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Editorial

Otoliths and Their Applications in Fishery Science

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Otoliths are one of the most useful and important biological structures for the various studies of fish, leading to many practical applications that are not limited only to ichthyology. It is, therefore, not surprising that different approaches to otolith research are experiencing continuous growth on a global scale. To collect the latest findings on these approaches and applications, the Special Issue entitled, "Otoliths and Their Applications in Fishery Science", was created. Collected papers cover several different research areas, from the otolith macro- (e.g., shape and size) to the microstructure (e.g., increment analyses and age estimates) and microchemistry, analyzing different types of otoliths (sagittae, asterisci and lapilli) and investigating various freshwater and marine species in their larval, juvenile and adult stages that were laboratory-reared or field-collected.

In a study regarding the morphological alterations in otoliths during ontogenesis, Gao et al. [1] found that both sagittae and lapilli of the laboratory-reared *Sinogastromyzon wui* were visible upon hatching, whereas asterisci were present four days post-hatching. The results show that lapillus developmental increments were deposited daily, and the authors proposed this otolith type as the most optimal for age determination and increment deposition rate confirmation. All different types of otoliths were also investigated by Zhu et al. [2] in one of the four major, commercially important carp species in China. However, this study focused on the marking of hard structures (from lateral-line scales and rays of all fins to all otolith types) in the juvenile *Hypophthalmichthys molitrix* by using a fluorescent marker. The lapilli and lateral-line scales were marked most effectively for all sampled hard structures. In general, such markings can be used in fishery science for a wide range of applications, including the investigation of fish life-history and movement patterns, as well as determining restocking effectiveness. These valuable applications guided the authors in their new research. This time, Zhu et al. [3] exposed the juvenile crucian carp (*Carassius carassius*) to a single concentration of $SrCl_2 \cdot 6H_2O$ and evaluated the efficiency of strontium marking all fish otoliths. Sr marking signatures formed a peak in all otolith types, but again, lapilli were the most suitable for these marking observations.

The study by Jawad and Mahé [4] took a different approach and tested the potential asymmetry in asterisci. They found significant fluctuating asymmetry between the length of the common carp (*Cyprinus carpio*) and every asterisci descriptor. Considering that the level of asymmetry can modify the boundaries of stocks according to the use of left or right otoliths, the authors highlighted the importance of verifying this phenomenon before using otoliths in fisheries research. Several other studies have also pointed out the importance of otolith macrostructures. Marval-Rodríguez et al. [5] used otolith shape analysis to test possible differences between two important red snapper species of the genus *Lutjanus* in the western Atlantic, for which there is a suggestion that the two are a single species. The otolith shape revealed differences, but not between the two investigated species; rather, differences were found among their populations in the studied area. In addition, Morawicki et al. [6] revealed the spatial stock structure of the silverside *Odontesthes argentinensis*, which is an ecologically and economically important species in the SW Atlantic. The authors used a combination of elliptic Fourier descriptors, Wavelet coefficients and otolith shape indices. More proof that otolith shape analysis is effective in discriminating fish groups, especially those experiencing different environmental conditions, was presented by Moura et al. [7].

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Using the traditional otolith shape descriptors, it was discovered that the European eel population in the Minho River (NW Iberian Peninsula) shows complete discrimination between the two main types of habitats (tributaries and estuaries).

Generally, otoliths have mainly been used in age and growth studies, and the significance of this application in fishery science continues today, as reflected by the number of related papers in this Special Issue. Given that the information on age and growth is essential for stock assessments and the development of management plans, Huang et al. [8] presented several analyses on the two important croakers (*Pennahia macrocephalus* and *Atrobucca nibe*) that are under high fishing pressure in SW Taiwan. The authors validated the periodicity of ring formation, examined three age determination methods and calculated the representative growth models using a multimodel approach. The validation of aging is crucial because it directly influences the correct determination of age, as proved by Rodriguez-Marin et al. [9]. The results obtained in their study provide evidence that the annulus formation in the otoliths of Atlantic bluefin tuna are completed later in the calendar year than previously thought. As a conclusion, it is necessary to delay the date of the current July 1 adjustment criterion to November 30. On the other hand, García-Fernández et al. [10] focused on the usefulness and potential of otolith daily growth analyses. The authors analyzed otoliths of adult *Merluccius merluccius* females from the Galician waters and showed that the daily growth of females decreases during their spawning period. Good environmental conditions are key for successful growth, and Denis et al. [11] highlighted the importance of small estuaries that are crucial habitats for supporting higher growth during a fish's growth phase. Particularly, they investigated eels in small estuaries along the French coast of the eastern English Channel.

Several papers on fish age and growth have presented the first data on certain areas of distribution of investigated species. Christoffersen et al. [12] provided new information about the quillback rockfish in the northern part of its range (SE Alaska) and detected similar growth patterns and rates that were previously identified in the southern area (Salish Sea). Moreover, Ferri and Brzica [13] investigated the age and growth of the European barracuda, *Sphyreana sphyreana*, in the eastern Adriatic for the first time. The authors also measured otolith length, width and mass to test the utility of these morphometrics as predictors of age in investigated fish. The results showed that counting otolith annuli produced a better estimation of age than proposed linear models based on relationships between observed fish age and otolith morphometrics. Using otolith morphometrics in aging is just one way to facilitate the challenging and time-consuming reading of otoliths. Over the last few decades, various autonomous techniques have been proposed to automate this tedious activity. In this context, Ordoñez et al. [14] used otolith images from the Greenland halibut to train a convolutional neural network (CNN) for the automatic predicting of fish age. The study demonstrated that applying a CNN model trained on images from one lab does not lead to a suitable performance when predicting fish ages from otolith images from another lab. The authors detected that this was due to a problem known as dataset shift, which can be handled using domain adaptations. In addition, Politikos et al. [15] presented DeepOtolith, an open-source artificial intelligence (AI) platform that provides a web system with a simple interface that automatically estimates fish age by combining otolith images with a CNN. This platform currently contains classifiers for only three fish species; however, the authors highlighted that more species will be included as soon as more related work on aging is tested.

Finally, several papers analyzed otolith microchemistry and emphasized applications of this research area in: (i) describing demographics of an anadromous fish's life-history; (ii) identifying whether fish exhibit homing and return to natal streams to spawn; and (iii) assessing population connectivity. Roloson et al. [16] examined two hypotheses that anadromous brook trout (*Salvelinus fontinalis*) are more likely to arise from sea-run mothers, and that freshwater entry timing makes them vulnerable to pesticide-induced fish kills; meanwhile, Shrimpton et al. [17] estimated the fidelity to natal streams of the Columbia-origin Kokanee (*Oncorhynchus nerka*) in the Williston Reservoir. The work by Jiang et al. [18]

assessed the population connectivity of *Coilia nasus*. Results strongly suggest that there are two original natal populations in the Qiantang and Changjiang Rivers, whereas the population in the Yellow Sea has little connectivity with that of the Qiantang River, but has a supplementary relationship with that of the Changjiang River.

Authors of all these papers dealt with different questions and tested various hypotheses, but they were all motivated by specific applications of otoliths in fishery science. Hopefully, these papers will inspire many more researchers and lead to compelling new advances in otolith research.

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