

At least as well-known internationally was Peter Wilhelm Lund, who spent most of his life in Brazil, where he collected large numbers of plants, insects, and birds. In the early 1830s, his became interested in fossil bones of animals in limestone caves near the small town of Lagoa Santa. This resulted in a comprehensive series of publications in the Academy's *Skrifter* (Writings) under the common title *Blik på Brasiliens Dyreverden før sidste Jordomvæltning* (A look at the fauna of Brazil before the last cataclysm) (1837-1846). The collections came to Denmark thanks to Johannes Theodor Reinhardt, who participated in the first Galathea expedition and spent considerable time with P.W. Lund. To a high degree, his own research centered on Lund's Brazilian collections, which numerous other researchers would also become interested in, not least Herluf Winge, who published the comprehensive work *E Museo Lundii* (1888-1915). He also analyzed bones from Danish archaeological digs, and was a pioneer of Danish nature conservation.

The large marine mammals were Daniel Frederik

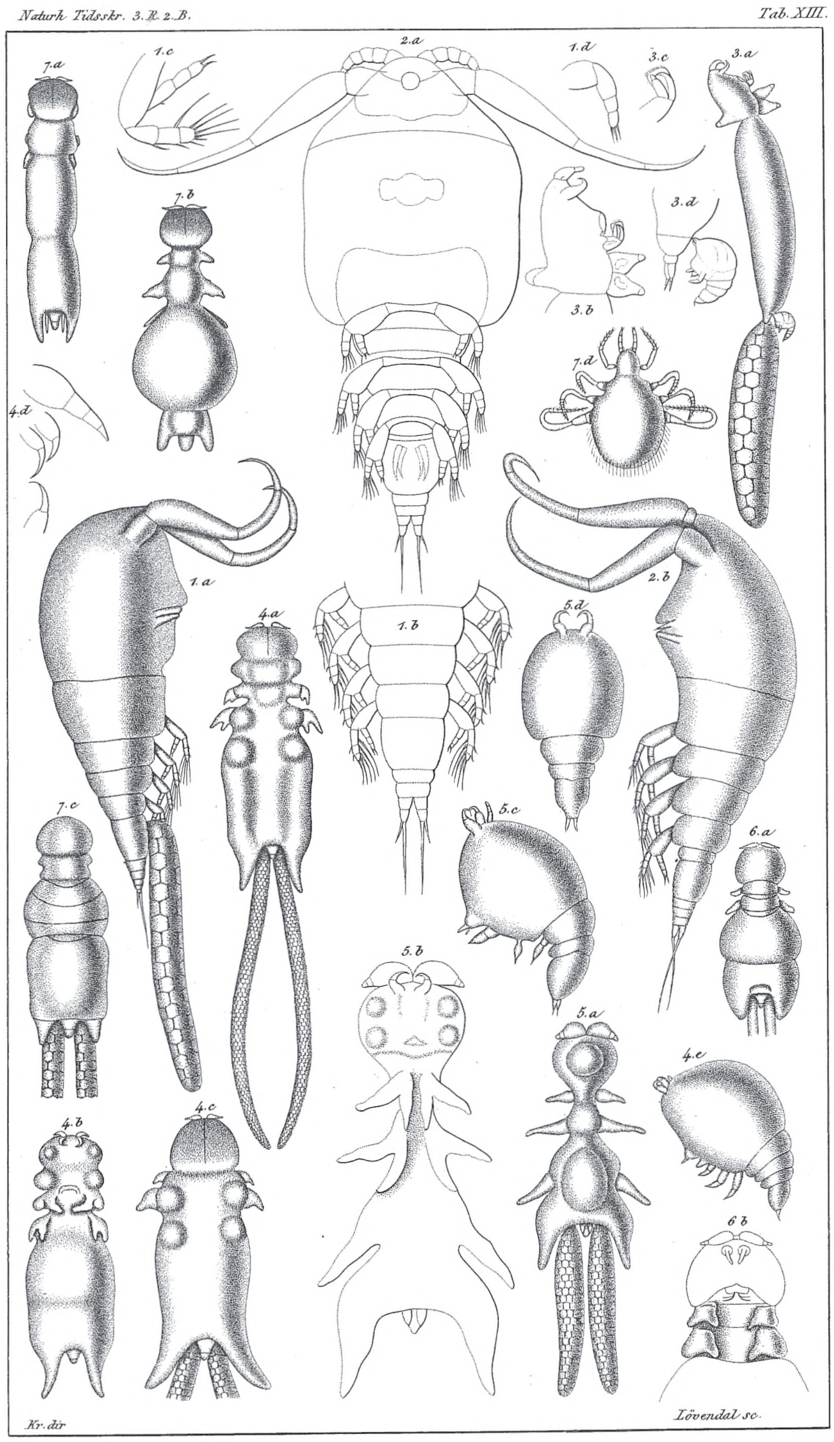

FIGURE 1. Parasitic water fleas (Copepoda, a subclass of crustaceans) were studied by the zoologist Henrik Krøyer. His attention was first drawn to these extremely modified crustaceans when he found them as fish parasites while engaged in his thorough studies of the fish living Danish waters. Krøyer's work on parasitic crustaceans was illustrated by his stepson Peter Severin Krøyer, who later became one of the most famous painters of the Danish Golden Age, and engraved by Emil Adolf Løvendal. Krøyer demonstrated that parasitic crustaceans start their lives as free-living, like non-parasitic species, but that the sexually mature females later latch on to fish, particularly onto their blood-filled gills, where they are fertilized by free-swimming males. The plate was published in the largest of Krøyer's works on parasitic crustaceans, "Bidrag til Kundskab om Snyltekrebsene" (Contribution to knowledge about parasitic crustaceans), which was published in *Naturhistorisk Tidsskrift* (Journal of Natural History), 3rd series, vol. 2, pp. 75-425 (1863).

Eschricht's primary interest. Although he was educated as a medical doctor, his scientific work focussed primarily on the anatomy and embryology of whales. Today, the Danish Museum of Natural History has one of the world's most complete whale collections, to a high degree thanks to Eschricht. Marine research in a broader sense was carried out by Henrik Nikolai Krøyer, who published the first comprehensive works on the fish of Denmark and Greenland, as well as a number of treatises on crustaceans, in particular the pioneer work *Bidrag til Kundskab om Snyltekrebsene* (Contribution to knowledge about parasitic crustaceans) (1863-1864). The illustrations in this work were done by the young Peter Severin Krøyer, who helped his stepfather with scientific illustrations and later became a famous painter. Krøyer did not achieve the university career he felt he deserved, to a high degree because of his more outgoing and better connected competitor, Japetus Steenstrup.

In 1837, Steenstrup published a groundbreaking treatise, which received a medal from the Academy; here he demonstrated that four periods with different forest vegetation had succeeded each other over the course of 5-6000 years – while at the same time he rejected the idea of an ice age. The intersection of natural history and archaeology interested Steenstrup throughout his life, and in 1848, he became a member of the committee, which was to study the large mounds of shells near the Limfjord, together with the geologist J.G. Forchhammer and the archaeologist Jacob Worsaae. In 1837, flint tools had been found in these mounds, and Worsaae was able to demonstrate that they were accumulated by humans during the Stone Age. Steenstrup identified the animals in the mounds and named them 'kitchen middens', which is still the internationally accepted term.

Steenstrup was influenced by the German *Naturphilosophie* (philosophy of nature) of the time and cel-

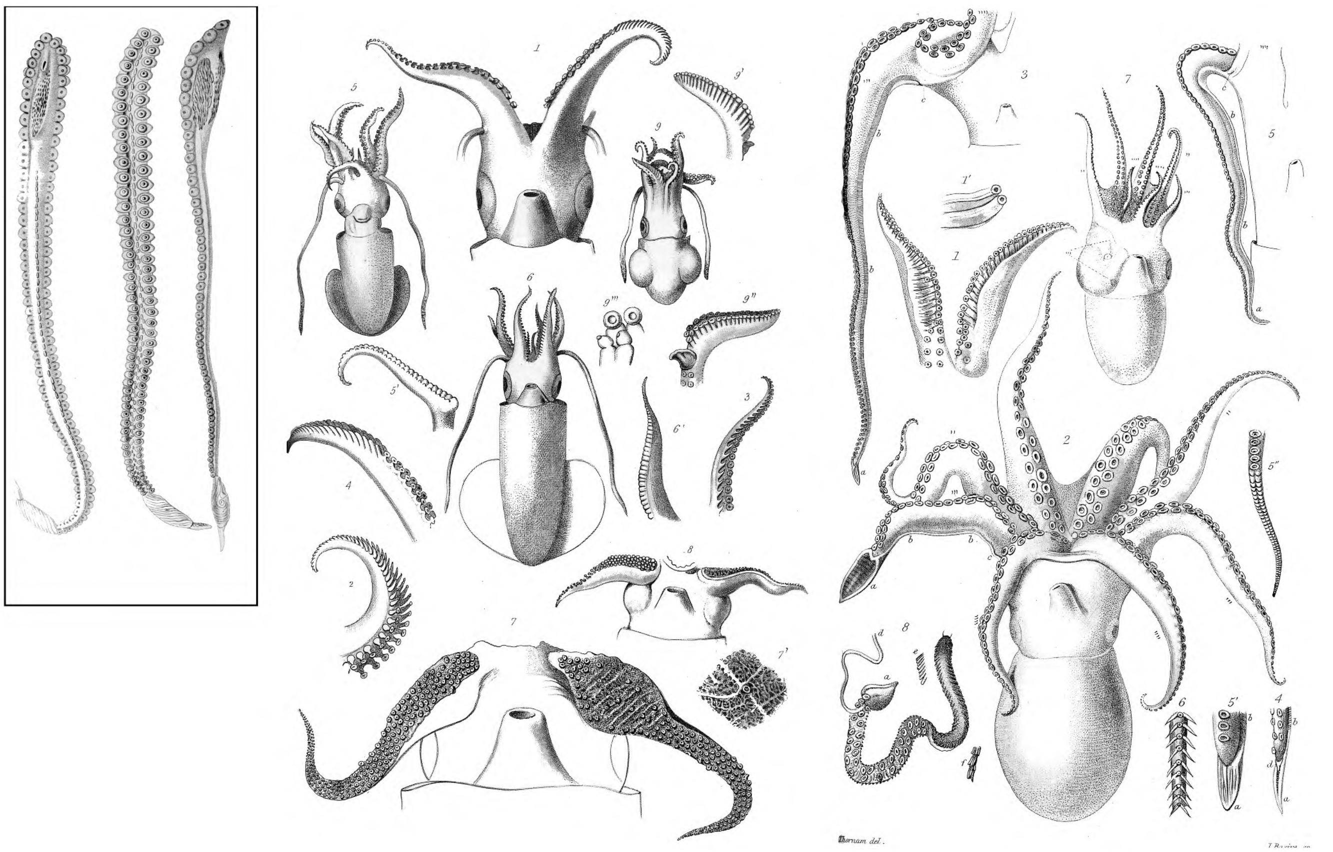

FIGURE 2. In 1829, the well-known French zoologist and comparative anatomist Georges Cuvier found what he believed to be a parasitic worm in the mantle cavity of a female octopus. He described it and named it *Hectocotylus octopodis* (framed figure on the left). The Danish zoologist Japetus Steenstrup proved that it was actually part of the arm of a male octopus. The arm was used to transfer semen to the female. On the plates on the right, Steenstrup demonstrated that 'hectocotylized' arms of this kind were found in other cephalopod genera, but in very different forms. The plates and the treatise "Hectocotyldannelsen hos Octopodslægterne *Argonauta* og *Tremoctopus* oplyst ved Iagttagelse af lignende Dannelser hos Blæksprutterne i Almindelighed" (Hectocotyl formation in the Octopod genera *Argonauta* and *Tremoctopus* illuminated by observations of similar formations in cephalopods in general), which was published in *Videnskabernes Selskabs Skrifter* (Writings of the Royal Danish Academy of Sciences and Letters*), Naturvidenskabelige og mathematiske afd.,* (Sciences and Mathematics), series 5, vol. 4, pp. 185-216 (1856).

ebrated the belief in an intuitive approach to solving scientific problems. This colors several of his works, which combine observation and speculative theorization, at times more of the former than the latter. In his best works, the two elements participate in a valuable balance, and almost all of his work on cephalopods have remained relevant. He was behind a number of important research policy decisions in Denmark, and as a close acquaintance of the brewer J.C. Jacobsen, he contributed to the development of the statutes of the Carlsberg Foundation and was a member of the foundation's first board of directors. He was secretary of the Academy from 1866 to 1878.

Steenstrup's intuitive method was controversial in his day. One of his contemporaries, who confined himself to precise observation and analysis was Jørgen Matthias Christian Schiødte. His major work is a study of beetles and their transformation from larval and pupal stages to adult animals. Her he demonstrated a close interplay between the animals' physical characteristics and their way of life, but without drawing connections between his observations and the new ideas of the time, including Darwin's theories of evolution. Schiødte was an important collector, and contributed to founding the large insect collections, which are now held at the Danish Museum of Natural History.

FIGURE 3. In 1837, the well-known paleontologist Peter Wilhelm Lund published the treatise "Bemærkninger over Vegetationen paa de indre Höjsletter af Brasilien, især i plantehistorisk Henseende" (Remarks on the vegetation of the inner plateaus of Brazil, with a particular focus on plant history) in *Videnskabernes Selskabs Skrifter* (Writings of the Royal Danish Academy of Sciences and Letters*), Naturvidenskabelige og mathematiske afd.,* (Sciences and Mathematics), series 4, vol. 6, pp. 145-188. In this treatise, he remarks on the frequent vegetation fires on the plateaus of Brazil and speculates on their possible effects. During his time with Lund in Lagoa Santa, Brazil in 1863-1866, the young botanist Eugene Warming analyzed the adaptation of plants to fire, among many other things – an early source of inspiration for his later pioneering works on ecology. His drawings of how plants species are adapted to survive in this environment are reproduced in the treatise "Lagoa Santa. Et Bidrag til den biologiske Plantegeografi" (Lagoa Santa. A contribution to the biological geography of plants) in *Videnskabernes Selskabs Skrifter* (Writings of the Royal Danish Academy of Sciences and Letters*), Naturvidenskabelige og mathematiske afd.,* (Sciences and Mathematics), series 6, vol. 6, pp. 153-488 (1892). After each fire, new shoots emerge from a thick underground corm or tuber in such different plants as the composite *Baccharis humilis* (left) and *Casselia chamaedryfolia* (right), a species of the verbena family, In both, the underground corm or tuber is well-protected from fire. The sooty remains of the burned stems are still visible next to the new shoots.

Anders Sandøe Ørsted, nephew of the famous jurist and prime minister of the same name, performed groundbreaking research on marine biology by classifying the ecological zones of the sea by the dominant groups of algae (brown algae, green algae, and red algae) and correlating these zones with the amount of light they receive. During an expedition to the West Indies, Nicaragua, and Costa Rica, he studies the phytoplankton of the oceans and concluded that plankton is "the essential plant matter for the nourishment of the smallest animals" – the base of the marine food chain.

Botany

In the early 19th century, the members of the Academy with an interest in botany were all students of Martin Vahl, either directly or indirectly (see p. 153). First and foremost among them was Jens Wilken Hornemann, who was primarily interested in the Danish flora and published the influential *Dansk oeconomisk Plantelære* (Danish economic botany) (1796). To a large extent, his slightly younger contemporaries studied plants from distant, even exotic, places.

From 1816 to 1820, Joachim Frederik Schouw travelled around Europe, and after he returned home, he wrote the first account of the principles of plant geography based in part on the pioneering work of Alexander von Humboldt, in part on his own observations. He provided a first overview of the plant geographical regions of the world, which could be characterized by a relatively uniform flora and vegetation, and he later developed his observations with studies of the distribution and height zones of tree species in Southern Europe, especially in Italy. He was also an energetic editor of the Academy's *Skrifter* (Writings) for many years.

In 1806, Nathaniel Wallich was posted as a surgeon at the Danish colony Frederiksnagore near Kolkata, but soon he went into British service, and over the next thirty years, he explored the flora and vegetation of India, Nepal, Burma, Penang, and Singapore and published a number of botanical works, including the magnificent *Plantae Asiaticae rariores* (1830-1832). Another important Danish scientific explorer was Frederik Michael Liebmann. From 1840 to 1843, he explored southern Mexico, where he studied the vegetation and flora of its volcanoes and moist forests. He brought back very large collections of living and preserved plants from his travels.

As a young man, Johan Martin Christian Lange studied the flora of Spain. He later shifted his focus to the flora of Denmark, when he became director of the Copenhagen Botanical Garden, and in collaboration with others, including the brewer J. C. Jacobsen, he organized the relocation of the garden from Nyhavn to its current location. His *Haandbog i den danske Flora* (Handbook of the Danish flora) (1850-1851) became a standard work, which was published in several revised editions. He became the last publisher of *Flora Danica*, the first volume of which had been published in 1761. After finishing that work in 1883, he published *Nomenclator Floræ Danicæ* (1887), which revises the identifications and names of all the plates in the work. He also wrote the first fundamental work on the flora of Greenland.

Johannes Eugenius Bülow Warming worked for some years in his youth with P. W. Lund in Brazil and contributed to the publication of *Symbolae Brasiliensis* (1867-1893). His major work *Haandbog i den systematiske Botanik* (1879) (*A handbook of systematic botany*, English ed. 1895), which was translated to German, English, Russian, and Swedish; updated editions of thus work was used in botany courses at the University of Copenhagen for almost a century. In his later years, he made a pioneering contribution to plant geography and the establishment of botanical ecology, which is the subject of his major work *Plantesamfund, Grundtræk af den økologiske Plantegeografi* (1895) (*Oecology of Plants – an introduction to the study of plant-communities*, English ed. 1909), which was translated to a variety of languages. He later published important monographs on Danish plant communities. He was also active in Danish research policy, for example as a member of the board of directors of the Carlsberg Foundation. He contributed to the design of the shared headquarters of the foundation and the Academy on H. C. Andersens Boulevard.

Medicine

The Academy's view of medicine has varied throughout its history. In the first period, no distinction was drawn between applied research and basic research, and practicing medical doctors were elected. The gradual elimination of applied research from the Academy's primary sphere of interest did not begin until H. C. Ørsted's term as the powerful secretary of the Academy (1815-1851). In his speech at the Academy's 100th anniversary in 1842, he characterized learned academies in these terms:

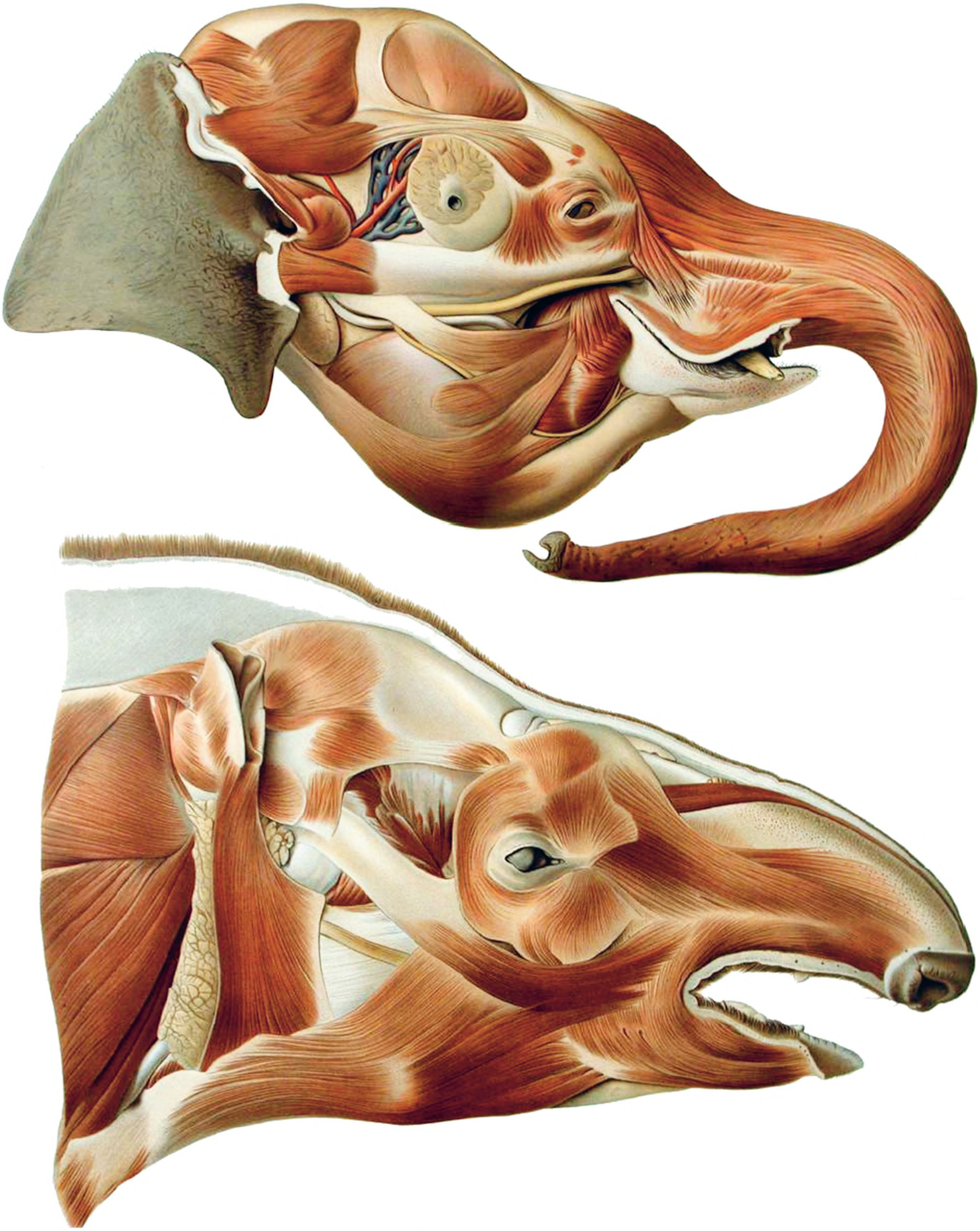

FIGURE 4. Two dissections of the musculature in heads of an Indian elephant (above) and a tapir (below). The elephant's head is considerably larger than the tapir's, and the two illustrations are not on the same scale. However, they make it possible to compare the musculature of the elephant's trunk and the trunk-like snout of the tapir. This is one important task of comparative anatomy, which involves determining whether outer similarity is accompanied by inner similarity, if so, it can provide support for a postulated affinity. The figure shows two of the 48 colored lithographic plates in J. E. V. Boas' and S. Paulli's book *The Elephant's head. Studies in the comparative anatomy of the organs of the head of the Indian elephant and other mammals* (1908). The other plates in the book show many other anatomical details, including nerves and blood vessels.

> It is deeply anchored in the essence of these academies that they are particularly concerned with the sciences, which do not immediately affect daily life. For example, they treat the philosophy of religion, but not church doctrine; jurisprudence, but not the interpretation of the country's laws; chemistry, anatomy, physiology, but ordinarily not medical practice ... A guiding light is lit, but the practitioner is left to navigate by it

Such considerations appear to have determined the Academy's principles for the election of new members since Ørsted's appointment. The physicians or veterinarians, who have been elected from that point have performed basic research in pathology, anatomy or physiology.

While still a student, Adolph Hannover demonstrated that the cause of a contagious disease among salamanders was a parasitic algae. To do so, he used microscopy, as he did in almost all of his work and the importance of which he emphasized. His work *Om Epithelioma* (On epithelioma) (1852) received international recognition; it presented a controversial theory about the existence of specific cancer cells, in opposition to the general perception of cancer cells as healthy cells, which had become diseased. Inspired by Hannover, Frederik Theodor Schmidt decided to study microscopic anatomy.

As a medical student, Peter Ludvig Panum was sent to the Faroe Islands in 1846 during a measles epidemic, which struck over two-thirds of the island's population in the course of seven months. He demonstrated that the duration of the course of the disease from infection to outbreak, the incubation period, was fixed, that the disease is spread from person to person, and that it could be contained by quarantining patients. As the last outbreak of the disease on the islands had taken place 65 years ago, he was also able to demonstrate that adult immunity lasts for at least 65 years. His treatise on the epidemic, *Iagttagelser anstillede under Mæslinge-Epidemien på Færøerne i Aaret 1846* (Observations made during the epidemic of measles on the Faroe Islands in the year 1846) (1847) became an international classic. In 1850, he succeeded in stopping the spread of a cholera epidemic by quarantining the sick. Among his later studies, his demonstration of the risks involved in blood transfusion is particularly famous. He became a member of the board of directors of the Carlsberg Foundation in 1876.

The Academy's biologists in the period approx. 1880-1950

Zoology

Steenstrup's intuitive method was the subject of a devastating attack by one of the newly elected zoologists, William Emil Sørensen. His own stringent studies were particularly focussed on marine animals and the functional anatomy of spiders. In an important treatise, he drew on physical studies of sound to solve problems in physiology. Sørensen's biological-physical research methods would be refined by August Krogh, who in his youth frequently visited Sørensen and considered him his tutor.

Frederik Vilhelm August Meinert and Christian Frederik Lütken came from each of the two quarrelling camps in Danish zoology. Meinert was a student of Schiødte and studied arthropods (insects, crustaceans and sea spiders), but gradually approached Steenstrup. Lütken was a student of Steenstrup, but his research was based on careful observations of marine invertebrates, fish and mammals. After Steenstrup's death, his work on the deep-sea giant squids was published by Lütken. Neither Meinert, nor Lütken supported Darwin's theory of evolution.

One of Steenstrup's defenders was Johan Erik Vesti Boas, who unlike Steenstrup was an adherent of Darwin's theory of evolution. As early as 1828, it had been demonstrated that the first stages of embryonic development are identical for all vertebrates, and Boas worked on the comparative vertebrate anatomy and embryology in support of the theory of evolution. In 1881, he presented the theory and arguments in its favor in a series of lectures. Crustaceans from the perspective of evolutionary biology were the subject of his first major works, and he later expanded his field of interest to include comparative anatomy of vertebrates, including dinosaurs and birds. His painstaking anatomical studies culminated with *The Elephant's Head,* a magnificent folio work, which was printed with support from the Carlsberg Foundation.

Boas' colleague – and competitor – Rudolph Sophus Bergh shared his support of Darwinism. Bergh was one of the first Danish scientists to perform research on histology and embryology on the foundation of Darwin's theory, and he taught the new theory of cytology, which operated with a nucleus and an outer cell membrane. His primary research focus was on worms, crustaceans, and flagellates (unicellular organisms, which move with whip-like structures called

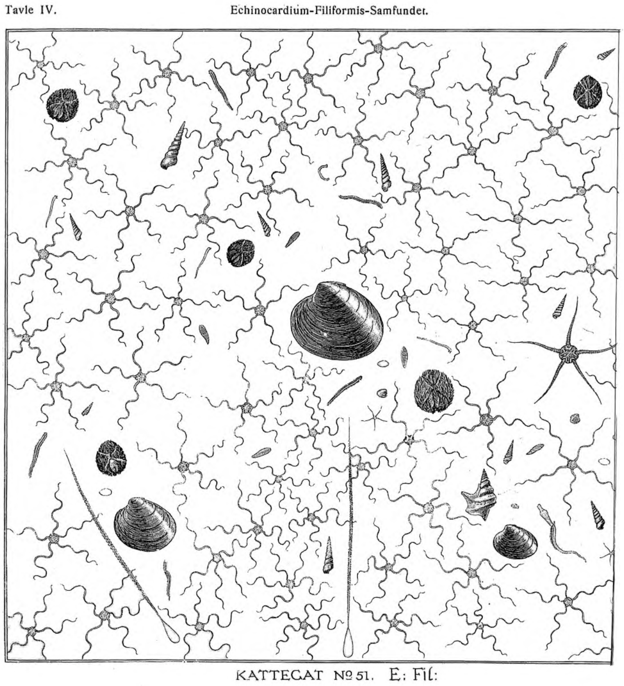

FIGURE 5. Using a bottom sampler of his own design, C.G. Johannes Petersen studied the animal life of the floor of the seas around Denmark and identified a number of animal communities. In a series of treatises, including *Havbunden og Fiskenes Ernæring: En Oversigt over Arbejderne vedrørende vore Farvandes Bonitering i 1883-1917. Beretning XXV til Landbrugsministeriet fra Den Danske Biologiske Station* (The sea floor and the nutrition of fish: an overview of works on the valuation of our waters in 1883-1917. Report XXV to the ministry of agriculture from the Danish Biological Station) (1918), he illustrated these animal communities with drawings of the dominant species in a way which indicated their relative numbers. One example is the community previously known as the *"Echinocardium filiformis"* community, now called the *Amphiura* community, which is found in soft sediments at depths of 20-100 m in the northeastern Kattegat, in parts of Skagerrak and the North Sea, as well as in the northern Oresund. The dominant species are brittle stars, including *Amphiura filiformis*. Other numerous species include the ocean quahog (*Arctica islandica*), pelican's foot snails (*Aporrhais*), tower snails (*Turritella*), heart urchins (in the sea urchin genus, *Ecchinocardium*), and species of bristle worms and sea pens. Petersen's graphic representation is a bit misleading in the case of the *Amphiura* community, because almost all of these animals live buried in the mud. The *Amphiura* community is found in regions of the sea which are important for cod and Norway lobster fishery.

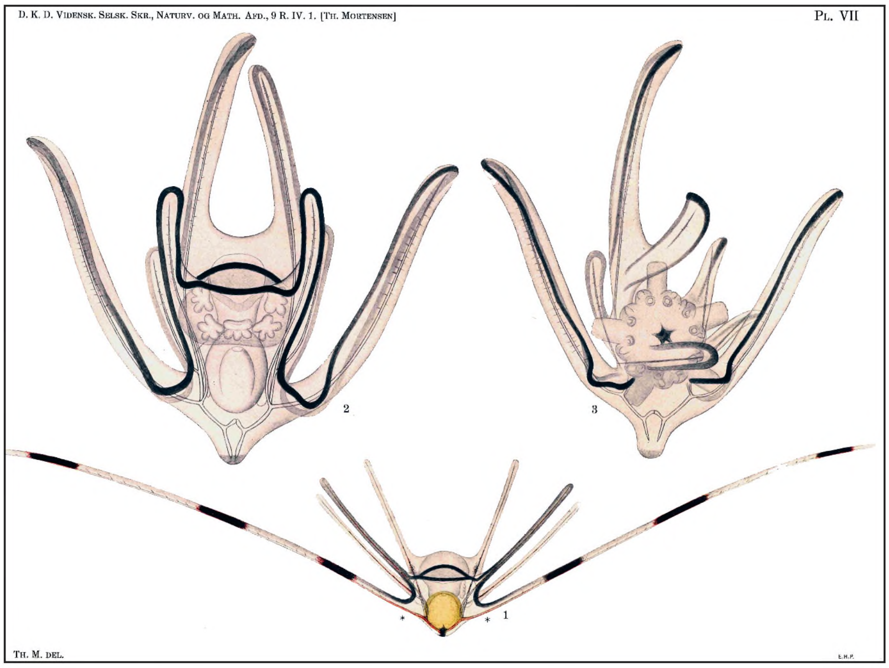

FIGURE 6. Brittle star larvae with their long flexible arms, only a few mm in size, live free-swimming as components of the ocean's plankton, while adult echinoderms such as starfish, brittle stars, sea cucumbers, sea lilies, and sea urchins are all bottom-dwellers. In a series of treatises, the echinoderm specialist Theodor Mortensen attempted to link the free-swimming larvae with adult animals, for example in "Contributions to the Study of the Development and Larval Forms of Echinoderms", which was published in *Videnskabernes Selskabs Skrifter* (Writings of the Royal Danish Academy of Sciences and Letters), *Naturvidenskabelige og mathematiske afd.*, (Sciences and Mathematics), series 9, vol. 4, pp. 1-40 (1931). In the plate, figure 1 shows a young larvae floating freely in the water, while figures 2 and 3 show stages in their transformation into adult brittle stars. The completely different adult animals (most clearly indicated in figure 3, but with shortened arms) develop on the top of the larva near the mouth, while the larva's arms degenerate.

flagella); but halfway through his career, he abandoned science to devote himself to a career as a composer and historian of music.

The first member of the Academy who primarily focussed on ecology was Peter Erasmus Müller, in part as a student of Warming (see p. 157). His most important contributions were his groundbreaking ecological studies of the formation of the two main types of forest floor soil humus, the fertile (mull) and the acidic and nutrient-poor (mor).

A modern ecologically oriented marine biology did not emerge until the second half of the 19th century, first represented in the Academy by Carl Georg Johannes Petersen. Over the course of four summers starting in 1893, he explored the physical factors, sea floor conditions, and animal life of over 500 stations in the Kattegat. This material was studied by a number of zoologists and formed the foundation of his own higher doctoral dissertation on the bottom fauna of the Kattegat. He introduced new models for population studies of fish, which are still used in fisheries biology, and he collected precisely defined samples of the sea floor using a new tool, 'Petersen's bottom sampler', which enabled him to identify and define eight animal communities in the waters around Denmark.

By the turn of the century, marine research held a strong position in Denmark and in the Academy. One of the researchers working in this field was Hector Frederik Estrup Jungersen, who participated in the Ingolf expedition to the North Atlantic and the Arctic circumpolar ocean in the period 1895-1896. The Arctic fauna was also Adolf Severin Jensen's primary interest.

It can be difficult to identify animals, which change considerably from the larval to the adult stage, especially if they live in two completely different environments at the two stages. This topic fascinated Theodor Mortensen, who studied the free-swimming larval stage of echinoderms, including sea lilies, starfish, sea urchins, and sea cucumbers, all of which are bottom-dwellers as adults. His goal was to collect material from all regions of the world's ocean, and he managed to study quite a few: the Gulf of Thailand, the Danish West Indies (US Virgin Islands), the Pacific, the coasts of Africa, Mauritius, and Saint Helena. Thanks to Mortensen, the Danish Museum of Natural History's collection of echinoderms is one of the world's most complete. His work culminated in the 16-volume work *A monograph of Echinoidea* (1928-1951), one of the most comprehensive zoological works by a single researcher.

Johannes Schmidt was another oceanographer, who worked on larval-adult association, and he became at least as well-known internationally as Mortensen. His life's work was research on the life cycle and ecology of fish species, in particular the eel. In the Mediterranean, small, compact, transparent fish had been discovered, which were given the generic name *Leptocephalus.* It was later demonstrated that these fish were a larval stage of the European eel, not a new genus of fish. In 1904, Schmidt caught intermediary forms between the *Leptocephalus* larvae and the young eel, the elver, and in subsequent years he searched for the different life phases of the eel in the Mediterranean and the Atlantic Ocean. In 1921-1922, he succeeded in establishing that the European eel must migrate from Europe to the Sargasso Sea to breed, after which the larvae migrate back to Europe with the help of the Gulf Stream. From 1928 to 1930, he headed a circumnavigation of the globe on the ship *Dana,* a general marine biology expedition but always on the look-out for eels. Among the many results produced by the expedition was the discovery of a previously unknown marine mountain chain in the collision zone between the African and Indo-Australian continental plates in the Indian Ocean. It was named the Carlsberg Ridge after the patron of the expedition.

Freshwater biology became represented in the Academy slightly later than marine biology, but the first representative of this discipline, Carl Jørgen Wesenberg-Lund, was one of the founders of modern freshwater biology, both in Denmark and internationally. While his first work was based on the collections of a group of Greenlandic crustaceans, the entomostracans, in the Zoological Museum, he soon moved on to direct observations in nature or in primitive laboratories. He worked on aquatic insects and microscopic animals, especially rotifers and bryozoans. He believed that the seasonal variations in the size of individual plankton depend on changes in the absolute gravity of the water, while the German chemist Wolfgang Ostwald believed that the changing viscosity was the cause; hence arose the Wesenberg-Lund-Ostwald flotation theory, later elaborated by Ostwald, but now these static models have been replaced by dynamic models.

Niels Mathias Peter Thomsen's broad field of interests spanned from decidedly application-oriented and experimental-ecological works on Danish fly species to cytology, in particular the determination of the sex of insects, to experimental and descriptive works on the hormones of insects and crustaceans.

Although comparative anatomy was represented in the Academy by several zoologists in the 19th century, Carl Marinus Steenberg was the first member to specialize in it. Gastropods were the subject of almost all of his works, and he studied their anatomy using highly specialized microscopic techniques he developed himself. In particular, his studies of the complex reproductive systems of hermaphroditic gastropods were highly superior to any previous analyses.

In this period, paleontology was the province of two members in particular. Jesper Peter Johansen Ravn was a specialist in invertebrates and worked on fossil molluscs, particularly mussels, which he studied in Danish deposits from the Cretaceous period, later extended with analyses of the mollusc fauna from Tertiary deposits. Magnus Anton Degerbøl's research interest was subfossil vertebrates, not least in an archaeological context, and he studied bone material from a wide range of prehistorical settlements. By comparing animal bones from the archaeological finds with living animals, he believed that he could demonstrate processes of evolution. The history of immigration of individual vertebrate species to Denmark was another of his fields of interest, and he attempted to demonstrate that the aurochs was exterminated by man.

Botany

Two members of the Academy studied the algae and the fungi, which at that time were both believed to be plants. Frederik Georg Emil Rostrup was the author of a large handbook on the fungal diseases of plants, as well as the more general *Vejledning i den danske Flora* (Guide to the Danish flora), which quickly became known as 'Rostrup's flora' and was extremely popular – revised new editions continued to be published until 1979. The study of algae became the life work of Janus Lauritz Andreas Kolderup Rosenvinge, grandchild of the famous jurist of the same name. His studies of algae were very broad, including aspects of developmental biology, taxonomy and plant geography-ecology. His works on the marine algae of Greenland (1893-1898) and Denmark (1909-1931) are only now being supplanted by new treatments of the subject.

In the period 1895-1898, Christen Christiansen Raunkiær published *De danske Blomsterplanters Naturhistorie, Bind 1. Enkimblade* (The natural history of Danish flowering plants, vol.1. Monocots), in which he clarified the morphological and anatomical characteristics, which influence the plants' ecology. Later he summarized his studies of the adaptation of plants to ecological conditions in *Planterigets Livsformer og deres Betydning for Geografien* (The life forms of plants and their significance for geography) (1907, French edition 1905). In 1921, Carsten Olsen published his higher doctoral dissertation *Studier over Jordbundens Brintionkoncentration og dens Betydning for Vegetationen, særlig for Plantefordelingen i Naturen* (Studies of the hydrogen ion concentrations in soil and their significance for vegetation, particularly for the distribution of plants in nature), which became an important foundation for botanical ecology, and which provoked a response from Raunkiær in the form of a study of the opposite reaction, the influence of plants on the soil. In *Dominansareal, Artstæthed og Formationsdominanter* (1928) (*The Area of Dominance, Species Density, and Formation Dominants*, English ed. 1934) Raunkiær introduced quantitative methods to the analysis of plant communities. Both his classifications of the life forms of plants and his methods of analyzing plant communities are still widely used around the world.

Carl Emil Hansen Ostenfeld contributed to two different fields: Danish and Arctic flowering plants and marine plankton. He organized research groups, an innovation at the time, and with the project *Danmarks topografisk-botaniske Undersøgelse* (The topographical-botanical survey of Denmark), which ran from 1903 to 1980, he achieved a through mapping of Denmark's flora in relation to geography and ecological factors. His plankton research resulted in the work *De danske farvandes Plankton i Aarene 1898-1901* (1913-1916) (The plankton of Danish waters in the years 1898-1901), co-authored with Johannes Schmidt. He was a member of the board of directors of the Carlsberg Foundation from 1921 until his death.

Otto Georg Petersen is the only member of the Academy, who has specialized in plant anatomy, inspired by Warmings early works in this field.

Steenstrup's studies of the history of vegetation founded a very rich research field in Denmark in the 20th century, first cultivated by Knud Jessen, who used pollen analysis in his exploration of the development of vegetation after the Ice Age. He was a member of the board of directors of the Carlsberg Foundation for 20 years.

Medicine and parasitology

Johannes Andreas Grib Fibiger's greatest contribution was in cancer research; he demonstrated that stomach tumors in lab rats could be caused by infection with a previously unknown roundworm, which they were given with their feed. For the first time, it was possible to provoke in healthy animals a disease, which resembled cancer. The studies were published in 1913, and received so much international attention that Fibiger was awarded the Nobel Prize in 1927 for his work, which, however, was later shown not to demonstrate genuine induced cancer. Cancer was also the subject of Vilhelm Ellermann's groundbreaking research. He demonstrated that leukemia can be transferred from sick to healthy chickens by inoculation with the blood of sick animals, even when cells are filtered out. This was an early demonstration that cancer can be caused by infection by biological material smaller than the cell. It was later demonstrated that this particular infection is caused by a virus.

Two other fields were explored by Knud Aage Buchtrup Sand, who performed experimental work on sexual characteristics and was able to produce hormonal hermaphroditism in mammals and animals, and Louis Sigurd Fridericia, whose most important work concerned heart rhythm and methods for recording and interpreting electrocardiograms.

The Academy's only parasitologist in more recent history was Harald Krabbe. As a medical doctor with an interest in zoology, he was sent to Iceland in 1863 to study the disease human echinococcosis (hydatidosis, or hydatid disease), which is caused by a tapeworm, *Echinococcus granulosum*. He elucidated the course of the disease and the life cycle of the tapeworm, which includes stages in dogs, sheep, and humans, often resulting in the death of the host. He later also studied avian tapeworms and identified and described 123 new species.

Although professor in human anatomy and embryolgy, Johan Henrik Chievitz also carried out research in comparative anatomy, for example comparative studies of the development of salivary glands and the retina in both humans and animals.

Bakteriologi

Between the 1890s and the 1930s, a number of bacteriologists and serologists were elected to the Academy. They focussed in particular on pathogenic bacteria and their control, as well as on industrial uses of bacteria. The first of these bacteriologists was Carl Julius Salomonsen, who demonstrated that tuberculosis is an infectious disease in 1878. Martin Kristian Kristensen worked on influenza and the bacteria, which were thought to cause the disease until the influenza virus was discovered in 1933. He also studied other pathogenic bacteria, which spread from animals to humans. The first known bacteria of this type, which causes contagious bovine abortion, had been discovered in 1897 by Bernhard Laurits Frederik Bang, whose primary focus was veterinary medicine, while Kristensen was also interested in human medicine. Jeppe Ørskov studied the so-called ray fungi or antinomycetes (species of the genus *Actinomyces)* and the diseases they cause. Although formerly classified as fungi, antinomycetes are actually bacteria, which can cause various diseases in humans and animals. Carl Olof Jensen, who studied bacterial diseases in farm animals, demonstrated that vaccination with weakened cultures or blood serum was an effective preventive measure against some of these diseases, and he was one of the pioneers in the understand of how vaccinations work. Thorvald Johannes Marius Madsen worked in the same field, and was a contributor to the development of a serum against diptheria and was able to demonstrate that the serum should be administered in large doses and as quickly as possible.

Sigurd Orla-Jensen studies the microorganisms, which occur in dairy products, including cheese, and he made a major contribution to the classification of microorganisms on the basis of their physiological effects, as well as of lactic acid bacteria (lactobacillales).

Animal and human physiology

The exploration of the fundamental physical and chemical processes of life (physiology and biological chemistry) accelerated in the 19^{th} century. Physiology is a discipline at the border between the natural sciences and medicine, and the members of the Academy named here came from both faculties of the university. Christian Bohr was the first true physiologist in the Academy. His primary interest was respiratory physiology, including the exchange of oxygen and carbon dioxide in the lungs and the absorption of gasses by the blood. To this day, the development of physiology in Denmark has been largely determined by his re-

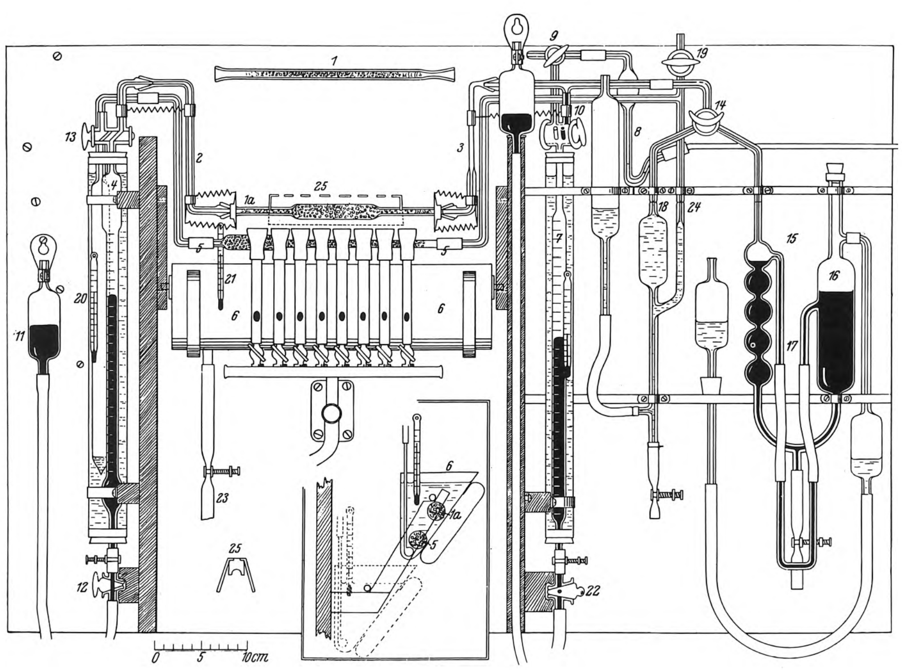

FIGURE 17 August Krogh manufactured a variety of devices to solve complex biological problems which could be studied through physical or chemical analysis. Krogh was a skilled artisan who manufactured his own equipment, not least out of glass. The illustration from Krogh's article "Eine Mikromethode für die organische Verbrennungsanalyse, besonders von gelösten Substanzen" in *Biochemische Zeitschrift*, vol. 221, pp. 247-263 (1930), shows one of Krogh's devices for the combustion analysis of organic matter dissolved in fresh water. The evaporation and combustion take place in the left side of the apparatus, while the analysis of the products of the combustion process takes place on the right side. Together with Kaj Berg, Krogh used this method in connection with freshwater biology analyses of dissolved organic matter as food for aquatic organisms in the lake at Frederiksborg Castle.

search and his collaboration with his students Valdemar Henriques and August Krogh, who nonetheless often departed from Bohr's theories. Henriques began his career with studies of respiratory physiology and then moved in the direction of biochemistry. He demonstrated that animals synthesize proteins from the proteins they get from their food, but only after they are completely broken down into amino acids; similarly, the body synthesizes fats after decomposing the fats in food into fatty acids and glycerol. In 1917, he became a member of the board of directors of the Carlsberg Foundation.

August Krogh is a central figure in Danish science and his influence is still being felt, both as a teacher and as a source of inspiration in research. In 1906, he became the country's first lecturer in physiology at the faculty of natural sciences (not medicine) at the University of Copenhagen. In the application to establish this new position, it was argued that placing the subject at the faculty of medicine would produce a tendency for physiology to "focus narrowly, zoologically speaking, on one species – man". In a newly established laboratory, he set up facilities for experiments with non-mammalian organisms, and the equipment was primarily manufactured at the laboratory workshop by Krogh himself and a laboratory attendant. Perhaps his most significant results were in relation to studies on respiration and muscle physiology. He developed methods of measuring the speed with which muscle tissues absorb oxygen and produce carbon dioxide, and he studied capillary exchange and muscle tissue, both at rest and during exercise. Through these studies, the majority of which were performed on frogs, he discovered that the blood flow in the capillaries in connection with their expansion and contraction is controlled by the oxygen consumption of the muscle. These discoveries earned him the Nobel Prize in Physiology or Medicine in 1920. He subsequently focussed on comparative physiological studies, including oxygen and nutrient absorption in aquatic invertebrates, and the absorption of ions through the skin of freshwater animals. His efforts to establish insulin production in Denmark at Nordisk Insulinlaboratorium, later part of Novo Nordisk, have had a decisive influence on the well-being of many people – in addition to the significant influence on Danish research and Danish society.

Krogh could have strong opinions, which he expressed without beating around the bush. In 1949, he expressed his dissatisfaction with what he saw as the Academy's insufficient efforts to advise on the role and tasks of research in society. He accused the Academy of failing to elect younger researchers, who could participate actively in developing a research policy, and proposed that members over the age of 70 should be transferred to passive membership (he was 75 at the time himself). When the Academy rejected his proposal, he asked for his membership to be withdrawn, but died before his difference with the Academy was settled (see p. 49s.).

In the 1920s, muscle metabolism was a hot topic, and many scientists were engaged in this type of research, including Einar Lundsgaard. He studied the biochemical processes, which transform nutrients in the form of sugars into energy in the muscles, with a particular focus on energy transfer in connection with muscle contraction. On the basis of his studies, he discovered that the production of lactic acid was a normal process, which aids in the resynthesis of the muscle's actual source of energy, creatine phosphate. This was a fundamental contribution to our understanding of high-energy phosphate bonds and their role in biological energy transfer, however without Lundsgaard reaching the full understanding of the most important cellular energy transfer process, the conversion between adenosine triphosphate (ATP) and adenosine diphosphate (ADP).

Johannes Lindhard participated from 1906 to 1908 as a physician in Ludvig Mylius-Erichsen's Denmark Expedition to northeast Greenland. This inspired his interest in human physiology under extreme conditions, which led to research on the theory of physical exercises with a focus on respiration, blood circulation and metabolism during hard physical exertion.

Plant physiology

If we disregard Carl Gottlob Rafn's *Udkast til en Plantefysiologie, grundet på de nyere Begreber i Physik og Chemie* (Towards a physiology of plants based on modern concepts in physics and chemistry) (1796), Wilhelm Ludvig Johannsen was the Academy's first plant physiologist. He began his research career with anatomical and physiological studies of plant seeds, but switched to the new field of genetics, which he helped to name and define. In *Om Arvelighed i Samfund og i rene Linier* (On heritability in society and in direct lines of descent) (1903), he distinguished between the *phenotype*, which can be observed directly, and which is influenced by external conditions, and the *genotype*, the information which is inherited and which is not influenced by the environment. This pair of concepts is still of central importance in genetics today. In *Elemente der exakten Erblichkeitslehre* (1909, with several subsequent expanded editions), he introduced the concept of the *gene* as a designation for hereditary factors, which would influence subsequent research. On the other hand, his rejection of the chromosomes as bearers of genes was untenable.

Perhaps the most important plant physiologist in the Academy's history was Peter Boysen Jensen. His studies of the involvement of plant hormones in the transmission of stimulation in plants were groundbreaking. Darwin had demonstrated that shining a light on one side of a grass seedling results in the development of a curvature lower down on the stalk, which causes the seedling to grow towards the light, but he was unable to explain how the stimulus was transmitted. Boysen Jensen demonstrated that the initial stimulation takes place on the side of the seedling facing away from the light, and that the stimulation is transmitted by a plant hormone, which regulates growth by moving from one location to another within the seedling.

The physiology of fermentation and genetics

Louis Pasteur was responsible for the groundbreaking work on the physiology of fermentation. The first member of the Academy to study this new area was Emil Christian Hansen. With the support of brewer J.C. Jacobsen, he completed his higher doctoral dissertation, *Om Organismer i Øl og Ølurt* (On organisms in beer and wort) (1879). He demonstrated that different strains of yeast can have different physiologies even when they are morphologically identical. In a series of treatises, he described different strains of "cultured yeast" and "wild yeast", and he succeeded in producing cultures of pure yeast from a single cell. The first pure culture, 'Carlsberg's bottom yeast no. 1', was used in brewing at Carlsberg in 1883 and became a decisive factor in brewing good beer.

Øjvind Winge was convinced that chromosomes are the bearers of genes. His 1917 higher doctoral dissertation lay the foundation for many studies of related forms of plants with genotypes consisting of multiple rows of haploid (unpaired) chromosome numbers, for example in wheat: 7, 14 and 21. He demonstrated that doubling the number of chromosomes in sterile hybrids makes it possible for them to produce offspring, which can reproduce themselves sexually, and he identified the sex chromosomes of plant species with male and female individuals. His research was mainly focussed on the genetics of barley, yeast, and hops, and he succeeded in demonstrating the existence of sexual reproduction in yeast, as well as breeding fertile species hybrids. Carl Adolf Jørgensen's research was closely connected with the work of Winge. In his 1928 higher doctoral dissertation, Jørgensen demonstrated a new method of chromosomal doubling, the so-called "Winkler-Jørgensen callus method", which is based on the discovery that the formation of callus tissue (the plant equivalent of scar tissue) can lead to chromosome doubling in the cells of this tissue, and that these cells can be cultured to regenerate new double-chromosome plants. Jørgensen also studied multiple chromosome numbers in wild plants from Denmark and Greenland.

The Academy's biologists studying zoology, botany, ecology, genetics and plant physiology after World War II

The discovery of the structure and function of the DNA molecule in 1953, later supplemented by insight into RNA, has been decisive for the Academy's biologists within all previously existing disciplines.

Zoology

Bent Christensen has done groundbreaking work on taxonomy, phylogeny, and population studies based on DNA analysis. Based on cell studies and genetics, he developed a critical taxonomical revision of Europe's potworms (enchytraeids), tiny white terrestrial worms. In his 1961 higher doctoral dissertation, he demonstrated the existence of polyploidy (containing more than two paired (homologous) sets of chromosomes) in potworms, a phenomenon common in plants but quite rare in animals. He later focussed on systematic analyses of worms and crustaceans at the molecular level using electrophoresis, a method for the separation and analysis of molecules based on their electric charge; using this technique, he was able to differentiate identical forms and populations in terms of variations in enzymes, differences which he linked to their food preferences.

After World War II, taxonomical, phylogenetic, and biogeographic methods of analysis were developed based on the work of the German entomologist Willi Hennig, to begin with independently of DNA studies. The goal was to develop a systematic classification of living organisms on the basis of well-founded theories about their evolutionary origin (phylogeny). Originally, the method was based on the morphological characteristics of the organisms studied, but the analysis of the phylogenetic relationships of species is also based on DNA analysis today. Among the Academy's members, the zoologists in particular have been responsible for introducing phylogenetic taxonomy into Danish research.

Butterflies and moths were the subject of almost all of Niels Peder Kristensen's scientific works, not least the primitive moths, which lack a proboscis; these moths are found in East Asia, Australia, New Zealand, and on islands in the western Pacific. Their morphology, anatomy, evolution, and taxonomy were the subject of Kristensen's 1984 higher doctoral dissertation, as well as numerous articles and detailed entries in zoological manuals and reference works. However, he also published a general systematic entomology, and in 2002, he and fellow researchers were able to describe a newly discovered order of insects, the first since 1914. His meticulous and rigorous textbook *Systematisk entomologi* (Systematic entomology) (1970) was known (and sometimes feared) for decades by biology students at the University of Copenhagen.

Niels Møller Andersen focussed on multi-facetted studies of water striders, insects which can walk on water – thanks to surface tension. His primary interest was quantitative methods for the analysis of the evolution of species. In the 1970s, there were two competing trends within systematic biology: phenetics, based on overall morphological similarities between organisms, and Hennig's phylogenetic systematics (cladistics), based on a combination of observations of taxonomic characters and theories about their evolution and resulting in the reconstruction of organisms' inferred descent from a common ancestor. In their most advanced forms, both methods require computer-based calculations. In the beginning, Andersen worked with computer-based phenetic studies, but later switched to cladistic methods.

Henrik Enghoff's research touches on almost all aspects of the taxonomy, reproductive and developmental conditions, evolution, and biogeography of millipedes and centipedes. He has pointed out (rather dryly) that none of the over 10,000 species of millipedes actually have 1000 legs – the record is held by a species in California with 'only' about 750 legs. The topic of his 1984 higher doctoral dissertation is the evolution of millipedes on isolated islands, and he has also worked on more general topics within historical biogeography. He played a decisive role in bringing the international secretariat of the Global Biodiversity Informatics Facility (GBIF) to the Danish Museum of Natural History in Copenhagen.

Reinhardt Møbjerg Kristensen has studied microscopic multicellular organisms in the fauna of the ocean floor, which were previously almost unknown, and has discovered or proposed three new phyla of animals: loriciferans, cycliophorans, and gnathiferans, including a new class within the latter (micrognathozoans). Phylae are the next-highest taxonomical category of animal and plant species, just under the category Kingdom (for example, animal kingdom or plant kingdom) and above the category Class. His other major research focus is the study of tardigrades ('water bears'), which are related to arthropods. Tardigrades have four pairs of legs, often with feet and claws on each leg; they are found in a wide variety of environments, are incredibly hardy, and are only about 0.05-1 mm long, which means they are among the world's smallest multi-cellular animals.

Peter Arctander is a Danish pioneer in the use of DNA in connection with taxonomic studies of mammals and birds and to the unravelling and mapping of population structures. In the 1990s, he was involved in the discovery and study of a previously unknown antelope-like animal from the mountainous rain forests along the border between northern Laos and Vietnam. In 1992, the animal was recognized as a new species on the basis of the morphology of the skulls, which local hunters had preserved as trophies. Using DNA analysis of the available parts of the animal, Arctander demonstrated that it was in reality a small ox unrelated to any previously known genus. He has since worked with DNA-based population studies of large East African mammals. His work is an important contribution to the conservation of these animals, and by extension to the economies of the countries of East Africa.

Eske Willerslev was the first scientist to extract ancient DNA from permafrost and ice. In 2008, his studies of DNA and C^{14} analyses of sub-fossil human excrement from Oregon demonstrated that people lived in this area 14,000 years ago, about 1000 years earlier than previously thought. Later studies of genomes of the remains of two early inhabitants of North America, 12,600 and 8,500 years old respectively, have demonstrated that these ancient genomes are closely related to the genomes of the Native Amerindian population. In 2010, Willerslev analyzed the genome of the 4,500-

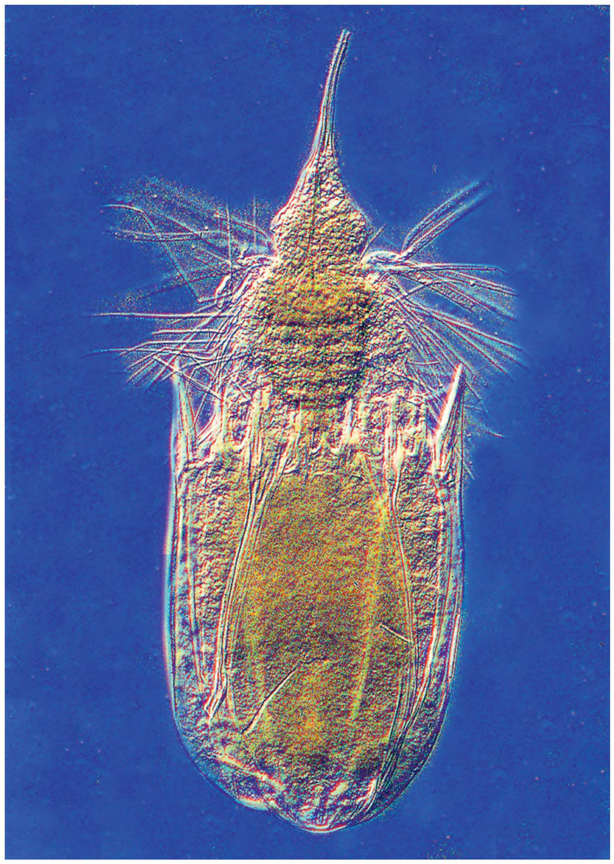

FIGURE 8. The first species to be described in Reinhard Møbjerg Kristensen's new phylum, 'loriciferans' (Loricifera Kristensen, 1983), described in the article "Loricifera. A new phylum with Aschelminthes characters from the microbenthos" in *Zeitschrift für Zoologische Systematik und Evolutionsforschung*, vol. 21, pp. 163-180. The animal is only about ¼ mm long and was first discovered in 1982 in the sea off Roscoff in northwestern France, where it lives in shell breccia and sand at a depth of about 25 m. It was given the species name *Nanaloricus mysticus* Kristensen (1983). Its abdomen is immobile and covered in stiff scales which end in spikes, while the head is mobile and equipped with appendages (235 in the female and 247 in the male) which are moved by muscles and equipped with sensory cells. The mouth is a trunk which can be extended and retracted. The photograph shows a male from the original collection from 1982 (a paratype).

year-old remains of a male from the extinct Saqqaq culture in Greenland, which showed no genetic connection to the ancestors of today's Inuit cultures. In 2011, he performed studies, which demonstrated that Aboriginal Australians are directly descended from a population which migrated to the continent about 50,000 years ago, long before the ancestors of contemporary Europeans and Asians reached the areas their descendants now inhabit.

Botany

After the World War II, several members of the Academy combined the new evolutionary and chromosome research with botany. One of these scientists was Thorvald Sørensen, who began his research career in Greenland. He presented his studies of the annual phenological rhythm of Arctic plants in his higher doctoral dissertation in 1941. He went on to study the chromosomal makeup and morphology of Arctic plants, and developed new methods of statistical comparison of different plant communities, known under various names including the Sorensen-Dice index and the Sorensen similarity index, which is widely used.

Tyge Wittrock Böcher also studied the flora of Greenland, and his works include his higher doctoral dissertation *Biological Distributional Types in the Flora of Greenland*. He co-authored the handbook *Grønlands Flora (The Flora of Greenland)*, which was published in English in 1968 and which went through several editions. He was particularly interested in the anatomical adaptation of plants to extreme conditions, and during World War II, when travel to Greenland was impossible, he turned to the study of the Danish plant communities of heathland and steep coastal cliffs. These studies have influenced Danish nature conservation efforts.

A number of members have studied the evolution of flowering plants. Rolf Martin Theodor Dahlgren carried out a systematic revision of *Aspalanthus*, a genus of flowering legumes found in South Africa, and he contributed to a revision of the taxonomy and evolution of flowering plants above the level of families, both in the textbook *Angiospermernes taxonomi* (The taxonomy of angiosperms) (1974-1976), in papers in journals and in monographs on the monocots; he passed away before he was able to incorporate phylogenetic or DNA-based taxonomy into his work.

Else Marie Friis is a specialist in paleobotany and has made significant contributions to our understanding of the development of early angiosperms during the Cretaceous and Tertiary periods. Through her work on small fossil flowers, she has demonstrated that a variety of flowering plants are older than previously thought, and that modern plant families already existed in the early Cretaceous.

Arne Strid has worked on experimental and chromosome-based studies. He has been particularly interested in the differentiation of species in isolated regions of Greece, islands and mountains. He has published the results of his research in works including *Mountain Flora of Greece*, vol. 1-2 (1986-1991), *Flora Hellenica*, vol. 1-2 (1997-2002) and recently in *Atlas of the Aegean Flora*, vol. 1-2 (2016).

Most tropical countries have been colonized at some point, and to a high degree botanists from the former colonial powers have been responsible for the fundamental botanical exploration of these countries. However, Thailand and Ethiopia are exceptions, having never been colonized, and in both countries, Danish researchers have collaborated with local researchers on the scientific exploration of their flora and vegetation. Gunnar Seidenfaden was originally a botanist, but changed careers and became a diplomat. As Danish ambassador to Thailand, he carried out comprehensive studies of Southeast Asian orchids in his free time in collaboration with Tem Smitinand, and published *The Orchids of Thailand – A Preliminary List* (1959), in addition to numerous later articles and books. The exploration of Thailand's flora was continued by Kai Larsen, after he had spent a number of years on experimental and chromosomal studies of Greenlandic and European plants. He carried out numerous expeditions to Thailand, at times in collaboration with Seidenfaden and Tem Smitinand, and was a central figure in a major international project on Thailand's tropic flora, which is published in a multi-volume handbook. The project continues and is now under the leadership of Henrik Balslev.

Ethiopia was an important research focus for Ib Friis, who has carried out numerous expeditions to study the flora and plant communities of Africa since 1970. His works include *Forests and Forest Trees of Northeast Tropical Africa - Their Natural Habitats and Distribution Patterns in Ethiopia, Djibouti and Somalia* (1992), which was part of his higher doctoral dissertation, and *Atlas of the Potential Vegetation of Ethiopia* (2010), the latter in collaboration with Paulo van Breugel and Sebsebe Demissew. Demissew and Friis also contributed to the ten-volume *Flora of Ethiopia and Eritrea* (1989-2009). Questions of ecology and plant geography summarized under the heading 'biodiversity' are an important focus of Ib Friis' research.

He shares this interest with Henrik Balslev, who has worked on many aspects of the botany of the tropics, especially in Ecuador. He has described the biodiversity of tropical rain forests and the high montane plant communities of the Andes Mountains (paramo) in numerous works, and in 1994, he demonstrated the most species-rich biodiversity yet known; it was found in the rain forest of eastern Ecuador. He has also worked on the taxonomy, biology, and ethnobotanical uses of palms. He is currently increasingly focussed on the flora of tropical Asia, particularly in connection with the publication of the *Flora of Thailand* series.

Øjvind Moestrup has worked on electron microscopy studies of structures in algae. His studies of structures in the flagellae (whiplike appendages) of the unicellular algae known as flagellates have brought him international recognition. This was the subject of his higher doctoral dissertation in 1983, which contributed to our understanding of the importance of these structures to the phylogeny and evolution of these algae – and thus to the understanding of the earliest phases of the history of life. He has directed several research projects on poisonous unicellular algae, which can cause fish die-off and shellfish poisoning.

Bacteriology

Martin Ottesen has worked at the boundary between bacteriology and biochemistry. He has described processes, which can activate or deactivate many enzymes with the help of the bacteria *Bacillus subtilis*. His research has been an important precondition for Novo's (after 2000 Novozyme's) enzyme products for detergents as well as the company's ongoing efforts to isolate and characterize useful enzymes from fungi and bacteria.

Terrestrial ecology and macroecology

Since World War II, rather few members of the Academy have worked on terrestrial ecology, despite the fact that this subject has received considerable public attention. Christian Overgaard Nielsen carried out ecological studies of the animal life of soil, especially the free-living roundworms. Sven Evert Jonasson and Bo Eberling work on the effects of global warming on terrestrial ecosystems in the Arctic, in particular the release of CO_2 (read more p. 197s.). Volker Helmut Otfried Loeschcke also works on ecological issues, including the effects of stress and heat shock on populations, a field known as stress ecology.

In recent years, a synthesis between ecology, biogeography, and evolutionary research has emerged, which is variously referred to as macroecology or ecoinformatics. The new concepts were introduced around 1990, and include studies of ecosystems 'from above' in relation to the conditions and biodiversity of individual species as well as geographically and historically. Carsten Rahbek's Center for Macroecology, Evolution and Climate performs analyses of biodiversity and the evolutionary and ecological factors, which determine the distribution of life on earth. Jens-Christian Svenning studies biological patterns on a global scale and draws on large data sets in his re-

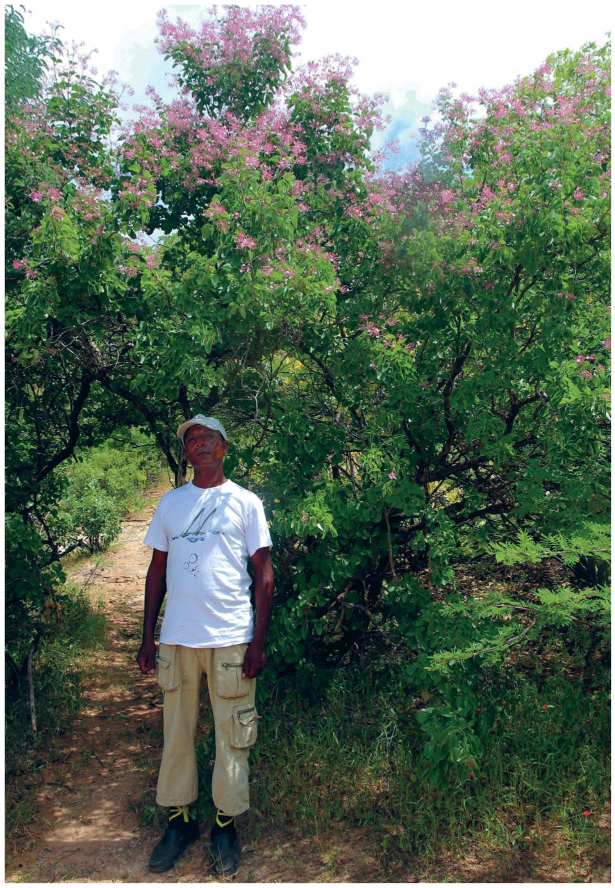

FIGURE 9. A previously unknown plant species, *Commicarpus macrothamnus* Friis & O. Weber, was discovered in 2013 by Ib Friis and Odile Weber on an isolated mountain in southeastern Ethiopia and described and named in the treatise "Two distinctive new species of *Commicarpus* (Nyctaginaceae) from gypsum outcrops in eastern Ethiopia" in *Kew Bulletin,* vol. 71, article 34, 19 pages (2016). The mountain, where other new plant species were also found, consists of deposits from the Cretaceous period and is very rich in the mineral gypsum. As gypsum is harmful to most plant species, the flora is poor but unique, and a number of the mountain's plant species are found nowhere else. *Commicarpus macrothamnus* is unique in its genus in being a large shrub, up to 3 m tall and with a well-developed trunk, while the other species in the genus are small herbaceous plants or climbing plants with fragile stems. It is still possible to find surprising new organisms in places with unique environments.

search. His work incorporates factors, which have influenced ecosystems on a geological timescale, which makes his research relevant in relation to modelling the geographical distribution of species in different future climate scenarios.

Plant physiology

Poul Lauritz Larsen's first works focussed on photosynthesis and the production of dry matter in higher plants. Subsequently, his primary focus became the study of plant growth substances. In his 1944 higher doctoral dissertation, he identified a new plant growth substance, 3-indoleacetaldehyde, and described its involvement in the formation of indoleacetic acid, the best-known growth-promoting auxin. He provided a general description of these substances in *Planternes vækststoffer* (Plant growth substances) (1962).

Birger Lindberg Møller has worked on many aspects of molecular plant biology. The subject of his 1984 higher doctoral dissertation was the photosynthetic membrane, and he has subsequently studied cyanogenetic glycosides, organic compounds with sugars, which produce the extremely poisonous substance cyanide on contact with degradative enzymes. Cyanogenetic glycosides are common in the plant kingdom, particularly in species, which are important food sources for human beings.

Michael Broberg Palmgren has worked on ion pumps and other forms of material transport across cell membranes in yeast cells and in more highly developed plants. His primary focus in this field has been the biochemical processes, which drive material transport by producing the energy needed to fuel them. He has also studied the genetic control of the enzymes, which are responsible for the chemical processes of membrane transport.

John Williams Mundy's research takes place at the interface between molecular genetics and plant physiology. Enzyme inhibitors are a major focus of his work, in addition to genetic control of cyan formation and drought-responsive genes and pathogen response regulators in plants. Many of his studies have been performed on thal cress (*Arabidopsis thaliana*), which has a small genome (for a plant), with about 157 million base pars in its DNA.

The physiology of fermentation and genetics

Mogens Westergaard was primarily interested in the genetics of vascular plants and fungi. By subjecting plants to cold shock at the moment at which the fertilized egg divides for the first time, he produced diploid plants, which he then backcrossed with the mother plant to produced plants with 1 1/2 times the original number of chromosomes. His studies of sex chromosomes demonstrated that the Y chromosome is so dominant that even plants with four X chromosomes and one Y chromosomes become male. In ascomycetes, he studied the exchange of genes between two identical chromosomes, so-called genetic recombination.

Diter von Wettstein's special focus was the genetic material in plant chloroplasts, which is transmitted independently of the chromosomes of the cell nucleus. In his other research, he attempted experimentally to produce mutants, primary of barley. Mutants with advantageous genomes can be used in plant breeding, for example the development of strains of barley, which reduce the perishability of beer, or strains of wheat, which do not provoke gluten allergy.

Ove Frydenberg's main interest was population genetics, in particular the mechanism, which maintain genetic variation in natural populations. There was intense research activity in this area in the 1960s, when it became possible to use electrophoresis (a technique for separating proteins on the basis of their electric charge) to characterize genetic variation in the enzymes of individuals in a population. The extent of this variation turned out to be much greater than one would assume on the basis of external morphological traits.

Morten Kielland-Brandt has carried out research in a row of topics within the genetics and physiology of yeasts; the purpose of this work has been both basic research and research of importance for industrial production. In recent years, he has studied membrane transport proteins in yeast. The macromolecules responsible for transport of small molecules across membranes can, for example, bind and transport glucose, whereby the cell can regulate the import of nutrition.

Michael Møller Hansen is a population geneticist with a special interest in the evolution of genetic adaptions among populations of fish. His work focusses on sticklebacks and river trout, with a particular emphasis on the influence of temperature. In connection with the third Galathea expedition, he demonstrated that the American eel and the European eel emerged as two distinct species when the Isthmus of Panama separated the Atlantic Ocean from the Pacific Ocean 3.5 million years ago. The subsequent changes in the Gulf Stream then brought the new eel species to Europe.

Mikkel Schierup is interested in early human evolution, and has mapped the genomes of different populations of chimpanzees, orangutans, and gorillas. He was the first scientist to demonstrate that the common ancestor of humans and chimpanzees lived about 3.5 million years ago, while our common ancestor with the orangutan lived about 12 million years ago.

The Academy has had and still has members, who work on human genetics. Tage Kemp was the first scientist to use cell culture to count and describe human chromosomes, as described in his higher doctoral dissertation of 1923. In the 1930s, when there was great interest in the influence of heritable factors on social structure, he gained an influence on Danish legal practice in relation to prostitutes and the administration of abortion legislation. He introduced counselling for 'genetically disadvantaged' individuals but was a strong opponent of race hygiene, the Nazi interpretation of eugenics. Jan Gunnar Faye Mohr's research interest was gene mapping, and he developed techniques for early prenatal diagnosis based on analysis of samples from the amnion.

Søren Brunak is a bioinformatician, who uses large sets of data to study how individual genetic differences between people result in different illness profiles in different populations. In this connection, Schierup and Brunak recently published a major article in *Nature* (2017), which describes a reference genome which can be used to develop tailored medicines, based on their analyses of genetic variation in the Danish population.

Marine biology

Bottom-dwelling animals and plankton were the primary focus of Gunnar Thorson's research. His studies, which began in Eastern Greenland and continued in the Oresund, were expanding to include the Persian Gulf, the Canary Islands, California, and Senegal after World War II. On the basis of these studies, he argued that "parallel animal communities" are found in all of the world's oceans. These communities were composed of a dominant population of a small number of species existing alongside many less common species. He was forced to adjust this theory when he discovered that the bottom fauna of the Gulf of Thailand is extremely diverse, but without dominant species. However, his demonstration of the ecological interplay between dominant animals and the relationships between predators and prey remains valid.

When the *Dana* circumnavigated the globe in 1928-

1930, Halfdan Einer Steemann Nielsen became interested in plankton algae, which became the subject of a number of his works. A breakthrough in his research occurred when he began working with radioactive isotopes, especially C^{14}, in 1949-1950. He developed a completely new method of measuring the production of organic matter in the sea based on C^{14}, originally from stationary observation platforms, the Danish lightships. Methods which could be used on ships during sailing were tested on a large scale by the second Galathea expedition (1950-1952), which had temperature-controlled aquaria for water samples on board.

Tom Fenchel works on marine microbiology and population ecology, with a special focus on marine ciliates (unicellular organisms) and their relationship to sediments and other microorganisms, as well as to larger animals such as gammarids (beach fleas) and water snails (*Hydrobia* ssp.). His research on the ecology of small and microscopic organisms has had a major influence on marine biology; he is particularly known for Fenchel's Law, which describes the relationship between exponential population growth and the body size of the organism. He has also worked on reconstructing the early stages of marine life. He was president of the Academy from 2004 to 2008.

Bo Barker Jørgensen works on marine biogeochemistry and marine microbial ecology, with a focus on the deep sub-seafloor biosphere. He studies the carbon, sulphur, and iron cycling of subsurface microorganisms in marine sediments in an attempt to understand how these organisms differ from those found at the sediment surface.

Thomas Kiørboe's research interests include the ecology of plankton of the open sea, including extremely small, almost microscopic water fleas. It can be difficult for extremely tiny animals in a large sea to find mates, and Kiørboe has demonstrated how pheromones are involved in helping males track down females. He has also worked on the energy balance of plankton swimming strategies and differences in the mobility and life cycle of males and females, as well as 'marine snow', a shower of larger and smaller particles of organic detritus, which is constantly sinking towards the ocean floor.

In a wide variety of publications, Michael Kühl has carried on and developed Tom Fenchel's studies of the ecology of microbial marine organisms, including aggregates of organisms, which attach to surfaces to form a thin layer (biofilm). He has used advanced technology, including microsensors and complex image analysis, to study the dry matter production and metabolism of diatoms, bacteria, and cyanobacteria – prokaryotic organisms which perform photosynthesis.

Freshwater biology

Kaj Berg's earliest research interests were water fleas, plant plankton, and mosquito larvae, which he later expanded to include more general limnological studies. His first major work was an important study of the bottom fauna of Lake Esrum (1938), which made the lake a classic location in freshwater biology. He went on to study the river Suså in collaboration with Pétur Mikkel Jónasson, among others (*The River Susaa,* 1943-1948), as well as Gribsø Lake (1956). In addition to Danish lakes, Pétur Mikkel Jónasson has explored the lakes of his homeland Iceland, in particular Mývatn and Thingvallavatn, which are included on UNESCO'S world heritage site lists, in part thanks to his comprehensive and broadly conceived works on the large lakes. In his 1972 higher doctoral dissertation, he described the ecology of Lake Esrum, with a special focus on the quantitative distribution of bottom-dwelling animals, recently followed by an updated description of the bottom-dwelling animals of the lake and their adaption to the lakes' varying oxygen conditions.

Morten Søndergaard's research covers many aspects of freshwater biology. He has worked on microbial ecology, including the bacterial decomposition of dissolved organic matter in lakes and functional diversity of microbial communities. He has also described the impact of climate change on freshwater ecosystems.

A major focus of Kaj Sand Jensen's research has been the physiology of aquatic plants and the interplay between these plants and the surrounding aquatic environment. For example, he has explored how plants are able to adapt to light attenuation at lower water depths by exploiting available light more efficiently and slowing down their metabolisms.

Comparative anatomy

The subject of Karl Georg Wingstrand's higher doctoral dissertation was the avian pituitary gland, and he went on to study the pituitary glands of marsupials and lungfish. His best-known work is his study of the anatomy of the famous 'urmollusk' (*Neopilinia*), which was discovered by the second Galathea expedition. He also studied crustaceans and some worm-like lung parasites and was able to demonstrate that these parasitic worms must be classified as highly modified and reduced crustaceans.

Jytte Reichstein Nilsson has worked on the interplay between form and function in unicellular animals using electron microscopy and autoradiography. She has also worked on the absorption of liquids by amoebas as well as cell division.

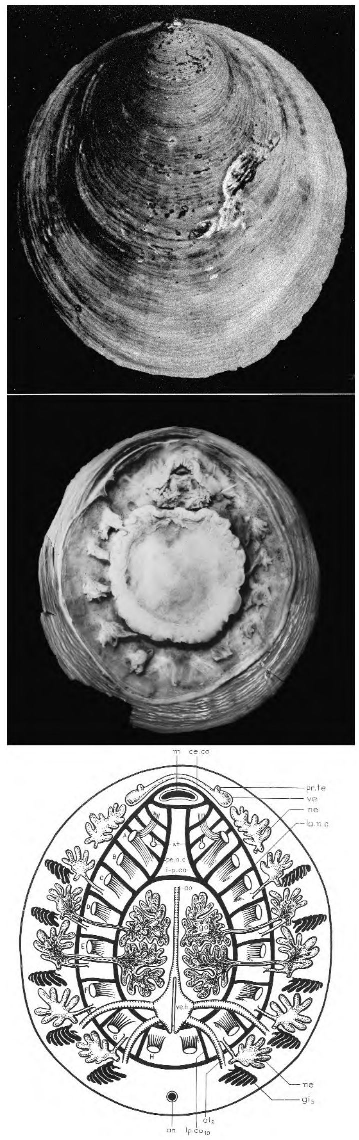

FIGURE 10. *Neopilinia galatheae* Lemche (1957), was discovered in 1952 in the sea off the coast of Costa Rica on the second Galathea expedition, and was subsequently studied thoroughly by the zoologist Henning Lemche and the comparative anatomist Karl Georg Wingstrand. Somewhat misleadingly, *Neopilinia* has been called the 'urmollusk'; fossilized shells of other related forms have been found from the Pre-Cambrian to the Carboniferous. On the basis of its segmentation, the animal must be assumed to be related to segmented primeval forms of all other molluscs (Mollusca); mussels, octopuses and snails all have shells, but are not segmented. On the other hand, segmentation is common among many other invertebrates, for example in the phyla Annelida and Arthropoda, including crustaceans, spider, and insects, and others). This means that segmentation must be considered a primitive trait among invertebrates. The figure, composed of partial figures from Lemche and Wingstrand's treatise "The anatomy of *Neopilina galatheae* Lemche, 1957 (Mollusca Tryblidiacea)" in *Galathea Report* 3 (1959), shows *Neopilinia's* mussel-like shell viewed from the dorsal side (above), while the animal's ventral side (figure in middle) lacks a shell and has six pairs of excretory organs, which suggest the animal's segmented anatomy. The segmentation is clearly seen in the schematic drawing of the animal's musculature and other internal organs (below).

Plant community history and paleontology

In the mid-20th century, Denmark was a world leader in research on plant community history. Johannes Iversen used pollen analyses to study the ecological tolerance of a wide variety of species in his reconstruction of the plant communities of the past. For example, he demonstrated that the distribution of ivy and holly are limited by extremely low winter temperatures, while mistletoe is limited by cool summers. He applied pollen analysis to the study of forest clearing and agriculture during the Neolithic revolution. Together with Jørgen Andreas Troels-Smith, he carried out experimental logging and farming using Neolithic techniques in order to explain the pollen diagrams. These methods were further developed by Svend Thorkild Andersen, who worked on the development of natural conditions during the Quaternary, including plant communities, soil, and climate in interglacial periods and short warm periods during glacial periods. He refined the pollen diagrams by studying the pollen production of individual tree species.

Paleontologists can be divided into two broad categories with regard to their primary research interests: the study of fossil invertebrates often takes place within a geological and stratigraphic framework (see p. 187s.) because the fossils are frequent and the faunistic composition change from stratum to stratum, which helps to define the stratigraphy, while the study of vertebrates is closer to biology, among other reasons because the fossils of these animals are relatively rare and usually not important for stratigraphy, but they are important parts of comparative studies with recent forms. Valdemar Jules Poulsen has studied trilobites, brachiopods, and conodonts in geographically disparate areas: Argentina, Greenland, Newfoundland, Siberia, and Australia – and on the island of Bornholm. His demonstration of the existence of a parallel faunal development on Newfoundland and in Scandinavia has influenced our understanding of continental drift. Hans Jørgen Steen Hansen's specialization is the microscopic foraminifera, unicellular amoeboid organisms with a calcium carbonate external shell (often called a test). He has studied the test structure of foraminifera using electron microscopy to understand their taxonomy and ecology. Olaf Michelsen has studied the same group of organisms from a geographic-stratigraphic perspective rather than the biological-evolutionary. He has also worked on a geological survey of Denmark's underwater territory in the North Sea.

Behavioral biology

Behavioral biology is one of the most recent branches of biology to be represented in the Academy. Jacobus Jan 'Koos' Boomsma studies social insects, and is best known for his work on the so-called monogamy hypothesis, which posits that the development of strict, life-long monogamy is an evolutionary condition for the complex social structures of hymenoptera (membrane-winged insects) such as bees, ants, wasps, and termites. According to this hypothesis, if a queen of one of these insect-societies is strictly monogamous, her young will be as closely attached to their siblings as to their own young, which promotes collaboration and social behavior. He has also made important contributions to the study of the 'fungus farms' of social insects.

Social behavior and collaboration occur not only among the hymenoptera, but among spiders as well, which is a central topic for Trine Bilde. Her experiments have shown that spiders are more likely to share their food with other spiders if they are related, and it appears that the development of social behavior in spiders is connected to inbreeding and uneven sex ratios. The degree of social organization varies considerably among spiders, and some species are permanently social while others only exhibit social behavior periodically.

The expansion of experimental subjects after World War II

By the end of World War II, a number of research disciplines within physiology – the study of how the body works – were firmly established in Denmark. Many of these specific research strengths can be traced directly to the enormous influence by August Krogh within both biological and medical physiology. In addition, the conferral of the Nobel Prize on Henrik Dam in 1943 for his discovery of vitamin K contributed to the consolidation of Danish experimental research, and with Herman Kalckar's contribution to our understanding of ATP (adenosine triphosphate) as the universal energy currency of the cell, a strong biochemistry tradition was also founded. Finally, the structure of DNA was decoded in the 1950s, and the subsequent establishment of molecular biology – an entirely new field of research – would revolutionize the experimental approach to biology and medicine. Several members of the Academy, including members outside the classical university milieus, played a decisive role in this development.

Bleeding chickens led to the discovery of vitamin K and a Nobel Prize

In 1928, Henrik Dam began studying poultry nutrition, with a particular emphasis on cholesterol. He soon observed that cholesterol-poor feed caused serious hemorrhages in the muscles, inner organs, and skin within just a few weeks. Through many well-planned studies with contributions from other national and international research groups, he demonstrated that the internal bleedings were caused by the failure to produce prothrombin, a protein central to blood clotting. This discovery, which earned Henrik Dam the Nobel Prize, was published in German, and the missing factor for prothrombin synthesis was named 'Koagulationsvitamin', abbreviated vitamin K. Soon after, Dam and his colleagues demonstrated that injections of vitamin K dramatically improved blood coagulation in newborn babies, and the treatment immediately reduced infant mortality at the country's hospitals. Her Majesty Queen Margrethe II was one of the first children to receive this treatment.

The structures and functions of proteins

In the post-war period, Danish researchers played an important role in clarifying how proteins are composed from amino acids, which contributed to the development of modern protein chemistry. Kaj Ulrik Linderstrøm-Lang defined the primary structure of proteins in terms, which are still used today: the primary structure which specifies the precise sequence of

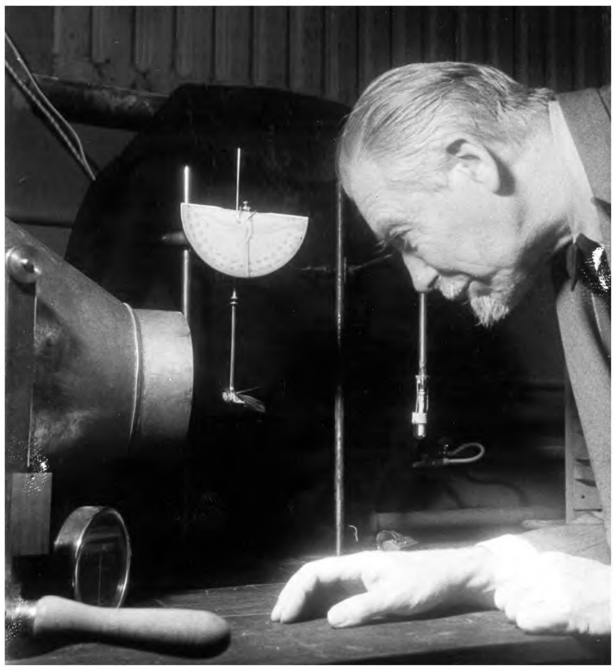

FIGURE 11. August Krogh, who was awarded the Nobel Prize in 1920 for his studies of capillary physiology, pioneered studies in many fields of physiology. Upon retirement, he moved his laboratory to the basement of his private home in Gentofte, north of Copenhagen. Here he spent his last years studying physiology and metabolism of flying locusts in collaboration with Erik Zeuthen and Torkel Weis-Fogh. Among other instruments, the group developed a wind-tunnel and a carrousel with flying locusts enabling sophisticated measurements while these large insects where flying around.

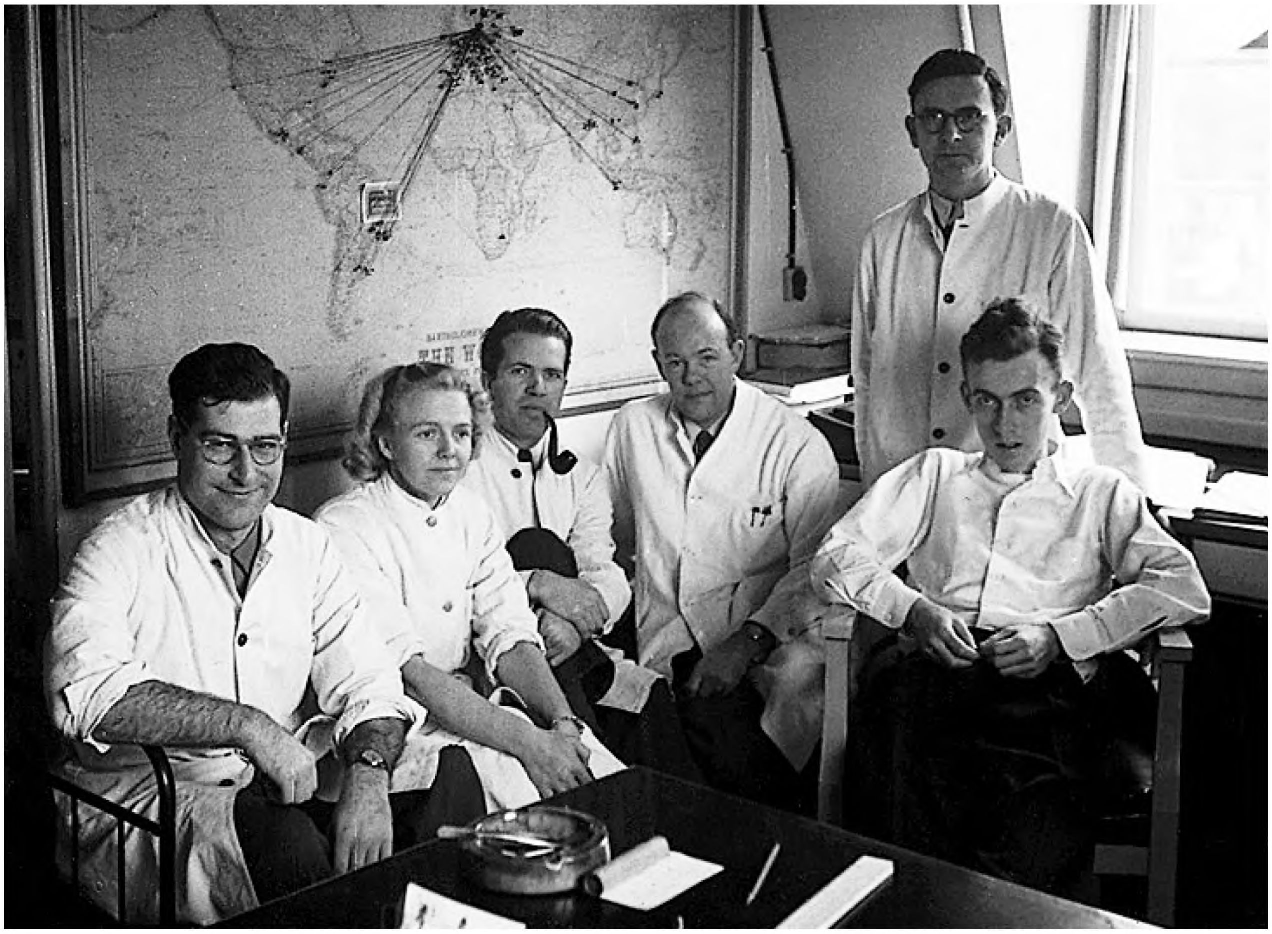

FIGURE 12. Ole Maaløe – the founder of molecular biology in Denmark – is seated in the middle with a pipe in his mouth in this photograph from 1950. The research group included two future Nobel Prize winners. Niels Kaj Jerne (Nobel Prize in 1984) is standing farthest to the back near the window, and James Watson (Nobel Prize 1962) is sitting in front of him.

amino acids, the secondary structure, which is the pattern of hydrogen bonds, which stabilize the molecule, and the tertiary structure, which is the three-dimensional structure determined by protein folding. Peter Roepstorff later advanced this research by using mass spectrometry to produce more detailed studies of the structures and functions of proteins.

Bacteria, bacteriophages and molecular biology

Directly inspired by courses in the United States, Ole Maaløe established a research programme to explore cell growth in bacteria in the late 1940s. It was evident that bacterial production of new proteins is proportional to the number of ribosomes (a cell organelle), and with the description of the structure of DNA in 1953, understanding protein synthesis became the central question in biology research in the 1950s. Some of these bacteria studies were carried out together with Niels Ole Kjeldgaard, who was also interested in bacteriophages (vira that reproduce themselves with the help of bacteria), and who had cloned the first gene in these bacteriophages during a sojourn to Paris. From the late 1960s, Kjeldgaard worked with Kjeld Marcker, who had been called home from Cambridge, where he and Frederick Sanger (who was later awarded two Nobel Prizes) had demonstrated that a special t-RNA is involved in the synthesis of all proteins. The English-born scientist Brian Clark joined the research group, and later Jens Nyborg initiated the first crystallographic studies of the structure and function of proteins and RNA molecules. Marcker's interest shifted to the molecular biology of legumes, and the research group developed a number of techniques for genetically engineering plants, in collaboration with Novo among others. Ole Maaløe's student Niels Peter Fiil, who was research director at Novo, also played a decisive role in the genetic engineering project, and based the industrial production of insulin on genetically engineered bacteria. Today, Søren Molin studies a variety of additional possible applications for genetically engineered bacteria, including treatments for diseases and the industrial production of biofuels.

Torben Heick Jensen studies how cells ensure precise and correct protein synthesis, with a particular focus on how cells ensure the quality of newly synthesized RNA and handle the destruction of defective RNA.

All cells in an organism share the same genetic material, so the many differences between the different types of cell are due to the way the so-called transcription factors determine which genes are expressed and which are repressed during cellular differentiation. Susanne Mandrup uses advanced genome techniques to study the molecular mechanism behind the development of fat cells.

Agnete Munch-Petersen carried out extensive biochemical, genetic, and physiological studies of bacterial nucleotide metabolism. Hans Klenow, who was particularly interested in the latter, had worked with Sanger at Cambridge in the 1950s and had discovered that the DNA polymerase (the enzyme responsible for DNA replication) consists of two fragments, one of which is still called 'the Klenow fragment'. Ole Westergaard's description of the topoismomerases was an important step towards understanding DNA replication; these enzymes participate in directing the coiling of the DNA molecule during cell division. While the molecular background for cell division is naturally of great scientific interest, it also has direct relevance for our understanding of the uncontrolled cell division which takes place in cancerous tissue.

Cancer research

As cancer is still a frequent cause of death, it is not surprising that many of the members who study the division, growth, and death of cells are interested in investigating which mechanism are altered in cancer cells. For example, Marja Jäättelä studies the molecular mechanisms responsible for programmed cell death, with a special focus on how cancer cells evade these processes, and to what extent it is possible to alter the sensitivity of cancer cells. Ulla Margrethe Wewer studies how the extracellular matrix is altered in tumors. Anja Groth and Kristian Helin focus on epigenetic changes in tumor cells, while Jes Forchhammer has studied the influence of viral infections. Finally, Henrik Clausen is exploring how the saccharides which coat proteins affect the structures of cells and proteins, with focus on how these functions are altered by cancer.

The Nobel Prize to Kaj Jerne – the role of the immune system in kidney transplant and epidemics

While Niels Kaj Jerne began his scientific career as a student of Maaløe, he quickly became interested in the functions of the immune system. Over a 20-year period from the mid-1950s, Jerne developed the theory that the body itself produces colossal amounts of different antibodies even before the foreign substance (the antigen) enters the body. When the foreign antigen binds to the surface of the lymphocyte with the right antibody, the lymphocyte multiplies, which stimulates the production of antibody. Jerne received the Nobel Prize in recognition of this insight in 1984. He also hypothesized that the surface proteins which recognize the antigens vary from individual to individual, which plays a role in the rejection reactions which follow organ transplantation.

Precisely the idea that implanted organs react against the antigens of the host was also put forth by Morten Simonsen, who experimented with kidney transplants in dogs in the 1950s. Similar immunological studies by Søren Buus and Arne Svejgaard led to the first successful kidney transplants involving Danish patients in 1964. Jørgen Kjems has just established a research center which will study the molecular basis for the ability of immune cells to recognize the difference between antigens and the proteins the body produces itself. This is important in relation to understanding the causes of autoimmune diseases with a view to developing treatments.

Two of the Academy's female members have focused on vira. Ebba Lund was an expert in virus infections in mammals and the spread of vira in waste water, while Lone Simonsen studies the spread of viral diseases during epidemics. The population geneticist Freddy Bugge Christiansen is also interested in the co-evolution between vira and our immune system.

Insulin and the many other hormones of the gastrointestinal system

With the establishment of insulin research at Novo, Danish scientists became interested in the hormonal regulation of metabolism and blood sugar levels early on, and since the 1970s, a number of new hormones have been identified which are released by the gastrointestinal tract and which affect metabolism, digestion, appetite, and other functions of the central nervous system. This development is primarily due to the new methods developed by Jens Frederik Rehfeld for the identification of very weak concentrations of circulating hormones, in particular gastrin and cholecystokinin (CCK). Rehfield's research group, with its sophisticated approach to applying new molecular methods, has produced cutting-edge endocrinological studies.

Jens Juul Holst discovered that blood sugar often falls after a meal in patients who have had gastrointestinal operations. This led to the discovery of a new peptide hormone which is released in the intestine, glucagon-like peptide-1 (GLP-1). GLP-1 stimulates the release of insulin and lowers blood sugar levels. Naturally, this effect is of interest to diabetes patients, whose blood sugar levels often spike dramatically after meals. As GLP-1 also inhibits appetite, it could be used to help overweight patients with type 2 diabetes to eat less. Unfortunately, GLP-1 breaks down very quickly in the body, so it was a sensation when Holst and his co-researchers discovered a peptide in the saliva of the North American gila monster, which has the same effect as GLP-1. This discovery led to the development of the medicine liraglutide, which stimulates the GLP-1 receptor, and is now used in the treatment of type 2 diabetes.

Early in his career, Thue Schwartz characterized a completely new hormone – pancreatic polypeptide. Today, he and Ulrik Gether are studying how so-called 7TM receptors (the name refers to the seven transmembrane segments) are stimulated by different hormones, and how this affects the brain's neurotransmitters and communication between individual brain cells. This research can help us understand which signals lead to a sensation of satiety, as well as the development of new medicines for the treatment of depression and dependence on addictive substances such as cocaine.

Hans Braüner-Osborne is also exploring 7TM receptors and is searching both for new receptors and the substances which stimulate them. He is studying the function of receptors, for example in connection with point mutations, where it is possible to determine the significance of individual amino acids. Søren Kragh Moestrup has received considerable recognition for the discovery and identification of a number of transport receptors which play a decisive role in the body's absorption of vitamins, hemoglobin, enzymes, and medicines.

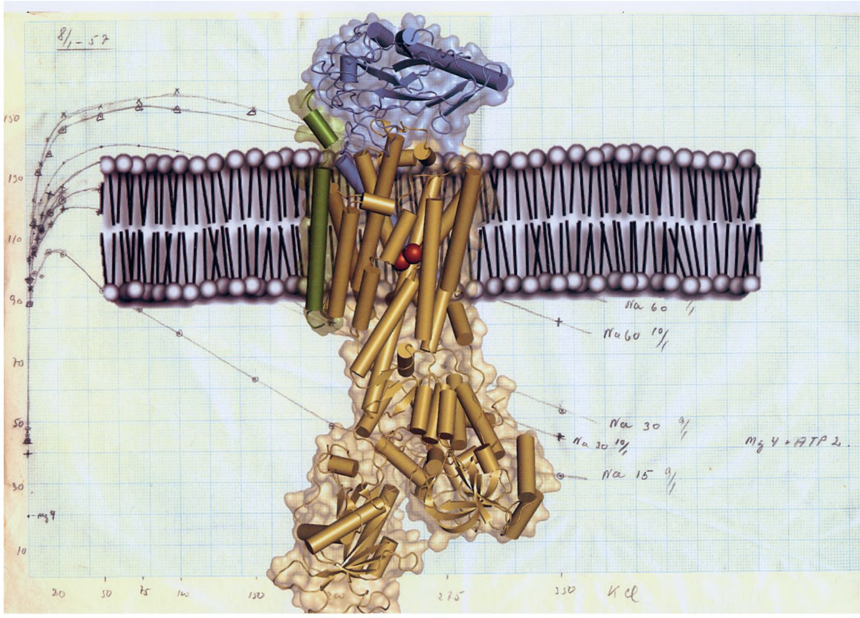

FIGURE 13. The sodium-potassium pump is the energy-demanding protein, which actively pumps sodium out of the cell while potassium is absorbed. Poul Nissen recently described the structure of this protein and the molecular basis for the active transport and consumption of ATP (*adenosine triphosphate*). One of Jens Christian Skou's hand-drawn graphs from the original discovery of the sodium pump are used as a background in this figure – a discovery that brought him the Nobel Prize in chemistry in 1997.

The sodium ion pump and the difference between active and passive ion transport

In 1946, August Krogh introduced the concepts of active transport (pumping) versus passive leakage of ions, and drew attention to the fact that active transport consumes energy. This conclusion was based on the groundbreaking introduction of radioactive isotopes in biology research, an area in which the work of Hans Henriksen Ussing would have a decisive influence. He developed a mathematical model to describe how the movement of ions over an epithelium (membranes that cover the inner and outer surfaces of the body) depend both on a difference in concentration and a difference in electric potential. To test this model, he designed an experimental apparatus known as an Ussing chamber, in which the skin of a frog is suspended between two identical saline solutions. After a short time, the underside of the skin becomes slightly positive, and Ussing theorized that this electric potential is created by the active sodium transport, while chloride is distributed passively. To prove this, he short-circuited the electric potential and demonstrated that the short-circuit current corresponds to the sodium transport: sodium is transported actively, and chloride follows along passively. In addition, the skin's metabolic rate increased with increased transport, and the active sodium transport stopped when the mitochondria were poisoned. Thus, active transport requires energy in the form of ATP.

At about the same time as the development of the Ussing chamber, Jens Christian Skou identified the sodium-potassium pump, for which he received the Nobel Prize almost 40 years later (1997). During a research stay in the United States, he stumbled across a description of an enzyme which splits ATP, and when he returned to Denmark and began extracting this enzyme from crab nerve cells, he discovered that the presence of both sodium and potassium ions stimulates enzyme activity. He published his results in 1957, and concluded that "the enzyme appears to fulfil a number of the conditions which must apply to an enzyme which is involved in the active elimination of sodium ions from nerve fibers". With this discovery, Denmark became a world leader in research on ion transport across biological membranes. Arvid Maunsbach used electron microscopy to determine the exact location of the pumps, particularly in the epithelial cells of the kidneys, and Peter Leth Jørgensen developed methods for producing extremely pure preparations of the pump. On the background of these preparations, Poul Nissen took over the cover of *Nature* in 2007 with three articles on the structure of the sodium pump. Currently, work is being done to develop new types of medicine to treat heart disease, cancer, and infectious diseases, among other conditions.

FIGURE 14. Bengt Saltin measuring the rate of oxygen uptake of the Swedish steeple chase runner Anders Garderud during the Olympic Games in Mexico City (1968) in connection with his studies on the differences in muscle type amongst different athletes.

The functions of the kidney

August Krogh is often credited for having said that "the kidney is a devilish organ" – in reference to the extreme complexity of its functions. This opinion, nevertheless, did not prevent Krogh from suggesting that Poul Christian Brandt Rehberg should study the physiology of the kidney. Rehberg was interested in determining how much liquid is filtered by the capillary net of the kidney (the glomerular filtration rate, or GFR), and conceived the idea of using the substance creatine, because this naturally occurring waste product of muscle metabolism is freely filtered by the capillaries of the kidneys without being absorbed or expelled afterwards. This enabled Rehberg to demonstrate that the kidneys of adults filter about 180 liters of liquid in a 24-hour period, and creatine is still used all over the world to measure kidney function.

Niels Anker Thorn initiated studies of the secretion of the hormone vasopressin by the pituitary gland in connection with the regulation of the water and salt balance of the kidneys. It had been known for some time that the hormone vasopressin increases the water permeability of the conducting duct system of the kidneys, and it was generally believed that the water simply ran through the cell membrane. Thus, it was a surprise when other scientists in the 1990s discovered that water actually does run through specific membrane proteins, the so-called water channels or aquaporins. Søren Nielsen played a central role in demonstrating the importance of these channels, particularly in the kidneys. Before the discovery of the water channels, Ulrik Vilhelm Lassen studied different membrane transporters in the kidneys.

Exercise physiology, muscle function, and oxygen transport

Hard physical exertion can increase the metabolic rate almost tenfold, and the ventilation of the lungs and the heart's pumping function increase almost immediately. Obviously, this response ensures that enough oxygen is delivered to the muscles, but how it is regulated is still poorly understood: it is based on a mixture of signals from the body and the brain's active role in initiating blood circulation and breathing as the muscles are activated ('feed forward' regulation). Erling Asmussen and Erik Hohwü-Christensen were interested in this regulation, and performed a number of early studies on how blood circulation, lung ventilation, body temperature, muscle function, and blood sugar are affected during walking and running. Fritz Buchtal and Ove Sten-Knudsen carried out a number of fundamental physical-mathematical electromyographic studies of the functions of the muscles and nerves. Ingmar Engberg and Hans Hultborn studied how the central nervous system activates the muscles; they implanted electrodes in nerve and muscle cells and added various neurotransmitters. Bengt Saltin was one of the world's leading sports physiologists, and he established a large research group with a special focus on the functions of muscles and metabolism. In his classic early studies, he demonstrated how differences in the composition of muscles determines their work capacity, and he performed detailed measurements of blood flow to muscles at various exercise intensities and under oxygen-poor conditions. Ulrik Christian Crone focussed on the physiology of microcapillaries, and Poul Weber Kruhøffer performed quantitative measurements of gas exchange in the lungs. Søren Peter Fuchs Olesen is currently studying how changes in specific ion channels affect heart rhythm and the contraction of the cardiac muscle. Bente Klarlund Pedersen's research continues and develop the tradition of work physiology, and has demonstrated that the muscles release special hormones – myokines – during exercise, which have a variety of effects on the metabolism of the different organs.

Brain research and modern scanning techniques

The human heart accounts for about one-fourth of the energy conversion of the body, despite the fact that it only weights just under 1.5 kg. For this reason, it requires a high volume of blood flow, and immediate and serious damage occurs if insufficient oxygen is supplied. By developing new methods, Niels Alexander Lassen was able to describe blood circulation and metabolism in the brain as early as the 1950s. This work lay the foundation for the subsequent mapping of the brain's normal functions, as well as contributing to important insights into the causes of disease and blood clots. Today, Leif Østergaard shares this interest in blood clots. Using a mixture of physiological measurements and mathematical models, he studies how the brain's blood vessels ensure adequate blood blow and oxygen transport. Olaf Bjarne Paulson, Gitte Moos Knudsen, and Liselotte Højgaard are central figures in the development of new scanning techniques, such as MR and PET, which enable more accurate measurements of blood circulation in the brain, and they have developed a number of substances which can provide detailed information on the brain's metabolism under different conditions.

Maiken Nedergaard has recently demonstrated that the brain removes cellular waste while we sleep, which can have great importance in relation to brain diseases such as Alzheimer's. It appears that the brain's support cells – in particular the so-called astrocytes – play an active and important role in this process.

Many modern drugs are extracted from plants or fungi, and therefore much pharmacological research begins by examining natural substances. Povl Krogsgaard-Larsen has focussed on muscimol from the red fly agaric (*Amanita muscaria*). If the mushroom is eaten, this substance will produce distinctive mental disturbances, but with rather minor changes of the molecular structure, muscimol can be used as an effective pain relief and sleeping medicine.

Jakob Balslev Sørensen studies how the brain's cells release the many different neurotransmitters which are involved in communication with other nerve cells. His major interest is the SNARE complex – a kind of protein hinge – which makes it possible for small intercellular vesicles to release their neurotransmitters.

The human brain is extraordinarily complex, which means studying the fundamental mechanisms of nerve and brain function in animals with simpler structures can be an advantage. This is why Cornelis Johannes Pieter Grimmelikhuijzen studies the neurophysiology of invertebrates to understand the evolution of both neuropeptides and their receptors. These studies are thus a fitting continuation of Denmark's proud tradition for comparative physiology.

Zoophysiology: comparative physiology

Flying insects were Torkel Weis-Fogh's research interest. He studied them in the laboratory the retired Krogh had installed in the basement of his home, where grasshoppers were placed in wind tunnels or hung up in carousels. Weis-Fogh demonstrated that grasshoppers stabilize their flight by sensing weak air currents with a small organ on their foreheads, and together with Buchthal, he carried out detailed studies of the mechanics of flight as well as electrophysiological studies. Weis-Fogh proved that the extremely large increases in metabolic rate during flight (approx. 50 times) are primarily fueled by burning fat. He also discovered that the grasshopper wing hinge contains the protein resilin, which behaves almost exactly like rubber: the reversible deformation takes place without loss of energy. Svend Olav Andersen continued the study of the biophysics and biochemistry of this exciting protein. Carl Christian Barker Jørgensen had an extremely varied research career which included projects on water and salt balance in addition to endocrinology, and he was particularly interested in how aquatic animals feed using suspension filtration over their gills.

Axel Albert Michelsen also worked on grasshoppers, and he demonstrated that these animals are able to hear a wide variety of frequencies early in his career. He has since carried out detailed biophysical studies of the insects' ability to determine the directionality of sound, and has also studied the dance language of bees.

During World War II, Erik Zeuthen and Kaj U. Linderstrøm developed a method of measuring the metabolism of extremely small animals and individual cells; this made it possible to understand the costs of cell division. Zeuthen also became interested in the influence of body size on metabolism, and his demonstration that small animals have a much higher weight-specific metabolism than large animals is still a relevant and unexplained biological question. Tobias Wang is currently performing a number of comparative studies of metabolism and cyclic physiology, in part in order to understand how giraffes are able to live with extremely high blood pressure.

Erik Hviid Larsen has performed a number of integrative studies of water and salt balance, in particular on amphibians, and combines an exploration of specific ion transporters with studies of intact animals. The results are analyzed using detailed mathematical models which have contributed to clarifying the isotone transport of water across the epithelium, for example how water is reabsorbed in the intestine. Else Kay Hoffman has focussed on the water and salt balance of cells, and her many studies show that changes in cell volume have wide-ranging consequences for cell division, migration, and programmed cell death. Therefore, the volume regulation of cells is important to our understanding of a variety of diseases.

Conclusion

Our historical review demonstrates that Denmark has had both strong traditions in biology in general and also very innovative researchers in new fields such as genetics, molecular biology and branches of physiology. It is clear that the progress of the research outlined here – both for the individual scientists and for the research groups, which in some cases have spanned several generations – has often not been linear, and that a considerable number of important results have been achieved when researchers have made new and unexpected findings by going against the stream. It is worrisome, especially for the young scientists, that riskier research programmes with somewhat 'eccentric' approach may have difficulty in finding funding in contemporary Denmark. Let us hope that future decision-makers at ministries and foundations will have faith in the scientists and allow genuine curiosity to direct the future course of Danish biological research.

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