Preface

The science of fine structure, development, and function of tissues and organs is histology [Greek histós 'tissue', 'fabric' and logos 'word', 'science']. The beginning of histology started with the invention of the first compound microscope at the end of the 16th century. Histology as an independent discipline of science separated in the early 20th century from descriptive anatomy. Since then, huge progress has occurred due to the development of new microscopes (transmission and scanning electronmicroscopy, confocal microscopes) and research and staining techniques (histochemistry, immunohistochemistry, fluorescence techniques) (see Chapter 1, Introduction to Histological Techniques) with a concomitant increase of our understanding of the fine structure and function of tissues and organs.

It was our conviction that this complexitity of new techniques and results in histology could only be demonstrated in a multi-author book of many specialists in the field sharing their knowledge and experience. Thus, a book with 18 chapters comprising the work of 28 authors and co-authors from 10 countries arose. We must admit that we sometimes underestimated the task and time in order to motivate all our collegues to meet the deadlines. An additional intention of this monograph was the integration of functional aspects and a comparative view on the diversity of histological features of fishes (actually more than 30.000 species described) with their amazing ecological specializations. To match with these expectations we also encouraged the authors to compile very detailed lists of references and to produce high quality figures. We therefore believe that this monograph with its eighteen chapters represents a useful compilation of the actual state-of-the-art of histology helpful for scientists and students in many disciplines. Though this monograph treats normal histology it will be useful as a guideline for fish pathology and fish histopathology.

In Chapter 1—**Introduction to Histological Techniques**—a description of the history of histology over five centuries is presented starting with the invention of the first compound microscopes at the end of the 16th century. The detailed description of the various histological techniques (fixation, staining, fluorescence techniques) represents a useful introduction for people at the start of their histological experience. The chapter is completed by the description of freezing, histochemical and immunohistochemical techniques. In Chapter 2—**Integument**—differences and common features of the integument of various taxa of fish are described comprising jawless, cartilagenous and teleost fishes. Particular intention is paid to the latest terminology of the various cell types of the epidermis. Specialisations of the integument of weakly electric mormyrid and gymnotiform fishes are also mentioned. In Chapter 3—**Fish Skeletal Tissues**—the amazing diversity, dynamics, and evolution of osteichthyan skeletal tissues is described. Fish skeletal tissues comprise mineralized bony tissues, cartilage, which can mineralize, teeth and some specialized unmineralized conjunctive tissues, which all serve various mechanical and physiological functions. It is shown that fishes consist of two main groups, those with bony tissues with embedded cells–cellular bone—and those which possess bone devoid of enclosed cell–acellular bone. The amazing characteristics of alive bony tissues is demonstrated which show a continuous more or less remodelling assuming various physiological functions, in particular exchanges between bone and the internal environment thus participating in various homeostatic activities and hormonal control. It is fascinating to learn how the improvement of techniques of sectioning undecalcified material and the recent great development of 3D computering has greatly increased our understanding of the structure and function of skeletal elements. The chapter also describes a bone anomaly termed hyperostosis which represents an abnormal swelling of bone. In Chapter 4—**Muscular System**—the three basic types of muscle, striated muscle, smooth muscle, and cardiac muscle are described both at the light and transmission

electronmicroscopical level. The specialized extrinsic eye muscles are also treated. A detailed description of the complex biochemical interactions underlying the process of muscle contraction is presented. The anatomical organisation of the muscle fibers of the axial muscle in myomeres and their functional implication is described. The different muscle fiber types—slow-red fibers, intermediate or pink fibers, white or fast fibers—and their function are shown based on biochemical and histochemical characteristics. A comparison of the heart of non-osteichthyan fishes (agnatha, elasmobranchs) terminates this chapter. In Chapter 5—**Structure and Function of Electric Organs**—an overview is presented on the eight groups of electric fishes which have evolved independently based on convergent evolution. Both the anatomy and the fine structure of the electric organs are described as well as functional aspects. Differences and similarities of the organs due to the convergent development are mentioned. Ontogenetic data are presented including larval electric organs which are found both in mormyrid and gymnotiform fishes. In Chapter 6—**Digestive System**—the anatomy and histology of the gastrointestinal tract, comprised of four main parts, is discussed. The morphological and physiological adaptations of different fish species to digestion of food as well as gas exchange through the digestive tract are presented. Histology of different parts of the gastrointestinal tract is also described, indicating types of epithelial cells and functions they perform. The change of the morphology, histology, and function of the gastrointestinal tract during ontogeny is also discussed. The glands of the gastrointestinal tract are described in Chapter 7—**Glands of the Digestive Tract**—they comprise the liver and the pancreas which both are characterized by exocrine and endocrine functions. Important functions of the liver comprise synthesis and secretion of lipoproteins and proteins and neutralisation of digestion products which are described in the chapter. The digestive enzymes produced in the exocrine part of the pancreas as well as the peptide hormones delivered by the endocrine part are subject of the second part of the chapter. One element of the gastrointestinal tract which emerges during ontogeny from the esophagus and which is not treated in Chapter 6, is the swim bladder. This organ is treated in Chapter 8—**Swim Bladder**—the different functions of the swim bladder—hydrostatic organ, respiration, transport of sound waves, sound production—are described. The anatomy and histology of the swim bladder are presented as well as the process of filling the swim bladder with gas. In Chapter 9—**Kidney**—the anatomy of the kidney and the anatomy and function of the nephrons, the functional elements of the kidney, are described. But in this chapter only the kidney of teleost fishes is treated. Particular attention is paid to anatomical and functional differences of the nephrons of freshwater and marine teleosts due to the adaptation to different environmental conditions. The anatomy of fish gonads varies considerably in relation to the phylogenetic position of the taxon. In Chapter 10—**Ovaries and Eggs**—the description is restricted to teleosts. First, anatomical and histological features of the ovary are treated with mention of the adaptations that occur in viviparous teleosts. The complicated processes that occur during folliculogenesis and oogenesis are described. The six stages of oogenesis—oogonial proliferation, chromatin-nucleolus stage, previtellogenesis, vitellogenesis, maturation, ovulation—are treated in detail and are accompanied by fascinating colour photomicrographs. The ontogenetic development of the ovary is described and the cyclic ovarian changes regulated by environmental factors. One feature of eggs, their envelopes, were not treated in detail in the preceding chapter. This information is presented in Chapter 11—**Egg Envelopes**—mainly based on scanning electron microscopy, the amazing diversity of the egg envelopes and their relation to the ecological function, though often not very well understood, are presented. Similarly diverse are the micropyle structures which can be grouped into four categories. The development of the egg envelopes is also described and data on the surprising physical resistance of egg envelopes are presented. Chapter 12 describes—**Testis Structure, Spermatogenesis, and Spermatozoa in Teleost Fishes**—most fishes exhibit external fertilisation, only a smaller part practises insemination. Both aspects are treated in this chapter. Three types of testis structure are described: the anastomosing tubular testis type, the unrestricted spermatogonial testis type, and the restricted spermatogonial testis type. In the course of spermatogenesis spermatozoa differentiate into spermatocytes, spermatids and finally spermatozoa. The diversity of the ultrastructure of spermatozoa is virtually astonishing visualized in the many excellent drawings and ultrastructural pictures. This diversity is seen both in spermatozoa which fertilize the eggs in water (aquasperm) and in those which fertilize eggs internally (introsperm). Many of the fine structural details are not well understood concerning their functions. A surprizing type of spermatozoa are the aflagellate spermatozoa found in mormyroidei and the biflagellate aquasperm found

in many families of the Euteleostomi. At the end of the chapter another astonishing fact is shown: In species of the family Hemitripteridae and in some of the family Cottidae two sperm types exist: so called euspermatozoa and paraspermatozoa. Additional investigations will probably reveal even more fascinating aspects of sperm ultrastructure and function. In Chapter 13—**Cardiovascular System and Blood**—the histological and structural characteristics of the fish heart are reviewed. The external and internal views of the heart reveal the presence of six distinct components: sinus venosus, atrium, atrioventricular segment, ventricle, conus arteriosus and bulbus arteriosus. The different parts of the heart are analyzed following the direction of blood, from the caudal to the cranial end. Because teleosts constitute the most evolved fish group and have experienced the widest radiation in vertebrate evolution, they constitute the backbone of this chapter. However, data from other fish groups—hagfishes, elasmobranches, Chondrostean and Holosteans—are also presented. Vascular histology, with special emphasis on the distribution of collagen and elastin, and structural details of the blood cells across several fish groups, are also treated. In Chapter 14—**Immune System of Fish**—it is shown that the immune system of fish has two components, the non-specific and the specific immunity. Both systems act together. The non-specific immunity is a very affective system acting in a non-specific way against pathogens and it is comprised of transferrins and lectins, lytic enzymes (chitinase, lyzosyme) and phagocytotic activity and it is a characteristic feature of fish. But there also exists in addition a great diversity of lymphoid and lymphomyeloid organs comprizing the thymus, kidney and spleen, the Leydig organ, the epigonal organ, the pericardial tissue, the orbital and the preorbital tissues. However, the specific immunity of fish is weaker than in higher vertebrates. These two kinds of immune system in their common action probably represent one aspect of the evolutionary success of fish. In Chapter 15—**Gills: Respiration and Ionic-Osmoregulation**—the remarkable ability of fish to uptake the O_2 needs for aerobic metabolism and to keep ionic and osmotic levels independent of the diverse characteristics of the habitat they inhabit are described. The adaptations of marine and freshwater elasmobranchs are treated, as well as adaptations of euryhyaline and marine teleosts, but emphasis is put on freshwater teleosts. In some fish the gills as the main organ for respiration do not fulfil this task sufficiently and therefore they have to emerge from the water and take O_2 from atmospheric air using air-breathing organs. The remarkable gill plasticity is described in euryhyaline teleosts and in carp and goldfish after exposure to hypoxia and changes in temperature leading to gill remodelling and intense reversible interlamellar cell proliferation thus reducing or increasing the respiratory surface area. In Chapter 16—**Sensory Organs**—the different categories of the sensory organs are described: they comprise chemoreceptors (olfactory and gustatory systems), photoreceptors (visual system), and mechanoreceptors (auditory and mechanosensory lateral line systems), which are found in all species, and electroreceptors, which are found only in a small subset of taxa. Sensory systems allow fishes to perceive and interpret their complex sensory environments comprizing a remarkably diverse range of marine, estuarine, and freshwater habitats, so it is not surprising that their sensory systems are structurally and functionally diverse which is demonstrated in an impressive way in this chapter based on a range of methods for the visualization of cells and tissues like light and electron microscopy, µCT, etc.

The central nervous system, in particular the brain, integrates sensory information and transforms them into appropriate behaviours. Due to the morphological plasticity of the brain the ecological and sensory specialisations of fish can be visualised in brain morphology. This is exemplified in Chapter 17—**Morphology and Ecomorphology of the Fish Brain: The Rhombencephalon of Actinopterygians**—first, an overview on the various fish taxa of high rank is presented which show the surprising variation in external brain morphology as an reflection of the species biology and the modification of the primary sensory and motor centers in response to environmental needs. In the main part of the chapter the morphological and histological features of the fish brain with special reference to the brainstem in relation to ecomorpholgy are provided. In a comparative way five actinopterygian species ranging from non-specialized to extremely specialized species belonging to major taxa were chosen as model objects for the brainstem description: (1) The senegal bichir (*Polypterus senegalus*), (2) the Siberian sturgeon (*Acipenser baerii*), (3) the spotted gar (*Lepisosteus oculatus*), (4) the European eel (*Anguilla anguilla*), (5) the common carp (*Cyprinus carpio*). Briefly mentioned are the brain of cartilaginous fish (Chondrichthyes), coelacanths, and lungfishes for additional comparative purposes. In Chapter 18—**Endocrine System**—the description is restricted to the endocrine system of teleosts. They possess, apart from the classical endocrine organs of higher

vertebrates, additional organs like the corpuscles of Stannius, the urophysis, the ultimobranchial body, and the pseudobranch. It is shown that the endocrine system, together with the central nervous system, is organized in a hierarchical manner. The highest hierarchic level is the hypothalamus triggering the pituitary by releasing (or inhibiting) hormones to stimulate the classical endocrine glands: thyroid gland, ovary and testis, adrenal gland, or the liver being a source of hormones (insulin like growth factor-I) as well as a target organ. The classical endocrine glands secrete their hormones into the blood circulation to affect their target organs. At each hierarchic level like the hypothalamus, the pituitary, the endocrine glands and the target organs further endogenous and exogenous factors can influence their regulation.

The 18 chapters of the monograph reflect the amazing diversity and complexity of the fine structure of tissues and organs of fishes and thereby convey an impression of the biological complexity at the morphological, physiological, and functional level of the so-called lower vertebrates. We would like to thank all contributors for their very valuable knowledge, their expertise, their effort and their contribution to the book. They are the real backbone of the book. In particular we would like to thank J.F. Webb who did a big job in harmonising as guest editor the different subchapters of Chapter 16, Sensory Organs. We are very sad to convey the death of Professor Dr. H.J. Grier who passed away during the preparation of the book and took part in the completion of Chapter 10, Ovaries and Eggs.

Last not least we would like to thank the publisher for the very constructive cooperation and patience over a period of years and his generosity concerning the number of color pictures which is so essential for the quality of a book on histology.

The editors dedicate this book to their respective wives, Yvonne (Frank Kirschbaum) and Marzena (Krzysztof Formicki).

May 2019

F. Kirschbaum
K. Formicki