

Get big fast! Patterns of first-year growth in seven species of minnows (Leuciscidae) from south-central Ontario

NORMAN W.S. QUINN^{1,*} and ANNA ROOKE²

¹Unit 511, 135 Orr Street, Cobourg, Ontario K9A 0J6 Canada

²Department of Biology, Queen's University, Kingston, Ontario K7L 3N6 Canada

*Corresponding author: normq4@gmail.com

Quinn, N.W.S., and A. Rooke. 2024. Get big fast! Patterns of first-year growth in seven species of minnows (Leuciscidae) from south-central Ontario. *Canadian Field-Naturalist* 138(4): 303–308. <https://doi.org/10.22621/cfn.v138i4.3045>

Abstract

Common patterns of growth are presented for the young-of-year of seven species of minnows (Leuciscidae) based on analysis of daily growth increments in the microstructure of otoliths. All seven species show a period of growth during May–September and reach approximately the same size (~4.3 cm) entering their first winter. The first annulus appears to develop in May. The most striking feature, observed in all seven species, is a sudden and marked increase in rate of growth at ~25 days post-hatch. The first 21 days of this surge in growth account for 29% of the first-year's growth. The growth surge may result from reaching a developmental milestone, such as the ossification of fin rays or flexion of the notochord that allows for greater mobility and capture of invertebrate prey. Given that small size is negatively associated with survival in juvenile fishes, achieving the growth surge in early life is likely important for survival. These results may be broadly applicable to leuciscids, an ecologically important and understudied group of fish.

Key words: Leuciscids; otolith; increments

Introduction

Fisheries biologists have found otoliths to be perhaps the most accurate, if not the easiest, structure to determine age of fishes. Otoliths are accretions of calcium carbonate (CaCO₃) that play a role in balance and hearing in fishes (Helfman *et al.* 2009). Annual demarcations (“annuli”) are readily observable in otoliths treated by sectioning and polishing. The annuli are formed as alternating opaque and translucent bands as the ratio of CaCO₃ to protein changes from the growing period to winter dormancy (e.g., Paxton *et al.* 2013). Less well known is that daily growth increments (DGIs) are also present in the microstructure of otoliths. The DGIs form similarly as opaque and translucent bands in a circadian rhythm (Campana 1992). Detailed growth of the otolith, revealed by DGI counts, is directly related to growth of the body of the fish (Campana and Neilson 1985) and has been used to reconstruct growth and timing of events in the early life history of fishes. For example, discontinuities in the deposition of DGIs have revealed the timing of settlement of pelagic larvae of coral reef fish (Wilson and McCormick 1999).

In this study we report patterns of DGI deposition in the lapillus otolith of young-of-year of seven leuciscid (minnow) species from south-central Ontario,

Canada. Our objective was to look for patterns of growth that would provide insight into the early life history and ecology of these fishes.

Methods

Seven leuciscid species, Creek Chub (*Semotilus atromaculatus*), Fathead Minnow (*Pimephales promelas*), Brassy Minnow (*Hybognathus hankinsoni*), Common Shiner (*Luxilus cornutus*), Golden Shiner (*Notemigonus crysoleucas*), Northern Redbelly Dace (*Chrosomus eos*), and Western Blacknose Dace (*Rhinichthys obtusus*) were captured with Gee traps (type of trap commonly used by bait fishers) from streams in the general vicinity of Bancroft, Ontario (45.062°N, 77.485°W) from spring through late fall 2018–2020. Smaller fish (generally <8 cm total length [TL]) were selected to focus on early life history. Fish were euthanized by immersion in a bath of 100 ppm tricaine methanesulfonate (MS 222; Syndel, Nanaimo, British Columbia, Canada) and TL was measured; voucher fishes were not retained. The lapillus otoliths were removed and stored in paper envelopes at room temperature for no more than one week. Age was determined by placing the lapillus, anti-sulcal side up, in a drop of immersion oil on a microscope slide painted black and counting annuli (rings) under low power of a

A contribution towards the cost of this publication has been provided by the Thomas Manning Memorial Fund of the Ottawa Field-Naturalists' Club.

compound microscope (Escot and Granado-Lorencio 1998). The annuli were often further revealed (Figure 1) as the specimen was treated (as described below) to reveal DGIs.

The otolith was then placed, sulcal side up, on a microscope slide and covered with a drop of thermoplastic cement (Buehler, Lake Bluff, Illinois, USA), a clear fixative, and left overnight to harden. The long axis of the otolith was then measured with an ocular micrometer. The specimen was ground in short intervals with a circular motion in a drop of immersion oil against 2000 grit sandpaper on a glass plate to erode the otolith matrix, gradually revealing the central core or nucleus and a plane along the long axis. If needed, the specimen was further worked against 30 μm lapping film to clarify the DGIs. Other examples of this procedure are described in Victor and Brothers (1982) and Huang *et al.* (2017). Studies (e.g., Victor and Brothers 1982) confirm our expectation that microincrements are deposited daily in the lapilli of leuciscids. The DGIs were counted from the nucleus into the posterior lobe of the lapillus, which grows more quickly than the anterior lobe (Escot and Granado-Lorencio 1998) and where the lines are spaced more widely.

The lapillus is also asymmetrical in lateral profile, and we found that in eroding the otolith matrix toward the nucleus, DGIs at varying distances from the core

appear (or are eroded away) sequentially, and it was unusual to be able to make a continuous count from the nucleus to the edge of the otolith (Brothers *et al.* 1976, also describe this problem).

Three counts were made. First, where the core area was clear, from the nucleus to the start of a nearly universal rapid surge in growth (Figure 2). This point, termed the transition zone (TZ), was usually abrupt but often occurred over several days and, in such cases, its precise location was an estimate. The DGIs inside the TZ were narrow and closely spaced (fine lines); those beyond it were markedly broad and widely spaced (bold lines, Figure 2). In specimens with DGIs clearly visible to the first annulus, this count was continued to the annulus to obtain a total period (days) of first-year growth. Where the core area was not clear, the DGIs were counted from the TZ to the annulus. The mean number of fine lines for the species was then added to this to get an estimate of total first-year growth. In a review of interpretation of the microstructure of fish otoliths, Campana (1992) noted that because of anomalous structures and the very fine nature of some lines, error is expected in counting long strings of DGIs and a 5% error rate is “acceptable”. Every annual series was counted twice and, if there was a difference in the total count, the mean was used. If the difference was greater than 5%,

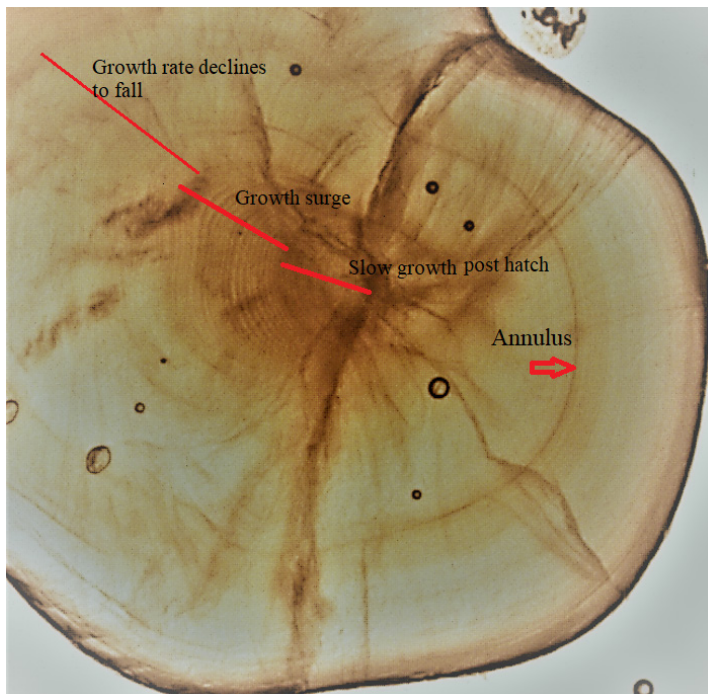


FIGURE 1. Section of a lapillus otolith from a yearling Creek Chub (*Semotilus atromaculatus*) showing the three zones of first year's growth and an annulus. Photo: Norman Quinn.

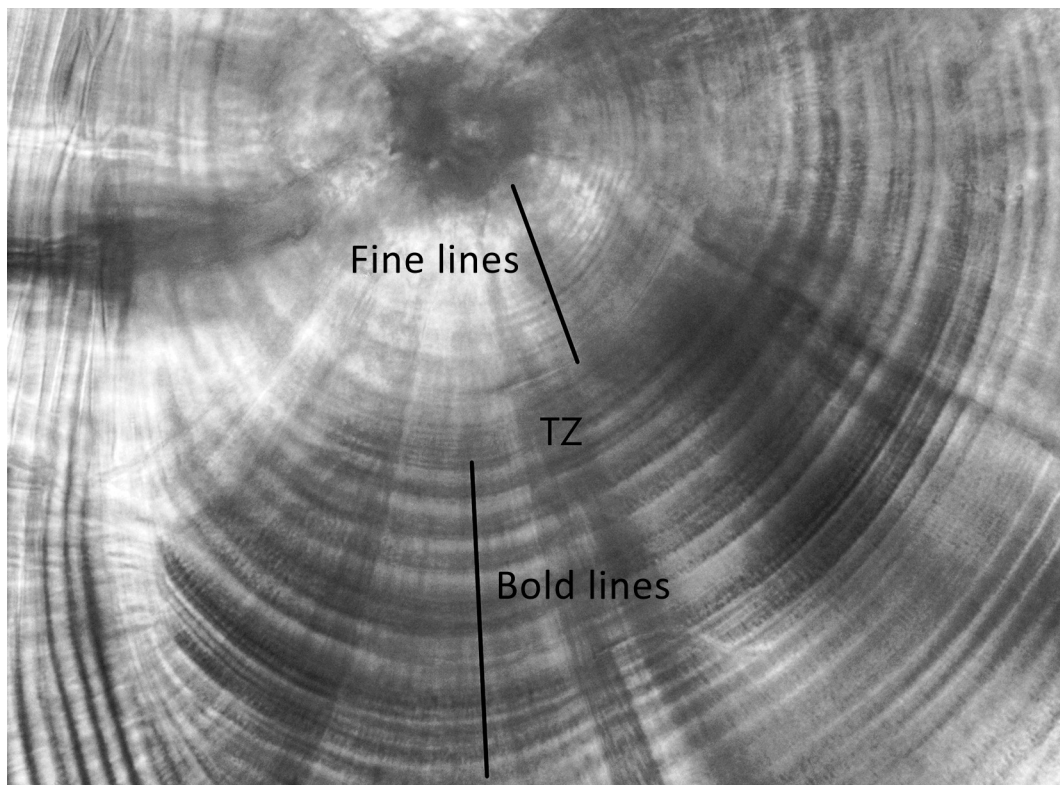


FIGURE 2. Detail of the core area of a lapillus otolith from a yearling Golden Shiner (*Notemigonus crysoleucas*) showing the fine lines around the nucleus, bolder lines of the growth surge, and transition zone (TZ) between the two. Photo: Norman Quinn.

the specimen was not used. All counts were made by N.W.S.Q.

Because there is some uncertainty about the timing of formation of the first annulus (Schemske 1974; Victor and Brothers 1982), we examined the edge of otoliths of one-year-old fish caught from April through mid-June to look for a clearly bolder line (assumed to be the annulus) forming amid the increments as evidence of timing of its formation.

The radius of the otolith from nucleus to posterior edge (LE) and length to the first annulus (LA) were measured with an ocular micrometer. Linear dimensions of otoliths and the body length of fish are strongly associated, and the relationship is normally linear (e.g., Morioka and Matsumoto 2007). The linear relationship of otolith radius and total length of our fish was strong in five of the seven species (r^2 for the linear model was 0.70 for Creek Chub, 0.87 for Brassy Minnow, 0.67 for Common Shiner, 0.71 for Golden Shiner, and 0.60 for Western Blacknose Dace). We considered the range of TL of the other two species (<2 cm) to be too narrow to test this. However, we assumed linearity for these two also because of its

expected occurrence as reported in the literature (e.g., Morioka and Matsumoto 2007). We estimated length at age one for all specimens having clear first annuli from $(LA / LE) \times TL$. The initial surge of growth is usually pronounced and our experience with examining the specimens showed this period to last about three weeks (N.W.S.Q. and A.R. pers. obs.). To assess the contribution of the growth surge to annual growth, we measured the distance covered by its first 21 days with the ocular micrometer and expressed this as a percentage of total first-year growth.

Results

We sampled 248 fish: 92 Creek Chub, 40 Fathead Minnow, 12 Brassy Minnow, 19 Common Shiner, 52 Golden Shiner, 22 Northern Redbelly Dace, and 11 Western Blacknose Dace. Of these, 130 were one-year-olds (caught during their second year of life), 92 were two-year-olds, 24 three-year-olds, and one was a four-year-old. Only one fish (a Creek Chub) was caught as a 0+, that is, during its year of hatch.

The range of TL at age one year among species was narrow (3.85–4.77 cm, mean 4.29; Table 1). The

TABLE 1. Featured elements (mean (*n*, range)) of growth and daily growth increment counts for young-of-year of seven species of minnows (Leuciscidae) from south-central Ontario.

Species	Size at 1 year, cm	Period of first year's growth, days	DGI count to TZ, days	% annual growth achieved in first 21 days of GS
Creek Chub (<i>Semotilus atromaculatus</i>)	4.54 (70, 3.00–6.47)	126 (17, 116–148)	26 (19, 18–35)	35 (35, 16–41)
Fathead Minnow (<i>Pimephales promelas</i>)	4.14 (26, 3.01–6.27)	136 (7, 125–151)	25 (9, 22–30)	26 (9, 22–28)
Brassy Minnow (<i>Hybognathus hankinsoni</i>)	4.77 (12, 3.94–6.47)	134 (4, 129–131)	25 (6, 19–29)	31 (6, 21–37)
Common Shiner (<i>Luxilus cornutus</i>)	4.08 (21, 2.78–5.44)	—*	27 (5, 21–29)	25 (5, 20–29)
Golden Shiner (<i>Notemigonus crysoleucas</i>)	4.27 (41, 2.71–6.19)	127 (13, 118–144)	24 (13, 19–29)	31 (20, 25–42)
Northern Redbelly Dace (<i>Chrosomus eos</i>)	3.85 (20, 1.89–6.29)	132 (7, 116–139)	22 (10, 18–26)	30 (4, 21–48)
Western Blacknose Dace (<i>Rhinichthys obtusus</i>)	4.41 (10, 3.18–5.73)	—*	26 (5, 25–27)	28 (4, 26–31)

Note: DGI = daily growth increment, GS = growth surge (the period of rapid growth of larvae following the TZ), TZ = transition zone (the point at which rapid growth of larvae begins).
*Fewer than three counts made.

annulus for most specimens appeared to be deposited during May: four of nine specimens (all species combined) caught in late April showed evidence of an annulus forming, eight of 20 in early May, 11 of 21 in late May, and 14 of 15 in the first two weeks of June. The area around the nucleus, where the otolith is thickest, was usually partly obscured. This problem, reported by others (e.g., Cavole *et al.* 2018), made counts of DGIs immediately around the nucleus difficult; clear counts could only be made in about one in five of our specimens.

Growth during the first year occurs in three phases (Figure 1): a period of slow growth immediately post-hatch (phase 1) followed by the abrupt onset of a period of fast growth into early summer (phase 2) and, finally, a gradual decline in rate of growth into fall (phase 3). Toward the end of annual growth (in fall), the DGIs become tightly compact, often forming an opaque band. Figure 2 shows detail of the core area showing the first two phases in a yearling Golden Shiner.

The mean period of first-year growth for five species for which there were more than three counts ranged from 126 to 136 days (Table 1).

Most specimens (195/209: 70/74 Creek Chub, 26/27 Fathead Minnow, 12/12 Brassy Minnow, 11/14 Common Shiner, 47/49 Golden Shiner, 20/23 Northern Redbelly Dace, and 9/10 Western Blacknose Dace), in which the central area of the otolith was sufficiently clear to show an overall pattern (if not actual count) of DGIs displayed the growth surge, i.e., the distinct increase in spacing of increments following narrow spacing post hatch. The growth surge begins at ~25 days post-hatch (dph; range 24–27) with the exception of Northern Redbelly Dace (dph of 22 days; Table 1). The first 21 days of the growth surge account for 29% of first-year growth (mean from Table 1, range 25%–35%).

Discussion

Five studies of leuciscids (or closely related Cypriniformes) show that the first DGI is deposited on the first day post-hatch (Smith and Walker 2003; Morioka and Matsumoto 2007; Paxton *et al.* 2013; Ding *et al.* 2015; Bounket *et al.* 2019). The period of active annual growth that we report for five species (126–130 days) corresponds to a period of about four months, from late May, when spawning usually begins in these species (Scott and Crossman 1973; Holm *et al.* 2022), to late September, with the onset of cooler weather. Size at age one year is essentially identical among the seven species, which is surprising because these species vary substantially in size as adults (Scott and Crossman 1973; Holm *et al.* 2022).

All seven species showed a rapid surge in growth of larval fish at ~25 dph, with the first 21 days accounting for nearly a third of first-year growth. Previous studies of larval leuciscids have documented slow growth (0.23–0.29 mm/day) in the first 14 dph (Weisel and Newman 1951; Faber 1985; Sakai 1990; Kupren *et al.* 2016; Yang *et al.* 2017; Bounket *et al.* 2019). Bounket *et al.* (2019) showed a pattern of growth through the first year from DGIs of the otolith of European Chub (*Squalius cephalus*) in France that is nearly identical to what we have documented: slow growth initially, with a sudden surge as late larvae, robust growth to early summer, and then a gradual decline into fall. The growth surge begins at 18 dph in *Squalius* raised in captivity (Bounket *et al.* 2019) and at 26 dph in wild fish (B. Bounket pers. comm. 27 January 2020).

A possible explanation for the growth surge is that these fish, as larvae, benefit from a profusion of foods as waters warm after they hatch in spring. However, this is unlikely because most leuciscids are batch spawners and spawn repeatedly through spring and

summer (Winfield and Nelson 1991). Batch spawning has been documented for six of our seven species (all but Golden Shiner; Gale and Buynak 1982; Powles *et al.* 1992; Quinn 2019). For example, Fathead Minnow spawns 16–26 times a season (Gale and Buynak 1982). Fish captured in our study would, therefore, probably have experienced variable food supply as developing larvae.

We propose that the growth surge is more likely a result of these larval fish reaching a developmental “milestone” resulting in increased mobility and ability to capture prey. In other words, they transform from passive drifting members of the zooplankton into active tiny predators. A marked change in diet, growth, or behaviour (swimming ability) of larval fishes is often linked to specific morphological developments (Reyes-Marchant *et al.* 1992; Ward and Cobourn 2008; Samarakis and Nikolioudakis 2010). Important milestones of development include inflation of the swim bladder, ossification of fin rays, and flexion of the notochord (e.g., Gozlan *et al.* 1999; Samarakis and Nikolioudakis 2010).

There is considerable literature on the larval and juvenile development of leuciscids. Metamorphosis, the transition from larva to juvenile, is commonly defined in fishes as the final absorption of finfolds into completely formed fins and achievement of an overall “adult” appearance (e.g., Kupren *et al.* 2016). Metamorphosis is usually reported to occur after 40 dph in leuciscids (e.g., Cooper 1980). The morphological developments in larvae that are reported to enhance mobility initiate shortly after hatch. Flexion of the notochord, for example, begins in leuciscids within a few dph and is completed by 25 dph (e.g., Cooper 1980; Huang *et al.* 2017). Flexion may be particularly important as Gozlan *et al.* (1999: 75) described it as vital to the “caudal–body connection” and Samarakis and Nikolioudakis (2010) proposed that it is the vital milestone of development for larval fish in general. Huang *et al.* (2017) believed that the completion of flexion at 19 dph in the leuciscid Mud Carp (*Cirrhinus molitorella*) of China allows the larvae to migrate to refuge in deeper water.

Rapid early growth facilitates escape from predators and is frequently linked to cohort strength in fisheries; indeed, the association is a common thread in population studies of fishes (Helfman *et al.* 2009). For example, Clark Barkalow *et al.* (2021) showed that larvae of the leuciscid Colorado Pikeminnow (*Ptychocheilus lucius*) begin to escape gape-limited predators after reaching 25 mm total length.

Leuciscids, formerly a subfamily of Cyprinidae (Nelson 2007), are widespread in North America and Eurasia and important in food webs, as bait-fish, and as food fish (Winfield and Nelson 1991). The

phenomenon we document, i.e., the rapid surge of larval growth at 25 dph for seven stream dwelling species in northeastern North America, may have broad application to their population biology. Its cause, in particular a possible common morphological development, should be further explored by a combination of field and laboratory (aquaria) studies.

Author Contributions

Writing – Original Draft: N.W.S.Q.; Writing – Review & Editing: A.R.; Conceptualization: N.W.S.Q. and A.R.; Methodology: N.W.S.Q. and A.R.; Formal Analysis: N.W.S.Q.

Acknowledgements

Marisha Lamond provided a critique of the original draft of the paper. Erling Holm helped with identification of specimens. Bernadette Bounket (Irstea, Ur Recover, Aix-en-Provence, France) provided data on *Squalius* additional to those which appeared in their paper. Robert Quinn (Michigan State University) assisted with the photographs. Specimens were collected under Scientific Collectors Permit #1079384 issued by the Ontario Ministry of Natural Resources, and we followed that agency’s Animal Care Protocol for fishes.

Literature Cited

- Bounket, B., P. Gilbert, V. Gennotte, C. Argillier, G. Carrel, A. Maire, M. Logez, and F. Morat. 2019. Otolith shape analysis and daily increment validation during ontogeny of larval and juvenile European Chub *Squalius cephalus*. *Journal of Fish Biology* 95: 444–452. <https://doi.org/10.1111/jfb.13976>
- Brothers, E.B., C.P. Mathews, and R. Lasker. 1976. Daily growth increments in otoliths from larval and adult fishes. *Fishery Bulletin* 74: 1–8. Accessed 12 June 2024. <https://spo.nmfs.noaa.gov/sites/default/files/pdf-content/1976/741/brothers.pdf>
- Campana, S.E. 1992. Measurement and interpretation of the microstructure of fish otoliths. Pages 59–71 in *Otolith Microstructure Examination and Analysis*. Edited by D.K. Stevenson and S.E. Campana. Canadian Special Publication Fisheries and Aquatic Sciences 117. Department of Fisheries and Oceans, Ottawa, Ontario, Canada. Accessed 20 August 2025. https://publications.gc.ca/collections/collection_2016/mpo-dfo/Fs41-31-117-eng.pdf
- Campana, S.E., and J.D. Neilson. 1985. Microstructure of fish otoliths. *Canadian Journal of Fisheries and Aquatic Sciences* 42: 1014–1032. <https://doi.org/10.1139/f85-127>
- Cavole, L.M., I.G. Cardoso, M.S. Almeida, and H. Haimovici. 2018. Unravelling growth trajectories from complicated otoliths — the case of Brazilian Codling, *Urophycis brasiliensis*. *Journal of Fish Biology* 92: 1290–1311. <https://doi.org/10.1111/jfb.13586>
- Clark Barkalow, S.L., M.J. Chavez, and S.P. Platania. 2021. Otolith microstructure analysis elucidates spawning and early life histories of federally endangered fishes in the San Juan River. *Ichthyology & Herpetology* 109:

- 860–873. <https://doi.org/10.1643/i2020011>
- Cooper, J.E.** 1980. Egg, larval and juvenile development of Longnose Dace, *Rhinichthys cataractae*, and River Chub, *Nocomis micropogon*, with notes on their hybridization. *Copeia* 1980: 469–478. <https://doi.org/10.2307/1444524>
- Ding, C., Y. Chen, D. He, and J. Tao.** 2015. Validation of daily increment formation in otoliths for *Gymnocypris selincuoensis* in the Tibetan Plateau, China. *Ecology and Evolution* 5: 3243–3249. <https://doi.org/10.1002/ec.31572>
- Escot, C., and C. Granado-Lorencio.** 1998. Morphology of the otoliths of *Barbus sclateri* (Pisces: Cyprinidae). *Journal of Zoology* 264: 89–94. <https://doi.org/10.1111/j.1469-7998.1998.tb00136.x>
- Faber, D.J.** 1985. The early development of the Northern Redbelly Dace, *Phoxinus eos* (Cope). *Canadian Journal of Zoology* 63: 1724–1729. <https://doi.org/10.1139/z85-258>
- Gale, W.F., and G.L. Buynak.** 1982. Fecundity and spawning frequency of the Fathead Minnow—a fractional spawner. *Transactions of the American Fisheries Society* 111: 35–40. [https://doi.org/10.1577/1548-8659\(1982\)111<35:fasfot>2.0.co;2](https://doi.org/10.1577/1548-8659(1982)111<35:fasfot>2.0.co;2)
- Gozlan, R.E., G.H. Copp, and J.N. Tourenq.** 1999. Early development of the Sofie, *Chondrostoma toxostoma*. *Environmental Biology of Fishes* 56: 67–77. <https://doi.org/10.1023/a:1007576222907>
- Helfman, G.S., B.B. Collette, D.E. Facey, and B.W. Bowen.** 2009. *The Diversity of Fishes: Biology, Evolution, and Ecology*. Wiley Blackwell, West Sussex, United Kingdom.
- Holm, E., N.E. Mandrak, and M.E. Burrige.** 2022. *A Field Guide to Freshwater Fishes of Ontario*. Royal Ontario Museum. Toronto, Ontario, Canada.
- Huang, Y., F. Chen, W. Tang, Z. Lai, and X. Li.** 2017. Validation of daily increment deposition and early growth of Mud Carp, *Cirrhinus molitorella*. *Journal of Fish Biology* 90: 1517–1532. <https://doi.org/10.1111/jfb.13250>
- Kupren, K., I. Rams, D. Źarski, and D. Kurharczyk.** 2016. Early development and allometric growth patterns of a rheophilic cyprinid Common Dace *Leuciscus leuciscus* (Cyprinidae: Leuciscinae). *Ichthyological Research* 63: 382–390. <https://doi.org/10.1007/s10228-016-0508-9>
- Morioka, S., and S. Matsumoto.** 2007. Otolith development and daily increment formation in larvae of the Kabyabya, a Malawian cyprinid, *Opsaridium tweddleorum*. *Ichthyological Research* 54: 44–48. <https://doi.org/10.1007/s10228-006-0372-0>
- Nelson, J.S.** 2007. *Fishes of the World*. Third Edition. Wiley, New Jersey, USA.
- Paxton, B.R., G.C. O'Brien, J.A. Slingsby, and R. Copin.** 2013. Validation of the periodicity of growth increment deposition in otoliths from larval and early juvenile stages of two cyprinids from Orange-Vaal river system South Africa. *African Journal of Aquatic Science* 38(suppl. 1): 49–54. <https://doi.org/10.2989/16085914.2013.775107>
- Powles, P.M., S. Finucan, M. van Haaften, and R.A. Curry.** 1992. Preliminary evidence for fractional spawning by the Northern Redbelly Dace, *Phoxinus eos*. *Canadian Field-Naturalist* 106: 237–240. <https://doi.org/10.5962/p.356935>
- Quinn, N.W.S.** 2019. Batch spawning in five species of minnows (Cyprinidae) from Ontario, Canada. *Canadian Field-Naturalist* 133: 325–328. <https://doi.org/10.22621/cfn.v133i4.1914>
- Reyes-Marchant, P., A. Cravinho, and N. Lair.** 1992. Food and feeding behaviour of Roach (*Rutilus rutilus*, Linné 1758) juveniles in relation to morphological change. *Journal of Applied Ichthyology* 8: 77–89. <https://doi.org/10.1111/j.1439-0426.1992.tb00670.x>
- Sakai, H.** 1990. Larval development intervals in *Tribolodon hakonensis* (Cyprinidae). *Japanese Journal of Ichthyology* 37: 17–28. <https://doi.org/10.11369/jji1950.37.17>
- Schemske, D.W.** 1974. Age, length and fecundity of the Creek Chub, *Semotilus atromaculatus* (Mitchill), in central Illinois. *American Midland Naturalist* 92: 505–509. <https://doi.org/10.2307/2424318>
- Scott, W.B., and E.J. Crossman.** 1973. *Freshwater Fishes of Canada*. Bulletin 184. Fisheries Research Board of Canada. Ottawa, Ontario, Canada.
- Smith, B.B., and K.F. Walker.** 2003. Validation of the ageing of 0+ carp (*Cyprinus carpio* L.). *Marine and Freshwater Research* 54: 1005–1008. <https://doi.org/10.1071/mf03010>
- Somarakis, S., and N. Nikolioudakis.** 2010. What makes a late anchovy larva? The development of the caudal fin seen as a milestone in fish ontogeny. *Journal of Plankton Research* 32: 317–326. <https://doi.org/10.1093/plankt/fbq132>
- Victor, B.C., and E.B. Brothers.** 1982. Age and growth of the Fallfish *Semotilus corporalis* with daily otolith increments as a method of annulus verification. *Canadian Journal of Zoology* 60: 2543–2550. <https://doi.org/10.1139/z82-326>
- Ward, S.A., and M.M. Cobourn.** 2008. Stepwise increases in maximum prey size of larval Creek Chubs, *Semotilus atromaculatus*, in an urbanized Ohio stream. *Northeastern Naturalist* 15: 349–362. <https://doi.org/10.1656/1092-6194-15.3.349>
- Weisel, G.F., and H.W. Newman.** 1951. Breeding habits, development, and early life history of *Richardsonius balteatus*, a northwestern minnow. *Copeia* 1951: 187–194. <https://doi.org/10.2307/1439094>
- Wilson, D.T., and M.I. McCormick.** 1999. Microstructure of settlement-marks in the otoliths of tropical reef fishes. *Marine Biology* 134: 29–41. <https://doi.org/10.1007/s002270050522>
- Winfield, I.J., and J.S. Nelson.** 1991. *Cyprinid Fishes: Systematics, Biology and Exploitation*. Chapman and Hall, London, United Kingdom.
- Yang, P., G. Jin, Y. Liu, J. Li, Z. Hu, and X. Luo.** 2017. Morphological development and allometric growth in hatchery-reared Caspian Shemaya (*Alburnus chalcoides*): from hatching to the juvenile stage. *Turkish Journal of Fisheries and Aquatic Sciences* 17: 427–435. https://doi.org/10.4194/1303-2712-v17_2_22

Received 6 September 2022

Accepted 11 August 2025

Associate Editor: K.L. Ilves