SPECIAL ISSUE

CSIRO PUBLISHING

*Marine and Freshwater Research*, 2016, **67**, i–iv
http://dx.doi.org/10.1071/MFv67n7_ED

Editorial

# Fish otoliths as indicators in ecosystem based management: results of the 5th International Otolith Symposium (IOS2014)

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## Introduction

Ecosystem-based fishery management (EBFM) represents a revolution in a field that has been focussed on the assessment and prediction of commercial fish harvest for the past seven decades. Increasing pressure, and conflicting demands, have made marine resource management a challenge that cannot be met with traditional models. Although there is debate about the benefits of EBFM, and many are struggling to understand what it means, a picture is slowly emerging of what is required in order to *operationalise* the concept and to test its application in the real world. The biggest problem has been to identify ecosystem drivers, and to define measurable ecosystem metrics and indicators (Shephard *et al.* 2015). It is against this background that the 5th International Otolith Symposium was convened with the theme: calcified tissues as tools to support management. The aim of the symposium was the exploration of the use of calcified structures as tools to support management and the formulation of a definition of indicators at environmental, community, population and individual levels. The growth characteristics of fish otoliths (and other structures such as scales, vertebrae, shells, coral skeletons) make them ideal indicators, incorporating information about individuals and their environment. Otolith analysis should have an important role to play in EBFM, and recent work has shown that a step-change is coming. For example, diversity, trophic levels of landings and mean life span are some of the indicators listed by IndiSeas2 (ICES 2016) that should be part of an integrated ecosystem assessment (IEA). Analysis of otoliths and other calcified structures can provide direct measurements of these across a broad range of species. Additional metrics relevant for IEA are population age structure and individual growth rate, which can be indicators of fish welfare, population status and ecosystem health.

## The diversity of otolith studies

This special issue of *Marine and Freshwater Research* gives an indication of the multiple types of data that can be extracted from otoliths, often from the same individual, to define indicators at environmental, community, population and individual levels. The analysis of otoliths has long been a standard tool of biological analysis in studies of fish and fisheries. Routine applications continue to support resource management by providing data from age determination and validation, growth studies, and species identification. Research into otolith growth and formation has resulted in a wider array of methodologies and applications. Elemental and isotope chemistry and shape analysis have demonstrated enormous potential for using otoliths in studies of ecosystems and populations – past and present. Some of these methods have also been applied to other calcified structures, such as scales and vertebrae. Connections with the biochronology community have developed and encouraged a flow of ideas from studies of invertebrate structures, such as coral skeleton, bivalve and gastropod shells, and squid statoliths. There has been an exponential increase in research and publications that aim to unlock the secrets contained in calcified structures, and much of this work shows the potential to use these methods and results as indicators, or to help define indicators, in support of management.

Individual data derived from otolith analysis provide information on growth, from which environmental signals can often be interpreted, but these are tempered by individual fish phenotype or physiology. Grønkjær (2016) covered fundamentals in his keynote address, emphasising that individual responses are the result of interactions between genes, physiology and the environment. He predicts that the next advances in both individual and ecosystem indicators will come from the integration of visual and chemical data (from otoliths) with bioenergetics modelling also playing a part. Indeed, biomineralisation studies of element incorporation in otoliths (Izzo *et al.* 2016*a*; McFadden *et al.* 2016) highlight the importance of considering the organic matrix. Surely to use otoliths as individual indicators, and otolith-derived data in ecosystem-based management, we will need better models that integrate temperature, metabolism, protein matrix synthesis and the resulting element incorporation, partitioning and binding. The ability to reconstruct an individual's entire growth history provides insight into life history strategy as well as important environmental conditions (e.g. Cerna and Plaza's (2016) study of Peruvian anchovy). Stormer and Juanes (2016) tested one of the fundamental assumptions of using otolith metrics to study fish growth – the direct proportionality assumption – showing that seasonal coupling and uncoupling of otolith growth from fish growth should be considered in surveys to support management.

Validation studies continue to be a critical part of otolith or hard structure analysis, to ensure data quality and reduce uncertainties in the increasingly complicated systems of assessment and management decision-making. Radiometric methods (Campana *et al.* 2016; Vitale *et al.* 2016), tagging studies with chemical marking of otoliths (Albert 2016) and direct estimates from microstructure measurements (Aldanondo *et al.* 2016) all underpin the routine ageing applications as well as the research into new applications. Campana *et al.* (2016) demonstrate the value of a combined approach, by utilising DNA extracted from tissue adhering to redfish (*Sebastes* sp.) otoliths stored in collections to determine species identity for individuals where tissue samples were not available. The taxonomic data, together with improved imaging techniques and radiocarbon age validation, produced the maximum information for each individual and better insight into different growth patterns. But the oldest methods can still be relevant – Uriarte *et al.* (2016) validated the ageing protocols for European anchovy by following strong year-classes, a method initially used by Hjort (1914) to follow the 1904 year-class of herring. Hjort's (1914) study also validated, among other things, the utility of scale reading for age and growth data.

Spatially explicit data about fish distributions and migration patterns are required for marine management, for example, in planning and monitoring Marine Protected Areas (MPA) or delineating essential habitat. Conditions in different water masses influence element and isotope incorporation, prompting the use of calcified tissues as geotags. Gleason *et al.* (2016) analysed otolith composition and hydrographic conditions, and could reconstruct age-related habitat use in two Arctic fish species. In a similar manner to elemental or isotopic geotags, fish collected from different locations may also have distinct growth patterns, which visually mark the otoliths. Stötera and Krumme (2016) found significant variability in visual quality of growth increments in otoliths of Baltic cod that led to quality problems in age readings. Instead of using this variability to indicate less reliable readings, they used the quantity and distribution of the 'poor' readings as an index or metric for spatial segregation of sub-populations.

Essential fish habitat can be an important component of ecosystem based management, and thus it is valuable to be able to determine nursery areas and develop indicators of population connectivity. The use of otolith element composition has matured as a tool in this field, as demonstrated by several papers in this special issue. As a first step in assessing population connectivity, the use of one or many nursery sources were studied by Barnett *et al.* (2016) for red snapper (*Lutjanus campechanus*) and Fraile *et al.* (2016) for North Atlantic albacore (*Thunnus alalunga*) and bluefin tuna (*T. thynnus*). Both studies looked for similarities in otolith core composition, and included both stable isotopes ($\delta^{13}C$, $\delta^{18}O$) as well as element ratios. This combination of variables is becoming more common as an elemental fingerprint or geotag, integrating the strongest signals for water mass, environmental conditions and fish growth. Lewis *et al.* (2016) extended the use of chemical signals to identify potential nursery areas to blacktip sharks (*Carcharhinus limbatus*) by measuring trace metal composition of the vertebral centra.

Determining population structure in exploited marine populations is a challenge for assessments and a worry for managers, since quotas and fishing rights need to be split and appropriately allocated. Population identification is also an increasing concern for consumers who want to know about food authenticity, and the diversity of sub-populations can be an indicator of ecosystem status in an integrated ecosystem assessment. A large number of studies are now applying otolith shape analysis to population studies. Improvements in image acquisition and analysis have increased the efficiency, and lowered the cost, making it possible to routinely process hundreds of otolith samples to achieve a high level of statistical power. Brophy *et al.* (2016) analysed otolith shape of bluefin tuna and illustrated how these methods can be used to improve estimates of population mixing rates and incorporate these into stock assessment. Diversity of fish assemblages may also be studied using otolith shape proxies (Tuset *et al.* 2016). Otolith shape analysis methods are moving rapidly, and techniques from other disciplines are being applied to characterise otolith outlines (Harbitz 2016) and also 3-D otolith surfaces (Marti-Puig *et al.* 2016).

As ecosystem-based management becomes a reality, as it becomes *operationalised*, it is clear that otoliths and other calcified structures will have an increasing role in producing the data required for indicators or metrics. This value is derived from two characteristics. (1) Many types of data can be extracted from the otolith (or scales, vertebrae, etc.) of a single individual, and these data provide time-stamped information about the individual, the population and the environment. (2) The archives and otolith collections, especially at fisheries institutes around the world, offer well-preserved records of the past, and can continue to provide data for indicators about past individuals, past populations, past communities and their interaction with the past environment (Izzo *et al.* 2016*b*).

## International Otolith Symposium special issues

In 2005, *Marine and Freshwater Research* published a special issue for the International Symposium on Fish Otolith Research and Applications that would come to be known as the 3rd International Otolith Symposium (Begg *et al.* 2005). The 4th International Otolith Symposium was published in *Environmental Biology of Fishes* (Miller *et al.* 2010) and the first part of IOS2014 was published in the *ICES Journal of Marine Science*

(Morales-Nin and Geffen 2015). We are happy to have the opportunity to release another special otolith issue here now, and to share the diversity of research and applications of otoliths and other calcified tissues. It is clear that these methods are no longer primarily fisheries orientated, but have an important role in marine ecology and marine resource management.

## Acknowledgements

IOS2014 was only possible through the support of individuals and organisations, including: Adi Kellerman and Claire Welling (International Council for the Exploration of the Sea, ICES); Juan José Ensenyat, Miquel Gomila, Silvia Pérez, Miquel Palmer, Itziar Alvarez, Ignacio Catalan, Bernat Morro, Elena Garcia, Bernat Aguiló and Borja Tolosa (Mediterranean Institute for Advanced Studies (IMEDEA), Spanish National Research Council (CSIC)–University of the Balearic Islands (UIB)); Palma Aquarium, Cristian Alfaro Park, Calvia City and Palmira Hotels. The local and international Steering Committees worked hard to construct the scientific programme. The University of the Balearic Islands, IMEDEA, and Institute of Marine Research provided support to the conveners. The American Fisheries Society (Estuaries Section and Early Life History Section) and the Fisheries Society of the British Isles subsidised student registrations and prizes. Françoise Daverat HDR (France) organised the 'Protolithe Art and Science' event at the Symposium. The support and enthusiasm of the symposium participants was a key ingredient in the success of IOS2014 – thank you, and thanks to the authors for supporting the Open Access option for this entire issue.

## References

Albert, O. T. (2016). Growth and formation of annual zones in whole otoliths of Greenland halibut, a slow-growing deep-water fish. *Marine and Freshwater Research* **67**, 937–942. doi:10.1071/MF15089

Aldanondo, N., Cotano, U., Álvarez, P., and Uriarte, A. (2016). Validation of the first annual increment deposition in the otoliths of European anchovy in the Bay of Biscay based on otolith microstructure analysis. *Marine and Freshwater Research* **67**, 943–950. doi:10.1071/MF15083

Barnett, B. K., Patterson, W. F. III, Kellison, T., Garner, S. B., and Shiller, A. M. (2016). Potential sources of red snapper (*Lutjanus campechanus*) recruits estimated with Markov Chain Monte Carlo analysis of otolith chemical signatures. *Marine and Freshwater Research* **67**, 992–1001. doi:10.1071/MF15076

Begg, G. A., Campana, S. E., Fowler, A. J., and Suthers, I. M. (2005). Otolith research and application: current directions in innovation and implementation. *Marine and Freshwater Research* **56**, 477–483. doi:10.1071/MF05111

Brophy, D., Haynes, P., Arrizabalaga, H., Fraile, I., Fromentin, J. M., Garibaldi, F., Katavic, I., Tinti, F., Karakulak, F. S., Macías, D., Busawon, D., Hanke, A., Kimoto, A., Sakai, O., Deguara, S., Abid, N., and Neves Santos, M. (2016). Otolith shape variation provides a marker of stock origin for north Atlantic bluefin tuna (*Thunnus thynnus*). *Marine and Freshwater Research* **67**, 1023–1036. doi:10.1071/MF15086

Campana, S. E., Valentin, A. E., MacLellan, S. E., and Groot, J. B. (2016). Image-enhanced burnt otoliths, bomb radiocarbon and the growth dynamics of redfish (*Sebastes mentella* and *S. fasciatus*) off the eastern coast of Canada. *Marine and Freshwater Research* **67**, 925–936. doi:10.1071/MF15002

Cerna, F., and Plaza, G. (2016). Daily growth patterns of juveniles and adults of the Peruvian anchovy (*Engraulis ringens*) in northern Chile. *Marine and Freshwater Research* **67**, 899–912. doi:10.1071/MF15032

Fraile, I., Arrizabalaga, H., Santiago, J., Goñi, N., Arregi, I., Madinabeitia, S., Wells, R. J. D., and Rooker, J. R. (2016). Otolith chemistry as an indicator of movements of albacore (*Thunnus alalunga*) in the North Atlantic Ocean. *Marine and Freshwater Research* **67**, 1002–1013. doi:10.1071/MF15097

Gleason, C. M., Norcross, B. L., and Spaleta, K. J. (2016). Otolith chemistry discriminates water mass occupancy of Arctic fish in the Chukchi Sea. *Marine and Freshwater Research* **67**, 967–979. doi:10.1071/MF15084

Grønkjær, P. (2016). Otoliths as individual indicators: a reappraisal of the link between fish physiology and otolith characteristics. *Marine and Freshwater Research* **67**, 881–888. doi:10.1071/MF15155

Harbitz, A. (2016). Parameter-sparse modification of Fourier methods to analyse the shape of closed contours with application to otolith outlines. *Marine and Freshwater Research* **67**, 1049–1058. doi:10.1071/MF15087

Hjort, J. (1914). Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. *Rapports et Procès – Verbaux des Réunions du Conseil International pour l'Exploration de la Mer* **20**, 1–228.

ICES (2016). Second interim report of the Working Group on Large Marine Ecosystem Programme Best Practices (WGLMEBP), 28 September–2 October 2015, Paris, France. ICES 2015 CM/SSGIEA:07. (International Council for the Exploration of the Sea: Copenhagen, Denmark.) Available at http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGIEA/2015/WGLMEBP%20FINAL%202015.pdf [Verified 4 May 2016].

Izzo, C., Doubleday, Z. A., and Gillanders, B. M. (2016*a*). Where do elements bind within the otoliths of fish? *Marine and Freshwater Research* **67**, 1072–1076. doi:10.1071/MF15064

Izzo, C., Doubleday, Z. A., Grammer, G. L., Gilmore, K. L., Alleway, H. K., Barnes, T. C., Disspain, M. C. F., Giraldo, A. J., Mazloumi, N., and Gillanders, B. M. (2016*b*). Fish as proxies of ecological and environmental change. *Reviews in Fish Biology and Fisheries*. doi:10.1007/S11160-016-9424-3

Lewis, J. P., Patterson, W. F. III, Carlson, J. K., and McLachlin, K. (2016). Do vertebral chemical signatures distinguish juvenile blacktip shark (*Carcharhinus limbatus*) nursery regions in the northern Gulf of Mexico? *Marine and Freshwater Research* **67**, 1014–1022. doi:10.1071/MF15088

Marti-Puig, P., Danés, J., Manjabacas, A., and Lombarte, A. (2016). New parameterisation method for three-dimensional otolith surface images. *Marine and Freshwater Research* **67**, 1059–1071. doi:10.1071/MF15069

McFadden, A., Wade, B., Izzo, C., Gillanders, B. M., Lenehan, C. E., and Pring, A. (2016). Quantitative electron microprobe mapping of otoliths suggests elemental incorporation is affected by organic matrices: implications for the interpretation of otolith chemistry. *Marine and Freshwater Research* **67**, 889–898. doi:10.1071/MF15074

Miller, J. A., Wells, B. K., Sogard, S. M., Grimes, C. B., and Cailliet, G. M. (2010). Introduction to proceedings of the 4th International Otolith Symposium. *Environmental Biology of Fishes* **89**, 203–207. doi:10.1007/S10641-010-9715-9

Morales-Nin, B., and Geffen, A. J. (2015). The use of calcified tissues as tools to support management – the view from the 5th International Otolith Symposium. *ICES Journal of Marine Science* **72**, 2073–2078. doi:10.1093/ICESJMS/FSV150

Shephard, S., Greenstreet, S. P. R., Piet, G. J., Rindorf, A., and Dickey-Collas, M. (2015). Surveillance indicators and their use in implementation of the Marine Strategy Framework Directive. *ICES Journal of Marine Science* **72**, 2269–2277. doi:10.1093/ICESJMS/FSV131

Stormer, D. G., and Juanes, F. (2016). Effects of temperature and ration on the otolith-to-somatic size relationship in juvenile Chinook salmon (*Oncorhynchus tshawytscha*): a test of the direct proportionality assumption. *Marine and Freshwater Research* **67**, 913–924. doi:10.1071/MF15206

Stötera, S., and Krumme, U. (2016). Use of otolith quality flags to assess distributional dynamics in Baltic cod stocks. *Marine and Freshwater Research* **67**, 980–991. doi:10.1071/MF15048

Tuset, V. M., Farré, M., Otero-Ferrer, J. L., Vilar, A., Morales-Nin, B., and Lombarte, A. (2016). Testing otolith morphology for measuring marine fish biodiversity. *Marine and Freshwater Research* **67**, 1037–1048. doi:10.1071/MF15052

Uriarte, A., Rico, I., Villamor, B., Duhamel, E., Dueñas, C., Aldanondo, N., and Cotano, U. (2016). Validation of age determination using otoliths of the European anchovy (*Engraulis encrasicolus* L.) in the Bay of Biscay. *Marine and Freshwater Research* **67**, 951–966. doi:10.1071/MF15092

Vitale, S., Andrews, A. H., Rizzo, P., Gancitano, S., and Fiorentino, F. (2016). Twenty-five-year longevity of European hake (*Merluccius merluccius*) from novel use of bomb radiocarbon dating in the Mediterranean Sea. *Marine and Freshwater Research* **67**, 1077–1080. doi:10.1071/MF15376