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Authors: Oka, Yoshitaka, and Umatani, Chie

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[OVERVIEW]

Zoology of Fishes

Yoshitaka Oka* and Chie Umatani†

Department of Biological Sciences, Graduate School of Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

The Zoological Society of Japan is one of the longest-standing scientific societies in Japan, and it has been publishing a unique prestigious international journal in zoology, *Zoological Science*, for a long period of time since its foundation in 1984 as the continuation of *Zoological Magazine* (1888–1983) and *Annotationes Zoologicae Japonenses* (1897–1983). One of the most salient features of the Society and the Journal may be the variety of species of animals used in the studies by the members of the society and the authors of the journal. Among various animal species, fish may have contributed to almost all disciplines of presentations and publications, including behavioral biology, biochemistry, cell biology, developmental biology, diversity and evolution, ecology, endocrinology, genetics, immunology, morphology, neurobiology, phylogeny, reproductive biology, and taxonomy. Owing to the recent advancement of modern molecular genetic methods in biology, not a few fish species have contributed to various research disciplines in zoological science as model animals. The present Special Issue includes various kinds of such studies in zoological science by taking advantage of a variety of fish species, which are contributed by authors of various generations ranging from junior to senior zoologists.

Key words: fish, genetics, physiology, morphology, neurobiology, behavior biology

INTRODUCTION

One of the most salient features of the Zoological Society of Japan and its official journal Zoological Science may be the variety of species of animals used in the studies by the members of the Society and the authors of the Journal. At present, fish consist of about 35,000 species according to FishBase (https://fishbase.mnhn.fr/search.php), which amounts to nearly half of all vertebrates. Such a wide diversity of fish species endows them with a variety of characteristics in morphology, behaviors, development, etc., some of which are especially advantageous for experiments for specific purposes. Thus, various studies have been conducted by taking advantage of such characteristics of fishes, and fishes may have contributed to almost all disciplines in presentations and publications in Zoological Science. Owing to the recent advancement of modern molecular genetic methods in biology, not a few fish species have contributed to various research disciplines in zoological science as model animals. To date, more than 1000 papers published in Zoological Science have used fishes, according to a search in ZooDiversity web (https://zdw.zoology.or.jp/) as of February 2023. The present Special Issue includes various kinds of such studies in zoological science using fishes, which are contributed by authors of various generations ranging from junior to senior zoologists. This Issue comprises a balanced mixture of five review articles and four original articles and covers GENETICS (1), PHYSIOLOGY (1), MORPHOLOGY (1), NEUROBIOLOGY (4), and BEHAVIORAL BIOLOGY (2). Of these nine articles, one article focuses on studies using a cartilaginous fish, and the other eight articles focus on teleost fishes (medaka, goby, goldfish, electric fish, guppy, cichlid fish, and so on).

* Corresponding author. E-mail: okay@bs.s.u-tokyo.ac.jp
† Present address: Division of Applied Biological Chemistry, Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8 Saiwai-cho, Fuchu-shi, Tokyo 183-8509, Japan
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GENETICS

In the article by Inoue and Takeda (2023), the authors review a novel group of herpesviruses widespread in teleost genomes, *Teratorn* and its related elements. Recently, the authors identified a novel group of herpesviruses *Teratorn* and its related elements in the genomes of various teleost fish species (Inoue et al., 2017). At least some of the *Teratorn*-like herpesviruses are fused with a *piggyBac*-like DNA transposon, suggesting that they have acquired the transposon-like intragenomic lifestyle by hijacking the transposon system. Inoue and Takeda (2023) described the sequence characteristics of *Teratorn*-like herpesviruses and phylogenetic relationships with other herpesviruses, and discussed the process of transposon-herpesvirus fusion, their life cycle, and the generality of transposon-virus fusion. The authors argue that *Teratorn*-like herpesviruses provide a piece of concrete evidence that even non-retroviral elements can become intragenomic parasites retaining replication capacity, by acquiring transposition machinery from other sources. The *Teratorn*-like herpesviruses represent the first example of herpesvirus adaptation to the intragenomic life cycle, and the research may contribute to the understanding of the evolutionary mechanisms of “jumping genes”, which may play important roles in species diversifications and evolution.

PHYSIOLOGY

In the article by Horie et al. (2023), the authors focused on adaptation to a high salinity marine environment exhibited by cartilaginous fishes, which have evolved a highly elaborate urea-based osmoregulation (ureosmotic) strategy called “four-loop nephron” in the kidney. The characteristic structure of the “four-loop nephron” has been proposed to play important roles in performing dedicated roles in each segment and contribute to its overall function, such as urea reabsorption from the glomerular filtrate to maintain a high concentration of urea in the body (Hyodo et al., 2014). This mechanism is considered to be important for reabsorption of urea from glomerular filtrate to maintain a high concentration of urea in the body. Horie et al. (2023) performed laser microdissection (LMD) of the kidney of cloudy catshark, *Scyliorhinus torazame*, and RNA-sequencing (RNA-seq) analysis to obtain segment-dependent gene expression profiles. They further examined expressions of the Na^+-coupled cotransporters abundantly expressed in the second loop samples. Although the proximal II (PII) segment of the second loop is known for the elimination of excess solutes, the authors’ results suggest that the PII segment is also crucial for reabsorption of valuable solutes. Since the regulatory mechanisms of renal function currently remain poorly understood in euryhaline elasmobranchs, the segment-dependent gene expression profiling reported here is expected to be a powerful method for unraveling the renal mechanisms and regulation in euryhaline elasmobranchs.

MORPHOLOGY

In the article by Hagio and Yamamoto (2023), the authors review the ascending visual pathways from the retina to the telencephalon in teleosts, focusing on forebrain visual centers, associated neural circuitries, and evolution. Most vertebrates, including fish, recognize food and predators for survival, as well as individuals of the opposite sex for reproduction, by using various sensory systems such as the visual sensory system. From the authors’ recent studies (e.g., Hagio et al., 2021), they propose that, in the common ancestor of teleosts, there were two visual pathways, the geniculate-like or thalamo-fugal pathway and the extrageniculate-like or tecto-thalamo-fugal pathway, and the geniculate-like system was lost in acanthopterygian fishes, which emerged relatively recently during evolution. Their in-depth analyses on the connections of visual centers also revealed that there are connections shared with those of mammals, and retinotopic organization of the ascending connections is maintained at least to the level of the diencephalon in the acanthopterygian teleosts, such as the yellowfin goby. The authors also propose neural circuitries involving telencephalic visual centers and their view of the evolution of highly specialized compartments of the telencephalic visual-receptive zone (lateral part of dorsal telencephalon: Dl) found in gobiid fish.

NEUROBIOLOGY

In the article by Kawasaki (2023), the author reviews the time-comparator neural circuits of gymnotiform electric fishes. A major goal of behavioral neuroscience is to explain functions of sensory systems in terms of activity, connectivity, and computational features of peripheral and central neurons that are involved in the control of behavior. In sensory systems, information is typically encoded in the number of action potentials per unit time (rate coding) or in the firing timing or time patterns of action potentials (time coding). While identifying which coding scheme is used at a particular level of neuronal circuits is generally difficult due to the complex relations between sensory input signals and action potentials responding to them, the electrosensory system of gymnotiform electric fishes offers an exceptional substrate where the time-coding neural pathway is distinguished from rate-coding pathway with exceptional clarity. Kawasaki (2009) previously published a comprehensive review of electrosensory systems including the rate-coding pathways in Zoological Science. This time (Kawasaki, 2023), the author focused on comparative anatomy and physiology of the timing pathway in a gymnotiform pulse-type fish, *Brachyhypopomus*, and a gymnotiform wave-type fish, *Apteronotus*, in reference to the previous findings on other species. The author also discusses the timing system of mormyriform electric fishes, which had evolved electrogenesis and electrosense independently from gymnotiform electric fishes. He concludes that comparative studies of the timing system of gymnotiform fishes have revealed neural circuits that are central for the detection of microsecond time differences between sensory signals with behavioral significance.

In the article by Oka (2023), the author reviews the neural control of sexual behavior in fish. Many vertebrate species show breeding periods and exhibit series of characteristic species-specific sexual behaviors only during the breeding period. Here, secretion of gonadal sex hormones from the mature gonads has been considered to facilitate sexual behaviors. Thus, the sexual behavior has long been considered to be regulated by neural and hormonal mechanisms. The author discusses recent progress in the study of neural control mechanisms of sexual behavior with a focus on studies using fish, which have often been the favorite animals used by many researchers who study instinctive animal behaviors. First, the control mechanisms of sexual behaviors by sex steroids are discussed in relation to the anatomical studies of sex steroid-concentrating neurons in various vertebrate brains, which are abundantly distributed in evolutionarily conserved areas such as preoptic area (POA) and anterior hypothalamus. The next focus is another brain area called the ventral telencephalic area, which has also been suggested to contain sex steroid-concentrating neurons and has been implicated in the control of sexual behaviors, especially in teleosts (Satou et al., 1984). The control of sex-specific behaviors and sexual preference influenced by estrogenic signals or by olfactory/pheromonal signals is also discussed. Finally, research on the modulatory control of motivation for sexual behaviors by a group of peptidergic neurons called terminal nerve (TN)-gonadotropin releasing hormone (GnRH) neurons (Umatani et al., 2022), which are known to be especially developed in fishes among various vertebrate species, is discussed.

In the article by Ikenaga et al. (2023), the authors performed histological and molecular characterization of the inferior olivary nucleus and climbing fibers, one of the main afferent input pathways to the cerebellum, in the goldfish. The cerebellum in all vertebrates receives two main inputs: 1) mossy fibers originating from a variety of precerebellar nuclei within the spinal cord and brainstem, and 2) climbing fibers from the contralateral inferior olivary nucleus in the ventral medulla. The climbing fibers in mammals are known to entwine and terminate onto both major and peripheral branches of dendrites of the Purkinje cells. However, the inferior olivary nucleus in teleost fishes has not been characterized well. Furthermore, previous neuroanatomical studies in teleosts failed to show whether climbing fibers only contact Purkinje cells or whether they also terminate on distal dendrites of eurydendroid cells, another type of cells in the teleost cerebellum. Ikenaga et al. (2023) first identified inferior olivary neurons by retrograde neural tracer application to the cerebellar hemisphere and found that most of them are calretinin-immunoreactive. Double labeling immunofluorescence with anti-calretinin and anti-zebrin II (marker of Purkinje cells; Ikenaga et al., 2005) antisera revealed that the calretinin-ir climbing fibers made synaptic-like contacts on the major dendrites of the zebrin II-ir Purkinje cells. These results support the idea that Purkinje cells, but not eurydendroid cells, receive strong inputs via the climbing fibers in teleosts, similar to the mammalian situation.

In the article by Tanaka et al. (2023), the authors used the whole cell patch clamp method to analyze firing activities of the TN-GnRH neurons in medaka during application of acetylcholine (ACh), which is one of the essential neuromodulators in the brain. Vertebrates generally possess hypophysiotropic and non-hypophysiotropic GnRH neurons. The TN-GnRH neurons are known to belong to the non-hypophysiotropic neurons and have been suggested to modulate sexual behaviors. These neurons show spontaneous pacemaker firing activity and release neuropeptides GnRH and neuropeptide FF to modulate motivation for male sexual behavior (Umatani et al., 2022). Since the spontaneous firing activities of peptidergic neurons, including GnRH neurons, are believed to play important roles in the release of neuropeptides, understanding the regulatory mechanisms of these spontaneous firing activities is important. The authors' results demonstrated that ACh induces hyperpolarization and inhibits their pacemaker firing. Electrophysiological analysis using an antagonist for acetylcholine receptors and in situ hybridization analysis showed that firing of TN-GnRH neurons is inhibited via M2-type muscarinic acetylcholine receptor. Taken together with literature from several other fish species including teleosts and elasmobranchs, the authors conclude that ACh may generally play an inhibitory role in modulating spontaneous activities of TN-GnRH neurons and thereby sexual behaviors in fish.

BEHAVIORAL BIOLOGY

In the article by Takeuchi (2023), the author reviews the developmental process of a pronounced laterality in the scale-eating cichlid fish *Perissodus microlepis* in Lake Tanganyika. Using high-speed video recordings, Takeuchi et al. (2012) previously showed that predation behavior of *Perissodus microlepis* consists of five subcomponents. Further, in a preferred-side attack, in which the mouth-opening direction coincides with the attack direction, the fish can bend its body more rapidly and strongly at the time of predation than in a non-preferred-side attack, increasing the chances of a successful predation. These experiments provided direct evidence that the morphological differences in mouth structure and kinetic differences in bending movements allow the scale-eating fish to engage in lateral predatory behavior. The authors' recent studies have also shown that behavioral laterality in this fish depends on both genetic factors and past experience. The attack-side preference of scale eaters is an acquired trait developed in the early developmental stage. Juvenile fish empirically learn which side of the prey is more effective for tearing scales and gradually select the dominant side for attacking. However, the superior kinetics of body flexion during the dominant side attack has innate characteristics that are not altered by experience. Additionally, left-right differences in scale-eater mandibles also develop during ontogeny. The author concludes by suggesting that further progress toward understanding the comprehensive mechanisms of laterality should address the following persistent barriers: (1) the effects of phylogenetic constraints and ecological factors on the level of laterality, and (2) the neuronal and molecular mechanisms that produce left–right behavioral differences.

In the article by Sogawa et al. (2023), the authors investigated the visual signal for individual-recognition in males of sexually dichromatic guppy (*Poecilia reticulata*, Cyprinodontiformes). Individual recognition is a necessary cognitive ability for the maintenance of stable social relationships. Recent studies have shown that, like primates, some fish species can distinguish familiar fish from unfamiliar strangers via face-recognition. However, the taxa of the studied fish species are restricted to Perciformes, and the visual signal used for the recognition of fish remains unclear. Kohda et al. (2015) reported on face-recognition by exploiting small individual differences in the shape and size of color patches near the eyes on the operculum in the territorial cichlid *Neolamprologus pulcher*. Using male guppies, Sogawa et al. (2023) examined the hypothesis that fish distinguish between familiar individuals and unknown strangers by their faces rather than by body coloration. Here, the authors made an important finding that male faces contain clear individual-variation in white/metallic colored patches on the operculum visible to the human eyes. From the fact that the present photo-model eliminated UV-light information (note that guppies are known to be capable of UV vision), they suggest that these patches might be an important visual stimulus for face-recognition in male guppies, like some cichlids. From the comparison among males of different guppy variants, including wild-type phenotype, the authors suggest that the face color-patch is stable regardless of variation in body color, with a different genetic mechanism potentially underlying face and body colors.

As described above, the present Special Issue covers many disciplines of research fields in zoological science by taking advantage of various fish species. We hope that the readers enjoy reading the entire issue and take this opportunity to discuss the future of the research in zoological science as a whole.

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COMPETING INTERESTS

The authors have no competing interests to declare.

AUTHOR CONTRIBUTIONS

YO and CU wrote the manuscript.

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