



ENCYCLOPEDIA OF FISH PHYSIOLOGY

FROM GENOME TO ENVIRONMENT



EDITOR-IN-CHIEF
ANTHONY P. FARRELL

ASSOCIATE EDITORS
E. DON STEVENS, JOSEPH J. CECH, JR. & JEFFREY G. RICHARDS



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FISH PHYSIOLOGY:
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ENCYCLOPEDIA OF FISH PHYSIOLOGY: FROM GENOME TO ENVIRONMENT

Volume 1

THE SENSES, SUPPORTING TISSUES, REPRODUCTION,
AND BEHAVIOR

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Tony Farrell is a graduate of Bath University, where he was fortunate to study with Peter Lutz. His fortunes grew further when he moved in 1974 to Canada and the Zoology Department at the University of British Columbia (UBC) to complete his PhD degree under the excellent tutelage of Dave Randall. In 2004, Tony returned to UBC when he accepted an endowed research chair in sustainable aquaculture. In between these positions at UBC, Tony was employed at the University of Southern California (PDF), the University of New Brunswick (sessional lecturer), Mount Allison University (first real job), and Simon Fraser University (moving through the ranks to a full professor). In addition to highly controlled laboratory experiments on fish cardiorespiratory physiol-

ogy, Tony is committed to working on animals in their own environment. Therefore, his research on fish physiology has taken him on an *Alpha Helix* expedition to the Amazon, the University of Gothenburg and the Kristineberg Marine Research Station in Sweden, the Portobello Marine Biological Station in New Zealand, the University of Christchurch and Massey University in New Zealand, the Bamfield Marine Science Station and the Huntsman Marine Station in Canada, the University of Aarhus in Denmark, the University of Adelaide Charles and Darwin University in Australia, and to the Danish Arctic Marine Station on Disco Island in Greenland. These travels have allowed him to work with many superb collaborators worldwide, as well as study the physiology of over 70 different species of fish. Tony has received a number of awards for his scientific contributions: an honorary degree from the University of Gothenburg in Sweden; Awards of Excellence from the American Fisheries Society for Fish Physiology, Conservation and Management; the Fry Medal from the Canadian Society of Zoologists; and the Beverton Medal from the Fisheries Society of the British Isles.



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Joe Cech grew up in northern Illinois <1 km from the Salt Creek Preserve, where he spent many hours as a boy. Summer trips to northern Wisconsin, northern Minnesota, and southern Ontario increased his interest in aquatic habitats and their fishes. He graduated from the University of Wisconsin (UW, Madison), where he was fortunate to study oceanography under Robert Ragotzkie and fish biology under Art Hasler and Fran Henderson in the UW Laboratory of Limnology. Before completing his BS degree in zoology, he was fortunate to serve as the resident zoologist aboard the R/V *Dante Deo*, for a year, as it crossed the Caribbean Sea and the South Pacific Ocean. Completing his degree upon his return, he was hired as a research assistant at the University of Texas' Marine

Science Institute (UTMSI), where he earned his MA and PhD degrees in zoology, under the supervision of Curly Wochschlag. During his graduate education in Austin (Texas), he studied fish biology under Clark Hubbs and physiology under Jack Myers and Jim Larimer. After a 2-year postdoctoral position in Maine, he was hired as a fish physiological ecologist faculty member at the University of California (UC), Davis, in the Department of Wildlife, Fish, and Conservation Biology.

During his 32 years as an active faculty member at UC Davis, his research on the physiological ecology of fishes took him to Canada (University of British Columbia, Bamfield Marine Station), Finland (University of Helsinki), and to other laboratories in the USA (University of Tennessee, Scripps Institution of Oceanography, R/V *David Starr Jordan* in the North Pacific Ocean, UTMSI, Oregon Institute of Marine Biology, and the UC Bodega Marine Laboratory) where he collaborated with many excellent scientists. During this period, he taught courses in physiology of fishes, physiological ecology, and field studies in fish biology; he supervised 25 graduate students (10 MS and

15 PhD) in the disciplinary areas of ecology, physiology, zoology, and pharmacology/toxicology at UC Davis. He is a fellow of the AIFRB and AAAS, and he received Awards of Excellence from the American Fisheries Society (Physiology Section, and California-Nevada Chapter) and the UC Davis Prize for Undergraduate Teaching and Scholarly Achievement. Finally, he co-authored a popular ichthyology textbook, with Peter Moyle, and he published more than 160 peer-reviewed publications on the physiological ecology of fishes. He is currently Professor Emeritus of Fish Biology at the University of California Davis.



Associate Editor

Jeffrey G. Richards, Department of Zoology, University of British Columbia, Vancouver, BC, Canada

Jeffrey Richards is an associate professor in the Department of Zoology at the University of British Columbia, Canada. He started his academic career in the Department of Biology at Wilfrid Laurier University obtaining a BSc in 1995. He then went on to do an MSc at the University of Waterloo under the guidance of the late Prof. Richard Playle. With Prof. Playle, he studied environmental physiology and toxicology in fish. Following his MSc, he entered the laboratory of Prof. Chris Wood at McMaster University and focused his research on energy metabolism in swimming fish. He completed his PhD in 2002 and took up a postdoctoral fellowship at the University of British Columbia with Prof. Patricia Schulte. After a 2-year postdoctoral work, he started at the University of British Columbia as an assistant professor in 2004. His lab studies the relationship between plasticity and adaptive variation in the mechanisms that initiate, maintain, and coordinate metabolic energy balance in animals during exposure to environmental stress. He is particularly interested in the adaptations to low oxygen (hypoxia) in fish and other lower vertebrates. He prefers, whenever possible, to study animals in their natural habitat; thus, he travels extensively to unique and challenging environments, including the Amazon and the Tibetan plateau.



Associate Editor

E. Don Stevens, Department of Biomedical Sciences, Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, PE, Canada

Don Stevens did an MSc with the late Edgar Black on the effects of severe exercise on metabolites in trout in the Physiology Department at UBC after an undergraduate degree in mathematics and zoology at the University of Victoria. He then moved across the street to do a PhD on effects of moderate exercise on respiration and circulation in trout with Dave Randall, who just had been hired in the Zoology Department at UBC (summarized in a JEB classics article, *Journal of Experimental Biology* 211: 1521). His first position was at the Zoology Department at the University of Hawaii where he discovered that there was more to the fish world than trout, and that there was no such thing as the physiology of fish, rather there was a physiology of fishes. In Hawaii, he worked mostly on the biology of tropical tunas with a focus on their warm-bodiedness, in particular how they achieved higher than ambient body temperatures and the adaptive advantage of them. He then joined the Zoology Department at the University of Guelph working in the general area of comparative physiology with a focus on exercise effects until he retired in 2004. He now has an adjunct position at the Atlantic Veterinary College and continues to do research in fish physiology.

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HOW TO USE THE ENCYCLOPEDIA

STRUCTURE OF THE ENCYCLOPEDIA

The material in the Encyclopedia is arranged as a series of articles within a certain topic.

There are three features to help you easily find the topic you're interested in: a contents list, cross-references to other relevant articles in the Encyclopedia, and a full subject index.

1. CONTENTS LIST

The contents list, which appears at the front of all volume, lists the entries in the order that they appear in the Encyclopedia. It includes both the volume number and the page number of each entry.

2. CROSS-REFERENCES

All of the entries in the Encyclopedia have been extensively cross-referenced. The cross-references which appear at the end of an entry, serve three different functions:

- i. To indicate if a topic is discussed in greater detail elsewhere
- ii. To draw the readers attention to parallel discussions in other entries
- iii. To indicate material that broadens the discussion

Example

The following list of cross-references may appear in text and at the end of the entry
The Muscles|Cartilaginous Fishes Cranial Muscles

See also: **Buoyancy, Locomotion, and Movement in Fishes:** Feeding Mechanics. **Chondrichthyes:** Physiology of Sharks, Skates, and Rays. **Food Acquisition and Digestion:** Energetics of Prey Capture: From Foraging Theory to Functional Morphology. **The Muscles:** Bony Fish Cranial Muscles. **The Reproductive Organs and Processes:** Anatomy and Histology of Fish Testis. **Ventilation and Animal Respiration:** Gill Respiratory Morphometrics.

3. INDEX

The index includes page numbers for quick reference to the information you're looking for. The index entries differentiate between references to a whole entry, a part of an entry, and a table or figure.

4. CONTRIBUTORS

At the start of each volume there is list of the authors who contributed to the Encyclopedia.