Ecology and Evolutionary Biology
2024, Vol. 9, No. 1, pp. 22-29
https://doi.org/10.11648/j.eeb.20240901.14

Research Article

Morphometry, Growth, and Condition of Hatchery-Reared Cisco (*Coregonus artedi*) and Bloater (*Coregonus hoyi*)

Marc Chalupnicki*, **Gregg Mackey, James McKenna, James Johnson, George Ketola**

U.S. Geological Survey, Tunison Laboratory of Aquatic Science, U. S. Geological Survey, Great Lakes Science Center, Cortland, US

Abstract

The re-introduction of native species that have been extirpated or in low abundance in the Great Lakes has been a binational initiative between the United States and Canadian governments. Recently, new management programs have been underway that use current hatchery facilities for the restoration of native forage fishes in Lake Ontario. These species include Bloater (*Coregonus hoyi*), which has been extirpated from Lake Ontario for approximately four decades, and Cisco (*C. artedi*), which exists at a fraction of its former abundance. We assessed morphometrics, length-weight relationships, and condition factors during early life development for eight cohorts of Cisco and Bloater reared from 2012-2019. Weekly samples for Cisco and Bloater were measured from hatch until release (29-45 weeks, 133-1,002 samples annually). Head width, gape, mandible length, and mouth height metrics were all larger for Cisco than Bloater at any given size but increased at similar rates for both species. Average condition factors for Cisco and Bloater were 0.54317 and 0.55892, respectively. This information may also improve field identification of these species, helping managers evaluate the relative success of different release strategies for rehabilitation of populations of these native species.

Keywords

Cisco, Bloater, Length/Weight Regression

1. Introduction

Cisco (*Coregonus artedi*), and Bloater (*C. hoyi*) are two native coregonines that were part of the historic forage base in Lake Ontario [21]. By the mid-1900's Bloater have become extirpated and Cisco have been reduced to extremely low levels due to overfishing, pollution, invasive species, and spawning habitat loss [2, 3, 6, 8, 18, 21]. In response, a binational, multiagency effort between the New York State Department of Environmental Conservation (NYDEC), U.S. Fish and Wildlife Service (USFWS), Ontario Ministry of Northern Development, Mines, Natural Resources, and Forestry (OMNDMNRF), and the U.S. Geological Survey (USGS) to restore native coregonine species into Lake Ontario was initiated. The broad objective is to re-establish the native prey base for the current top predators in Lake Ontario by reintroducing Cisco and Bloater to locations from which they have been extirpated. The culture of Cisco has been accomplished by several conservation hatcheries within the Great Lakes basin, but recent interest in culture of Bloater is limited to one USFWS hatchery, one Canadian hatchery, and the USGS Tunison Laboratory of Aquatic Science. The focus

*Corresponding author: mchalupnicki@usgs.gov (Marc Chalupnicki)

Received: 11 January 2024; **Accepted:** 23 January 2024; **Published:** 13 March 2024

on the restoration of native species in the Great Lakes has given rise to new fish culture techniques and management programs designed to reduce pathogen transmission, while producing enough fish to help re-establish or conserve wild populations.

Cohort success in most fish species is often determined during embryo development and first year survival. Identifying factors that directly influence population survival and relate to the success of a restoration program is essential, but basic biological information is rare for these species, including morphometric descriptions and age and growth responses. Early life stage morphometric measurements on coregonine species are rare and results are inconsistent [9, 11, 14, 20, 22]. Weekly growth indices are lacking for both Cisco and Bloater. Our early growth and size measurements in a hatchery setting expand the knowledge base for these species and may help improve current rearing practices, enhancing success of future restoration projects.

The objectives of this study were to evaluate and measure growth metrics of Cisco and Bloater under controlled conditions throughout their first year of growth. From these evaluations, we are developing fish culture standards that would be used as baseline measurements to improve current practices rearing Cisco and Bloater. In addition to traditional growth measurements, we provide baseline morphometric features for both species that should aid in field identification.

2. Materials and Methods

Adult Cisco were captured during December from Chaumont Bay, NY and transferred to outside raceways at the USGS Tunison Lab of Aquatic Science (TLAS) in Cortland, NY. Adults were hand spawned and moved to the hatchery to develop and hatch. Bloater are extirpated from Lake Ontario and were sourced from two places. Adult Bloater are collected from Lake Michigan by the USFWS Jordan River National Fish Hatchery. These fish were spawned, and the eggs were shipped overnight to TLAS. A Bloater brood stock has been established at White Lake Fish Hatchery in Sharbot Lake, Ontario, Canada. Fish were spawned and the eggs were transported to TLAS once they eye-up and are safe to transport prior to hatching.

Hatched fry were grown in circular hatchery tanks (190 L) and then moved to outside concrete raceways (500 L) while receiving 1.8-3 liters of well water per minute. The mean temperature, pH, and total hardness of this water were 9.8^{0}C, 6.82, and 230 mg/L as calcium carbonate, respectively, and remains constant. Daily fish husbandry duties including care and maintenance are detailed in the TLAS Coregonid Culture Manual [23] and were followed for the duration of the study. Fish were fed a variety of pelletized commercial feeds using automatic feeders to maximize growth at appropriate feeding rates according to nutritional requirements [23].

We measured growth and development of Cisco for the first 33-45 weeks of life, and that of Bloater for the first 29-39 weeks, January (hatch) through October (release), in consecutive year classes from 2012 to 2019. Five individuals of each species per each year class were randomly weighed (to the nearest 0.1 mg wet weight after blotting off excess water) and measured for total length (nearest 0.1 mm) weekly, using a digital microscope camera (Scope Photo 3.0, Hangzhou, Zhejiang Province, P. R. China) equipped with image measuring software (Image J). All fish evaluated were euthanized following standard American Fisheries Society IACUC procedures [1] with Trican S (MS-222, Syndel USA) and immediately measured fresh to eliminate change in size by preservation. Length-weight relationships were estimated using the general allometric equations,

$W = aTL^b$ or $W = aTL + b$, where 'W' is the wet weight of the fish in mg, 'TL' is the total length of the fish in mm, and 'a' and 'b' are fitted regression parameters. For the 2012-year class, additional growth metrics (yolk sac depth, head width taken posterior to the eye, mouth width or gape, lower jaw mandible length, and mouth height) were measured (to the nearest 0.1 mm) to identify additional characteristics that may differ between species (Figure 1 [8, 12, 13]). Condition factor of fish from the 2012, 2016, and 2017 year classes was calculated using the formula: $K = W(100/TL^3)$, where 'K' is the fish condition factor, and W and TL are defined as above [16, 17]. All metrics were plotted against total length to generate growth curves for each species. Differences in growth, condition factor, and additional metric measurements within and between species at a given length or age were tested using Analysis of Variance comparisons (ANOVA; Statistix 10.0, Analytical Software, Tallahassee, Florida). We considered $P \leq 0.05$ to be significant.

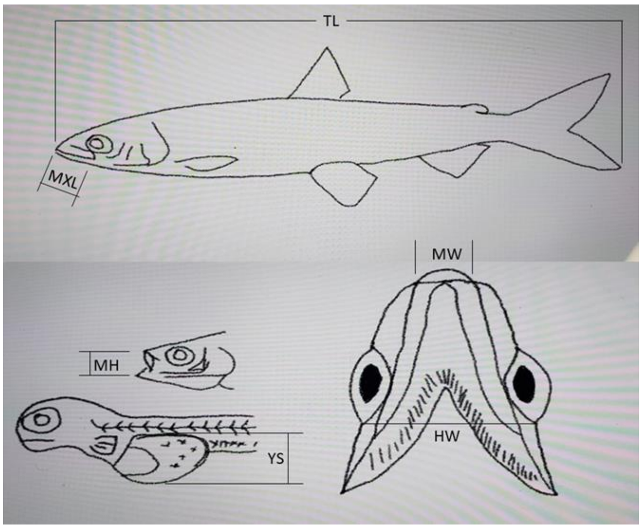
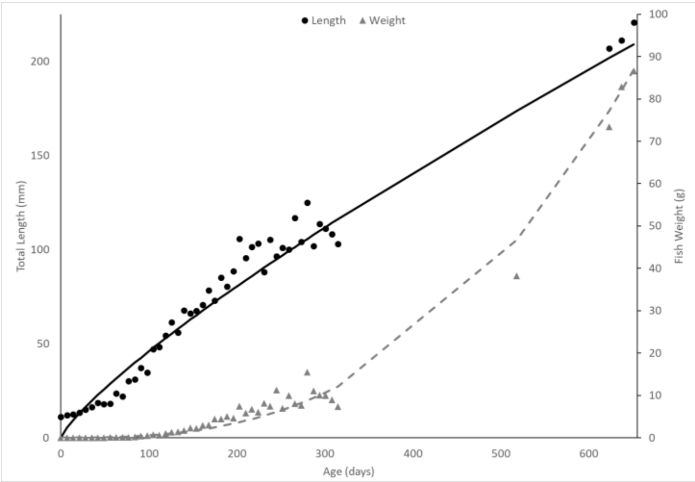


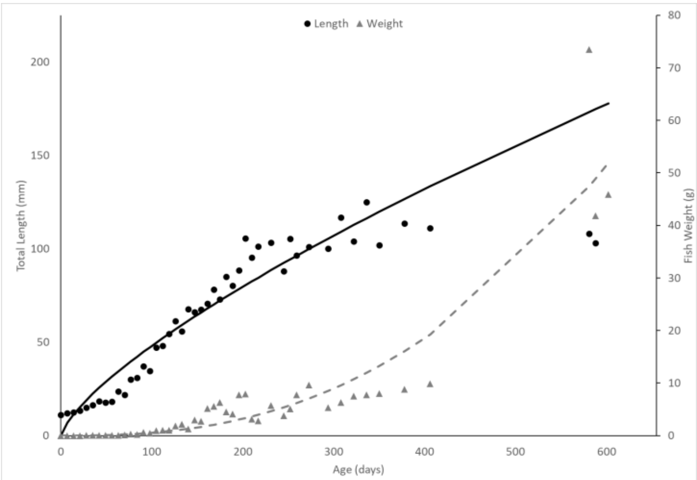
Figure 1. *Morphometric measurements recorded weekly to determine unique characteristics between Cisco and Bloater during the first year of growth. Morphometrics are defined as Total Length (TL), Yolk Sac Depth (YS), Head Width (HW), Mouth Width or Gape (MW), Lower Jaw Mandible (MXL), and Mouth Height (MH).*

3. Results and Discussion

We measured the growth and development of Cisco (n=4,243, 530±130/year class) for the first 45 weeks of life, and that for Bloater (n=3,627, 453±123/year class) for the first 39 weeks of life, for the 2012-2019 year-classes. Growth regressions at age (in days) for Cisco were $L=5.3318*Age^{0.8095}$, $W=0.004*Age^{2.7147}$, and for Bloater were $L=1.6762*Age^{0.7288}$, $W=0.000005*Age^{2.5243}$, respectively for predicted lengths and weights (Figure 2). From hatch, mean larval yolk sac depth decreased daily by 28% for Cisco and 33.3% for Bloater. Average maximum sizes (mm ±SE, g ±SE) attained were 103 ±0.89 mm and 9.32 ±0.19 g for Cisco and 92.1 ±0.67 mm and 6.2 ±0.13 g for Bloater (Table 1). Between weeks, mean total length tended to be larger for Bloater than Cisco (0.36 ±0.16 mm v 0.29 ±0.2 mm), but was not significantly different ($p = 0.7$, $t = 0.29$, $df = 31$), while mean weight was nearly identical (Cisco: 0.02 ±0.01g and Bloater: 0.02 ±0.04 g) ($p = 0.9$, $t = 0.04$, $df = 31$). Allometric regressions for Cisco and Bloater were $W=7x10^{-7}TL^{3.4832}$ and $W=1x10^{-6}TL^{3.3706}$, respectively (Figure 3, Table 2). Weekly mean condition factor value was significantly greater for Bloater ($0.09x10^5 – 1.14x10^5$) than Cisco ($0.06x10^5 – 2.3x10^5$) ($p<0.01$, $t = -15.8$, $df = 199$). Weight increased with fish total length according to equations W = 0.0036TL + 0.2866 for Cisco and W = 0.0035TL + 0.3454, for Bloater (Figure 4). Additional meristic measurements were all significantly larger for Cisco (Gape, $p<0.01$, $t = -3.72$, $df = 27$; Head Width, $p<0.01$, $t = -5.03$, $df = 27$; Mandible Length, $p<0.01$, $t = -4.75$, $df = 27$; Mouth Height, $p<0.01$, $t = -2.55$, $df = 27$) than Bloater at a given fish length (Table 3, Figure 5).



(A)

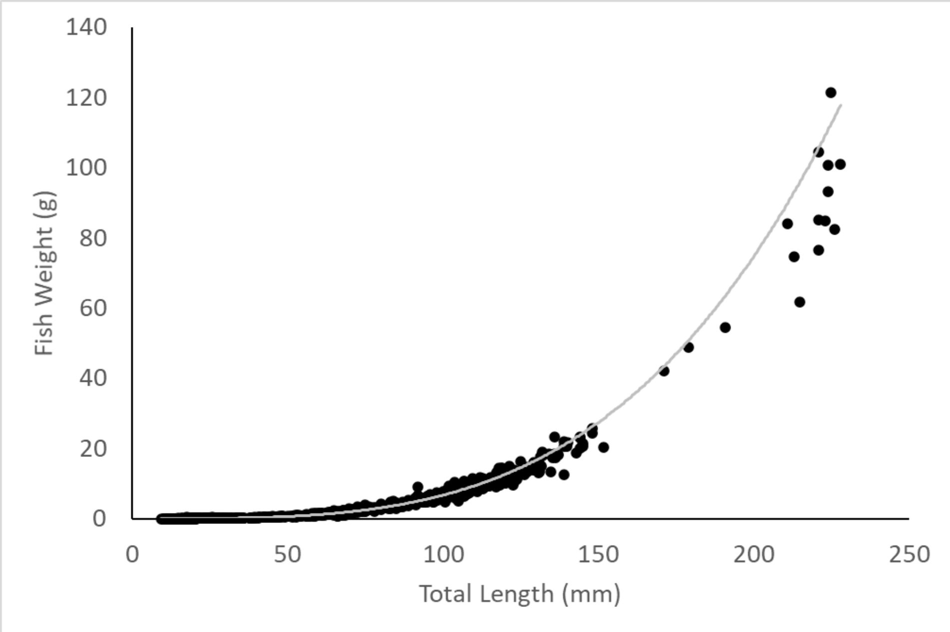


(B)

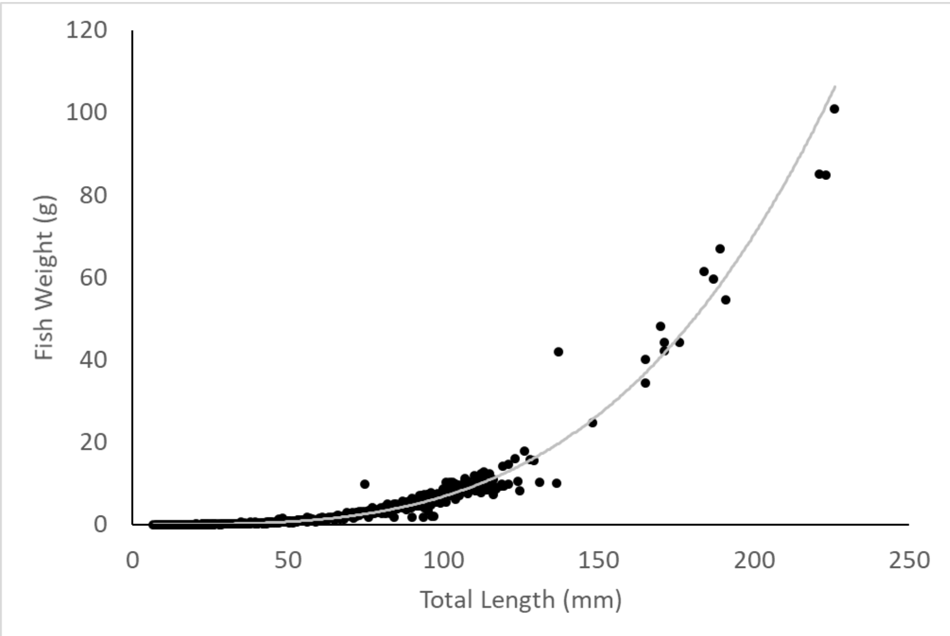
Figure 2. *Average weekly length and weight regressions for (A) Cisco and (B) Bloater among the 8-year classes evaluated during their first year of growth.*

Table 1. *Largest attainable size ranges for Cisco and Bloater cultured at Tunison Lab of Aquatic Science from 2012-2019.*

		Total Length (mm)				Total Weight (g)			
Species	**Attainable Age (Weeks)**	**Average ± SE**	**Max**	**Min**	**Count**	**Average ± SE**	**Max**	**Min**	**Count**
Cisco	33-45	103 ± 0.89	164.0	65.0	675	9.32 ±0.19	25.6	3.0	621
Bloater	29-39	92.1 ± 0.67	136.5	47.0	759	6.2 ±0.13	17.9	7.9	517



(A)

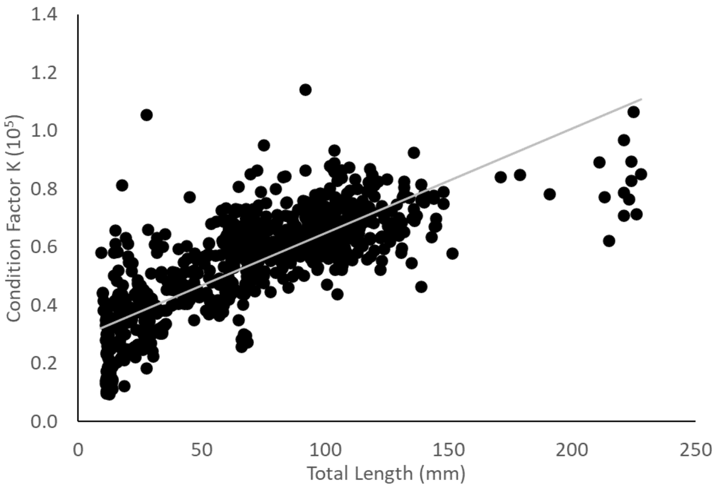


(B)

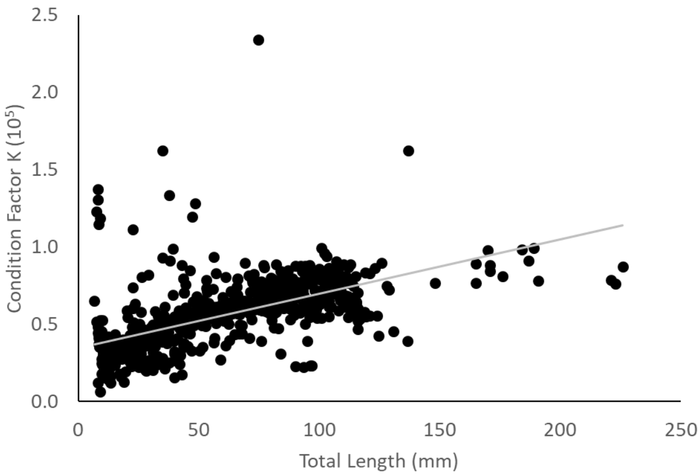
Figure 3. *Overall length-weight regression for (A) Cisco and (B) Bloater among the 8-year classes evaluated during their first year of growth.*

Table 2. *Length-weight regression for (A) Cisco and (B) Bloater for the 8-year classes evaluated during their first year of growth.*

Year	Cisco	Bloater
2012	$W = 4E\text{-}07TL^{3.5956}$	$W = 9E\text{-}07TL^{3.459}$
2013	$W = 2E\text{-}06TL^{3.2258}$	$W = 1E\text{-}06TL^{3.3947}$
2014	$W = 4E\text{-}07TL^{3.5964}$	$W = 1E\text{-}06TL^{3.3599}$
2015	$W = 6E\text{-}06TL^{3.0137}$	$W = 1E\text{-}27TL^{13.831}$
2016	$W = 2E\text{-}06TL^{3.2765}$	$W = 2E\text{-}06TL^{3.2135}$
2017	$W = 2E\text{-}06TL^{3.2486}$	$W = 2E\text{-}06TL^{3.3069}$
2018	$W = 2E\text{-}06TL^{3.253}$	$W = 3E\text{-}06TL^{3.1694}$
2019	$W = 5E\text{-}07TL^{3.5872}$	$W = 1E\text{-}06TL^{3.3416}$
OVERALL	$W = 7E\text{-}07TL^{3.4832}$	$W = 1E\text{-}06TL^{3.3706}$



(A)

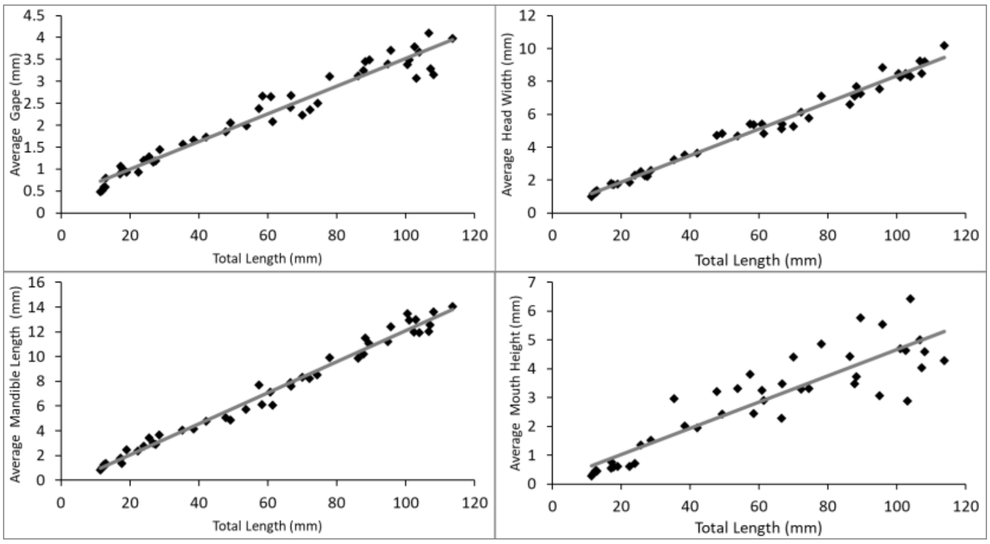


(B)

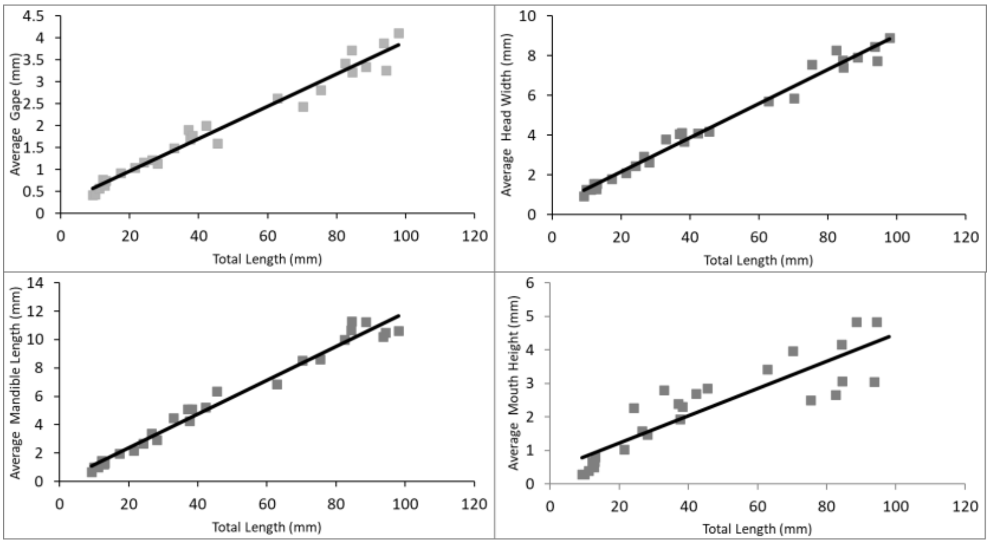
Figure 4. *Condition Factor (K, 10^5) for (A) Cisco and (B) Bloater related to the total length of the fish.*

Table 3. *Length-weight regression for regression equations for (A) Cisco and (B) Bloater meristic measurements) for the 8-year classes evaluated during their first year of growth.*

	Cisco	Bloater
Gape	W = 0.0314TL + 0.3737	W = 0.0369TL + 0.2254
Head Width	W = 0.0807TL + 0.2772	W = 0.0858TL + 0.427
Mandible Length	W = 0.1257TL + (-0.4652)	W = 0.1194TL + (-0.0276)
Mouth Height	W = 0.0455TL + 0.1153	W = 0.0407TL + 0.4063



(A)



(B)

Figure 5. *Morphometric measurements for (A) Cisco and (B) Bloater related to the total length of the fish.*

Relationships between fish length and other physiological measurements have been used as standard measures of successful operation in hatcheries for many decades [15] and are convenient indicators of fish health [22]. While length-weight relationships have been published for numerous species from water bodies around the world [4, 10], only one other report directly compares Cisco and Bloater growth metrics, and their results showed similar length-weight responses for both species [19].

Both species studied here exhibited similar growth characteristics (length, weight and condition) under standard hatchery conditions. Although Bloater hatched later, growth characteristics were similar at the same age as Cisco. High coefficients of determination (R^2) for all comparisons suggest that length is a reliable measure of growth in both species, but not for condition factor, which had the lowest coefficients and may have multiple determining factors. Carlander [4] observed low correlations for freshwater fishes between fish size and condition factors even within a species across multiple year classes. However, an increasing condition factor is indicative of an increase in feeding intensity and positive growth in weight [4], as we observed in this study.

Additional meristic measurements increased for both species and were indicative of differential growth of body components. Overall, Cisco grew larger than Bloater, resulting in the need for larger body parts to consume larger food sources [5, 21]. The smaller Bloater mouth and head size observed here suit them well for their more selective planktivorous nature.

4. Conclusion

Growth of both Cisco and Bloater under standard culture conditions resulted in similar length-weight responses. Morphometric changes demonstrate the differential growth of various body components of these two species in their earliest life stages. Our findings provide fisheries managers with baselines for monitoring growth metrics in culture settings and for valuable comparisons with field observations.

Acknowledgments

We would like to thank staff at the Jordan River NFH, Green Bay FWCO, and the New York Department of Environmental Conservation for help in providing Cisco and Bloater eggs. We are also grateful to all support staff at Tunison Lab for assistance in the hatchery. Major funding was provided by the Great Lakes Restoration Initiative (GLRI). Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. All sampling and handling of fish during research are carried out in accordance with guidelines for the care and use of fishes by the American Fisheries Society (http://fisheries.org/docs/wp/Guidelines-for-Use-of-Fishes.pdf).

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] American Fisheries Society (AFS). 2014. Use of Fishes in Research Committee (joint committee of the American Fisheries Society, the American Institute of Fishery Research Biologists, and the American Society if Ichthyologists and Herpetologists. Guidelines for the use of fishes in research. American Fisheries Society, Bethesda, Maryland. 104 pages.

[2] Baldwin, N. A., R. W. Saalfeld, M. R. Dochoda, H. J. Buettner, and R. L. Eshenroder. 2009. Commercial fish production in the Great Lakes 1867–2006. http://www.glfc.org/databases/commercial/commerc.php

[3] Brown, T. A., S. A. Sethi, L. G. Rudstam, J. P. Holden, M. J. Connerton, D. Gorsky, C. T. Karboski, M. A. Chalupnicki, N. M. Sard, E. F. Roseman, S. E. Prindle, M. J. Sanderson, T. M. Evans, A. Cooper, D. J. Reinhart, C. Davis, B. C. Weidel. 2022. Contemporary spatial extent and environmental drivers of larval coregonine distributions across Lake Ontario. Journal of Great Lakes Research. In Press.

[4] Carlander, K, D. (1969). Handbook of freshwater fishery biology. Volume One. The Iowa State University Press, Ames.

[5] Carlson, D. M., R. A. Daniels, and J. J. Wright. (2016). Atlas of Inland Fishes of New York. New York State Education Department and Department of Environmental Conservation. 362 pages.

[6] Christie, W. J. 1973. Review of the Changes in the Fish species composition of Lake Ontario.

[7] ErNsu-n, W. (1966). Problem of fish larvae survival in nature and the rearing of economically important middle European freshwater fishes. Calif. Coop. Oceanic Fish. Invest. Rep. 10: 24-30.

[8] Eshenroder, R. L., Vecsei, P., Gorman, O. T., Yule, D. L., Pratt, T. C., Mandrak, N. E., Bunnell, D. B. and Muir, A. M., 2016. Ciscoes of the Laurentian Great Lakes and Lake Nipigon. Ann Arbor, MI.

[9] Fechhelm, R. G., W. B. Griffiths, W. J. Wilson, B. J. Gallaway, and J. D. Bryan. (1995). Intra-and inter seasonal changes in the relative condition and proximate body composition of broad whitefish from the Prudhoe Bay region of Alaska. Transactions of the American Fisheries Society. 124: 508-519.

[10] Froese, R., J. T. Thorson, and R. B. Reyes Jr. 2013. A Bayesian approach for estimating length-weight relationships in fishes. Journal of Applied Ichthyology. 30: 78–85.

[11] Kadri, S., N. B. Metcalf, F. A. Huntingford, and J. E. Thorpe. (1995). What controls the onset of anorexia in maturing adult female Atlantic Salmon? Functional Ecology. 9: 790-797.

[12] Koelz, W., 1929. Coregonid fishes of the Great Lakes. Bulletin of the U. S. Bureau of Fisheries 43, 297–643.

[13] O'Malley, B. P., Schmitt, J. D., Holden, J. P., Weidel, B. C., 2021. Comparison of Specimen- and Image-Based Morphometrics for Cisco. Journal of Fish and Wildlife Management 12, 208–215. https://doi.org/10.3996/jfwm-20-029

[14] Pinder, L. J., and J. G. Eales. (1969). Seasonal buoyancy changes in Atlantic salmon (Salmo salar) parr and smolt. Journal of the Fisheries Research Board of Canada. 26: 2093-2100.

[15] Piper, R. G, J. L. Blumberg, and J. E. Holway. (1975). Length-weight relationships in some salmonid fishes. The Progressive Fish Culturist. 37(4): 181-184.

[16] Piper, R. G., I. B. McElwain, L. E. Orme, J. P. McCraren, L. G. Fowler, and J. R. Leonard. (1982). Fish Hatchery Management. United States Department of the Interior Fish and Wildlife Service. Washington D. C.

[17] Poxnovsrlr, V. V. (196l).' Basic environmental factors determining the abundance of the whiteflsh. Tr' Sovesch. Ikhtiol. Kom. Akad. Nauk. SSSR l3: 228-234. (Translated from Russian by the Ministry of Agriculture, Fisheries and Food on behalf of Fisheries Laboratory, Lowestoft, Suffolk, England 1963.

[18] Rook, B. J., M. J. Hansen, C. A. Goldsworthy, B. A. Ray, O. T. Gorman, D. L. Yule, and C. R. Bronte. 2021. Was historical cisco *Coregonus artedi* yield consistent with contemporary recruitment and abundance in Lake Superior? Fisheries Management and Ecology. 28: 195-210.

[19] Schneider, James C., P. W. Laarman, and H. Gowing. (2000). Length-weight relationships. Chapter 17 in Schneider, James C. (ed.) 2000. Manual of fisheries survey methods II: with periodic updates. Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

[20] Simpson, A. L., N. B. Metcalf, and J. E. Thorpe. (1992). A simple non-disruptive biometric method for estimating fat levels in Atlantic salmon, Salmo salar L., parr. Aquaculture and Fisheries Management. 23: 23-29.

[21] Smith, C. L. (1985). The Inland Fishes of New York State. New York State Department of Environmental Conservation. 522 pages.

[22] Sutton, S. G., T. P. Bult, and R. L. Haedrich. (2000). Relationships among fat weight, body weight, water weight, and condition factors in wild Atlantic Salmon parr. Transactions of the American Fisheries Society. 129: 527-538.

[23] Chalupnicki, M. A., Mackey, G. E., and McKenna, J. E., Jr., 2024, Cisco (*Coregonus artedi*) and bloater (Coregonus hoyi) culture manual: U. S. Geological Survey Techniques and Methods, book 2, chap. A20, 25 p., https://doi.org/10.3133/tm2A20