FISHERIES & AQUATIC LIFE (2025) 33: 216 - 220
DOI 10.2478/aopf-2025-0020

SHORT COMMUNICATION

Unusual development of an accessory otolith in herring (*Clupea harengus*) larva

Małgorzata Dembek, Dariusz P. Fey, Szymon Smoliński

Received – 04 July 2025/Accepted – 28 December 2025. Published online: 31 December 2025; ©National Inland Fisheries Research Institute in Olsztyn, Poland
Citation: Dembek, M., Fey, D.P., Smoliński, S. (2025). Unusual development of an accessory otolith in herring (*Clupea harengus*) larva. Fisheries & Aquatic Life 33, 216-220.

Abstract. Otoliths are key to reconstructing fish life history, as their structure records individual and environmental information. These inner ear structures grow incrementally, revealing growth rates, migration patterns, and environmental conditions. However, internal factors (e.g., genetic mutations and stress) and external factors (e.g., temperature changes and pollution) can cause structural anomalies, such as shape deformities, asymmetry, and altered composition. This study describes a unique anomaly, an unusual accessory otolith, in the sagittal otolith of an Atlantic herring (*Clupea harengus* L.) larva collected from the Vistula Lagoon in the southern Baltic Sea, a vital spawning area. A 40 mm larva exhibited a rare otolith anomaly (found in only one of ~2000 specimens analyzed) characterized by a main otolith measuring 0.47 × 0.39 mm with an average of 64 daily increments, and an attached accessory measuring 0.20 × 0.10 mm with an average of 25 daily increments. This anomaly, previously unreported in Baltic herring larvae, may reflect environmental stressors and is significant for understanding developmental abnormalities in fish.

Keywords: otoliths, herring, anomalies, fish, sagitta, larvae

M. Dembek [✉], D.P. Fey
National Marine Fisheries Research Institute, Department of Fisheries Oceanography and Marine Ecology, ul. Kołłątaja 1, 81-332 Gdynia, Poland
E-mail: mdembek@mir.gdynia.pl

S. Smoliński
National Marine Fisheries Research Institute, Department of Fisheries Resources, ul. Kołłątaja 1, 81-332 Gdynia, Poland

Introduction

An otolith, or ear stone, is a small, hard structure located in the inner ear of fish (Campana 1999). These structures are integral to the fish's balance and hearing systems, enabling orientation in space and the detection of underwater vibrations (Popper and Lu 2000). Composed primarily of calcium carbonate and proteins, otoliths grow throughout a fish's life via the regular deposition of material layers, forming a microstructure similar to tree rings (Degens et al. 1969). This growth pattern provides researchers with invaluable insights into fish life history and environmental interactions (Campana and Thorrold 2001). For example, daily growth increments within otoliths enable precise age determination, as each layer represents a single day of growth (Campana 1999). Additionally, otolith microstructure records environmental parameters such as water temperature (Fey 2001), salinity (Tonheim et al. 2020), and food availability that fish experience during different life stages.

Research on otolith anomalies is important not only for refining methodologies but also for enhancing our understanding of fish ecology and developing indicators of environmental change in aquatic ecosystems, driven by both natural processes and anthropogenic pressures (Béarez et al. 2005). For example, otolith anomalies serve as valuable proxies for understanding the effects of global changes, including rising water temperatures, ocean acidification, and salinity shifts driven by climate change (Folkvord et al. 2004). These stressors not only affect fish physiology but also alter broader ecosystem dynamics, potentially disrupting food webs and reducing biodiversity (Perry et al. 2005, Pinsky et al. 2020). By studying otolith anomalies, we can potentially trace the historical and contemporary impacts of these global changes, gaining a better understanding of how aquatic species and their habitats are being reshaped.

This study presents evidence of an unusual sagitta anomaly in herring larvae collected from the Vistula Lagoon in the southern Baltic Sea, characterized by the presence of an accessory otolith. Notably, our observations revealed that the accessory otolith formed daily growth increments and was located in a different plane, away from the main otolith center, which, to our knowledge, has not been previously reported.

Materials and Methods

The sample of larvae was collected on April 27, 2023 in the eastern region of the Polish zone of the Vistula Lagoon (N 54.3842; E 19.6083). The Vistula Lagoon serves as the primary spawning ground for Baltic herring in the southeastern Baltic Sea (Krasovskaya 1998). Herring larvae were caught using a 5-meter neuston net with a 2 m^2 surface area of the opening and a mesh size of 500 μm. The net was towed at a speed of approximately 2 knots, traversing the upper water layer. The samples were immediately placed in vials containing 96% ethanol. In the laboratory, the length of the larvae (mm, SL) was measured to the nearest 0.01 mm using an electronic caliper. The sagitta were dissected with the aid of a fine needle and mounted on glass slides with Eukitt mounting medium. The otolith length was determined by measuring the distance between the anterior and posterior edges of the otolith, and the width was measured from the dorsal and ventral edges of the otolith perpendicular to its length. Otolith size measurements and photographic documentation were conducted under Nikon image analysis system (microscope: Nikon SMZ1270; camera: Nikon DS-Fi3; software: Nikon Nis Elements v. 5.42.04). A total of 2015 pairs of sagittae from herring larvae were examined, and the anomaly described here was found in only one individual.

Results and Discussion

An accessory otolith was discovered in a 40 mm herring larva caught in the Vistula Lagoon. The larva came from early spring spawning that occurs in the Vistula Lagoon when the water temperature reaches 6–8°C (Fey et al. 2014). The right otolith measured 0.47 × 0.39 mm, and an accessory otolith was observed on its surface. The size of the overgrown otolith was 0.20 × 0.10 mm. The number of increments in both otoliths differed depending on the radius along which they were counted. Counting them along five axes from the nucleus, the average number of increments of the accessory otolith was 25 ± 0.81 (standard error – SE), while that of the main otolith was 64 ± 2.25. This substantial difference suggests that the accessory otolith forms significantly later, likely following a specific developmental disturbance or an abrupt physiological shift. Although the accessory otolith is attached to the actual otolith, the two structures are only partially fused and are clearly situated in different planes, rather than forming a single continuous growth axis (Fig. 1).

This phenomenon suggests a unique interruption or alteration in the normal growth process of the otolith at a certain point in the larval life. Anomalies in otolith structure in fish larvae are the result of a complex set of environmental, genetic, and physiological factors (Vignon and Morat 2010, Mahé et al. 2019). These irregularities can significantly affect the interpretation of otolith data, which are crucial in studies related to the age, growth, and ecology of fish (Campana and Neilson 1985). In our study, we found

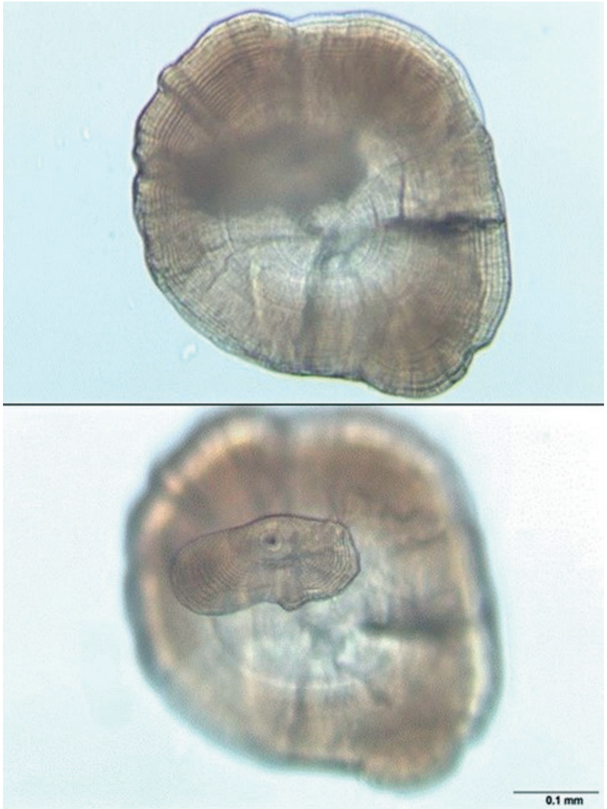

Figure 1. Photos of the main and accessory otolith of herring larva from the Vistula Lagoon. Note that the accessory otolith growth-center is located in a different plane, away from the main otolith center.

only one such otolith among approximately 2000 pairs of herring larva sagitta. Therefore, it is difficult to speculate on the causes of this phenomenon.

The formation of otoliths in larvae is driven by environmental conditions (Fey 2005). For example, changes in water temperature can affect the metabolism rate of fish larvae, which in turn can lead to irregular patterns of otolith material deposition (Sweeting et al. 2004). Studies have shown that sudden temperature changes can cause anomalies in otolith structures, making it difficult to accurately date larval age (Miller 2011). On the other hand, changes in salinity can disrupt ionic homeostasis in fish larvae, leading to alterations in the mineral composition of otoliths (Martinho et al. 2020). For instance, higher salinity can cause faster calcium deposition, resulting in the formation of more complex otolith structures (Elsdon and Gillanders 2002).

Environmental pollution, such as heavy metals, pesticides, and other toxins, also affects otolith development (Elsdon and Gillanders 2003). Toxins can disrupt biochemical processes in fish larvae, leading to improper deposition of calcium and protein layers in the otoliths (Tomás and Geffen, 2003). Understanding the impact of pollution on otoliths is crucial for interpreting data from polluted areas (Lombarte and Lleonart 1993, Hardersen, 2000). Oxidative stress may also result from anomalies in the otolith structure (Payan et al. 2004). Free radicals generated during metabolism can damage the cells responsible for otolith formation, leading to abnormal development. Oxidative stress can arise from environmental factors, such as pollution, and biological factors, such as diseases (Tomás and Geffen 2003). Another factor is genetic mutation, which may influence otolith growth and mineralization processes (Tomás and Geffen 2003).

Anomalies in otoliths can lead to difficulties in proper spatial orientation (Weigele et al. 2015). The consequences can include problems with seasonal migrations, which are critical for the survival of many fish species. Moreover, fish may have a reduced ability to respond quickly to the presence of predators (Vignon and Aymes 2020). This can increase their exposure to attacks and raise the mortality rates within the populations. In terms of defensive and adaptive behaviors, the ability to quickly detect and avoid threats is vital for fish survival in their natural environment. Damage to otoliths can lead to balance problems in the water, which can affect swimming efficiency (Gagliano et al. 2008). These disturbances can lead to increased physical stress and limit fish movement in their natural habitats.

Acknowledgements. We want to thank Hanna Wróblewska for extracting the otoliths of Vistula Lagoon herring larvae. This work is a contribution to the statutory project Dot23/CONHER conducted at the National Marine Fisheries Research Institute and funded by the Ministry of Science and Higher Education, Poland.

Authors contribution. M.D.: Writing – original draft, Visualization, Methodology, Investigation, Project administration. D.P.F.: Writing – original draft, Visualization, Methodology, Investigation. S.S.: Writing – original draft, Visualization, Methodology, Investigation.

ORCID iD

Małgorzata Dembek https://orcid.org/0000-0003-2407-5130

Szymon Smoliński https://orcid.org/0000-0003-2715-984X

References

Béarez, P., Carlier, G., Lorand, J.P., Parodi, G.C. (2005). Destructive and non-destructive microanalysis of biocarbonates applied to anomalous otoliths of archaeological and modern sciaenids (Teleostei) from Peru and Chile. Comptes Rendus Biologies, 328, 243-252, https://doi.org/10.1016/j.crvi.2005.01.003.

Campana, S.E., Neilson, J.D. (1985). Microstructure of fish otoliths. Canadian Journal of Fisheries and Aquatic Sciences 42, 1014-1032.

Campana, S.E. (1999). Chemistry and composition of fish otoliths: pathways, mechanisms and applications. Marine Ecology Progress Series, 188, 263-297.

Campana, S.E., Thorrold, S.R. (2001). Otoliths, increments, and elements: keys to a comprehensive understanding of fish populations? Canadian Journal of Fisheries and Aquatic Sciences, 58(1), 30-38, https://doi.org/10.11-39/cjfas-58-1-30.

Degens, E.T., Deus, W.G., Haedbzc, R.L. (1969). Molecular structure and composition of fish otoliths. Marine Biology, 2, 105-113.

Elsdon, T.S., Gillanders, B.M. (2002). Interactive effects of temperature and salinity on otolith chemistry: Challenges for determining environmental histories of fish. Canadian Journal of Fisheries and Aquatic Sciences, 59(11), 1796-1808, https://doi.org/10.1139/f02-154.

Elsdon, T. S., Gillanders, B. M. (2003). Reconstructing migratory patterns of fish based on environmental influences on otolith chemistry. Reviews in Fish Biology and Fisheries, 13, 219-235.

Fey, D.P. (2001). Differences in temperature conditions and somatic growth rate of larval and early juvenile spring-spawned herring from the Vistula Lagoon, Baltic Sea manifested in the otolith to fish size relationship. Journal of Fish Biology, 58(5), 1257-1273, https://doi.org/10.1006/jfbi.2000.1529.

Fey, D.P. (2005). Is the marginal otolith increment width a reliable recent growth index for larval and juvenile herring? Journal of Fish Biology. 66(6), 1692-1703, https://doi.org/10.1111/j.0022-1112.2005.00716.x.

Fey, D.P., Szkudlarek-Pawełczyk, A., Woźniczka, A. (2014). Abundance and distribution of larval herring, *Clupea harengus* (Actinopterygii: Clupeiformes: Clupeidae) in the Pomeranian Bay, Baltic Sea as an indicator of spawning sites. Acta Ichthyologica et Piscatoria, 44(4), 309-317, https://doi.org/10.3750/AIP2014.44.4.05.

Folkvord, A., Johannessen, A., Moksness, E. (2004). Temperature-dependent otolith growth in Norwegian spring-spawning herring (*Clupea harengus* L.) larvae. Sarsia, 89, 297-310, https://doi.org/10.1080/00364820410002532.

Gagliano, M., Depczynski, M., Simpson, S. D., Moore, J.A. (2008). Dispersal without errors: symmetrical ears tune into the right frequency for survival. Proceedings of the Royal Society B: Biological Sciences, 275(1634), 527-534.

Hardersen, S. (2000). The role of behavioural ecology of damselflies in the use of fluctuating asymmetry as a bioindicator of water pollution. Ecological Entomology, 25(1), 45-53.

Krasovskaya, N. V., (1998). Reproduction and abundance dynamics of the Baltic herring (*Clupea harengus membras* L.) in the Vistula Lagoon of the Baltic Sea. Proceedings of Symposium "Freshwater fish and the herring populations in the coastal lagoons". Sea Fish. Inst., Gdynia, 125-142.

Lombarte, A., Lleonart, J. (1993). Otolith size changes related with body growth, habitat depth and temperature. Environmental Biology of Fishes, 37, 297-306.

Mahé, K., Gourtay, C., Defruit, G. B., Chantre, C., de Pontual, H., Amara, R., Claireaux, G., Audet, C., Zambonino-Infante, J. L., Ernande, B. (2019). Do environmental conditions, temperature and food composition, affect otolith shape during fish early-juvenile phase? An experimental approach applied to European Seabass, *Dicentrarchus labrax*. Journal of Experimental Marine Biology and Ecology, 521, 151239, https://doi.org/10.1016/J.JEMBE.2019.151239.

Martinho, F., Pina, B., Nunes, M., Vasconcelos, R. P., Fonseca, V. F., Crespo, D., ... & Reis-Santos, P. (2020). Water and otolith chemistry: implications for discerning estuarine nursery habitat use of a juvenile flatfish. Frontiers in Marine Science, 7, 347, https://doi.org/10.3389/fmars.2020.00347.

Miller, J.A. (2011). Effects of water temperature and barium concentration on otolith composition along a salinity gradient: Implications for migratory reconstructions. Journal of Experimental Marine Biology and Ecology, 405(1–2), 42-52, https://doi.org/10.1016/j.jembe.2011.05.017.

Payan, P., de Pontual, H., Bśuf, G., Mayer-Gostan, N. (2004). Endolymph chemistry and otolith growth in fish. Comptes Rendus Palevol, 3(6–7), 535-547, https://doi.org/10.1016/J.CRPV.2004.07.013.

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D. (2005). Climate change and distribution shifts in marine fishes. Science, 308(5730), 1912-1915.

Pinsky, M.L., Selden, R.L., Kitchel, Z.J. (2020). Climate-driven shifts in marine species ranges: Scaling from organisms to communities. Annual Review of Marine Science, 12, 153-179, https://doi.org/10.1146/annurev-marine-010419-010916.

Popper, A.N., Lu, Z. (2000). Structure–function relationships in fish otolith organs. Fisheries Research, 46(1-3), 15-25.

Sweeting, R.M., Beamish, R.J., Neville, C.M. (2004). Crystalline otoliths in teleosts: Comparisons between hatchery and wild coho salmon (*Oncorhynchus kisutch*) in the Strait of Georgia. Reviews in Fish Biology and Fisheries, 14, 361-369.

Tomás, J., Geffen, A.J. (2003). Morphometry and composition of aragonite and vaterite otoliths of deformed laboratory reared juvenile herring from two populations. Journal of Fish Biology, 63, 1383-1401, https://doi.org/10.1046/j.1095-8649.2003.00245.x.

Tonheim, S., Slotte, A., Andersson, L., Folkvord, A., Berg, F. (2020). Comparison of otolith microstructure of herring larvae and sibling adults reared under identical early life conditions. Frontiers in Marine Science, 7, 529, https://doi.org/10.3389/fmars.2020.00529.

Weigele, J., Franz-Odendaal, T.A., Hilbig, R. (2015). Spatial expression of Otolith Matrix Protein-1 and Otolin-1 in normally and kinetotically swimming fish. Anatomical Record (Hoboken). 298(10), 1765-1773, https://doi.org/10.1002/ar.23184.

Vignon, M., Morat, F. 2010. Environmental and genetic determinant of otolith shape revealed by a non-indigenous tropical fish. Marine Ecology Progress Series, 411, 231-241, https://doi.org/10.3354/meps08651.

Vignon, M., Aymes, J.C. (2020). Functional effect of vaterite – the presence of an alternative crystalline structure in otoliths alters escape kinematics of the brown trout. Journal of Experimental Biology, 223(12), jeb222034, https://doi.org/10.1242/jeb.222034.