MANAGEMENT BRIEF

**Growth curve estimates for Stonecats (*Noturus flavus*) from Lake Champlain tributaries**

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**ABSTRACT**

Little is known about Stonecat (*Noturus flavus*) populations, especially in the Northeastern United States, which these madtoms are at the edge of their range. In Lake Champlain tributaries, Stonecats are listed as endangered in Vermont, but not in New York. In studying the stability of the Vermont populations, we wanted to determine their age structure. However, we could not remove body parts from endangered fish, so we aged fish from New York and estimated ages of Vermont fish from mark-recapture data. From fish collected in New York, we created a von Bertalanffy growth model that was based on aging dorsal spines. The Fabens growth model was based on time at large and changes in length of marked and recaptured Stonecats from the two Vermont tributaries. The asymptotic total length predicted by von Bertalanffy was 175 mm for New York fish and Fabens predicted 200 mm for Vermont fish. K values were 0.48 for von Bertalanffy and 0.65 for Fabens. The two growth models are intrinsically different; yet, model predictions overlapped between ages 3 and 4, when many Stonecats reach maturity. Although our results could be more accurate with age validation and increased numbers of smaller individuals in the analyses, these size at age data are important in monitoring the stability of Stonecat populations.

Age estimates are often used to assess populations and to monitor changes in population structure through time. Making effective management decisions becomes more imperative in the case of an endangered species. In Vermont, the Stonecat (*Noturus flavus,* Rafinesque 1818) is listed as endangered by the Agency of Natural Resources because its known distribution is limited to two systems, the LaPlatte and Missisquoi rivers, two Lake Champlain tributaries (Langdon et al. 2006). The restricted distribution and lack of knowledge of this species is cause for concern in the continued survival of these populations.

To effectively manage for this cryptic species, knowledge of basic life history demographics, including age distribution and growth, is important. Hard parts including spines, vertebrae, and otoliths are commonly used to estimate ages of ictalurids and other fish species (Gilbert 1953; Walsh and Burr 1985; Chan and Parsons 2000; Maceina et al. 2007; Quist et al. 2012). Collection of vertebrae and otoliths is lethal to fish and the taking of spines is considered harmful in some instances. Thus, we could not collect hard parts from our study organisms in Vermont of the the state-listed endangered status, meant that we were we could collect hard parts from Stonecats across Lake Champlain in New York where they were not listed.

Our objective of this study was to use two methods to estimate growth metrics and length at age of Stonecats from Lake Champlain tributaries. We derived a von Bertalanffy growth equation using aging data from Stonecats collected in New York to estimate the asymptotic length (L∞), growth coefficient (K), and the time at which the length of a fish would theoretically be zero (t0) (Isely and Grabowski 2007). With Vermont fish, we used the Fabens growth model to estimate L∞ and Kfrom marked and recaptured Stonecats collected through time (Isely and Grabowski 2007). Fabens growth model is especially useful for endangered species when body parts cannot be removed.

**METHODS**

*Study sites*.—We collected Stonecats from three Lake Champlain tributaries. In New York, fish were collected from the Great Chazy River, which originates near Ellenburg, New York, and empties into northern Lake Champlain (44.93236N; 73.38537W). The Great Chazy River is approximately 86 km long and drains a watershed of 790 km2. Stonecats were collected in portions of the lower 33 km of river. Stonecats collected in Vermont were from the LaPlatte and Missisquoi rivers. The LaPlatte River is a 24-km long tributary that drains a watershed of 138 km2 (Pelton et al. 1998) and enters Lake Champlain in Shelburne Bay (44.39959N; 73.23385W). The Missisquoi River is 130 km long, drains a watershed of 2,200 km2 in northern Vermont and sections of Quebec, Canada into Lake Champlain at Missisquoi Bay (44.99630N; 73.15729W).

*Dorsal spine data*.—Stonecats from the Great Chazy River, New York were collected as part of a visual post-assessment survey on 17-19 October 2012. Stonecats were mortalities from a lampricide treatment conducted on 16-18 October 2012. Stonecats were also collected on 8-9 August 2011 and 15 November 2011 from the Great Chazy River, NY as part of a bioassay study (M. Calloway, U.S Fish and Wildlife Service, unpublished data). Stonecats were frozen as quickly as possible and returned to the lab. Individuals were later thawed and measured for total length (TL) to the nearest mm. We removed the dorsal spine at the base following the procedures of Buckmeier et al. (2002) for pectoral spines and Manny et al. (2014) both pectoral and dorsal spines.\_) Spines were placed in boiling waer to remove excess flesh, set in epoxy to prevent splitting when cut, and allowed to dry. Spines were cut into one or two 0.5-mm sections using a Buehler isomet low speed saw (Buehler, Lake Bluff, Illinois) then glued to slides. Spines were cut at the base to avoid losing annuli.

After establishing criteria for identifying annuli as a group, three readers independently estimated the age of fish of unknown length spine two times. If there were age differences among readers, the spine was read by the three readers together to arrive at an agreed upon age estimate. In cases of no age agreement, the spine was removed from the analysis.

*Recapture data*.—Sampling in Vermont took place from June to October 2012, May to October 2013, and June to October 2014. We used backpack electrofishing and minnow traps, both of which are effective methods of collecting Stonecats (McCulloch and Stewart 1998; Pollard 2004). Wire-meshed (0.6 cm) minnow traps (42 cm long × 23 cm dia. and 2.5 cm openings at each end) were baited and set in gangs of three or four attached to a single weight. Minnow traps were set for 18-24 hours and checked in the morning after Stonecats stopped nocturnal movement. Sampling details are in Puchala et al. (2016).

Captured, unstressed Stonecats were anesthetized in MS-222 at a concentration of 100 mg/L. For each individual captured, we measured total length (TL) to the nearest mm. All Stonecats greater than ~90 mm TL were marked with a passive integrated transponder (PIT) tag (Biomark, Boise, Idaho, 134-kHz, 8.4 mm x 1.44 mm) inserted into the peritoneal cavity. Individuals were recaptured during subsequent sampling events and time at large and total length were recorded.

*Data analysis.*—We used the FSA Package (D. Ogle, fishR, http://derekogle.com/fishR/packages) for both the von Bertalanffy and Fabens models, which used a maximum likelihood procedure to estimate parameters. We bootstrapped the data 1000 times to obtain 95% confidence intervals. The von Bertalanffy equation is:

Lt= L∞ (1-e^-K(t-t0))

where, Lt is the length at time t, L∞ is the asymptotic total length, and K is the growth coefficient.

The Fabens model is:

Ri= Mi +(L∞- Mi)(1-e ^ (-K∆ti))

where, Ri is the length at recapture, Mi is the length at mark, and ∆ti is the duration an individual is at large. L∞ and K are as defined above.

The fundamental difference in the two growth models is that the Fabens model assumes t0= 0 and von Bertalanffy model does not. To examine the relationships between the two growth models, we calculated the percentage deviations between the predicted length from the von Bertalanffy model and the empirical data from recaptured fish (Nitschke et al. 2011). Also, we combined the data from the two Vermont rivers to maximize the number of recaptured individuals for analysis.

**RESULTS**

Stonecats (N=177) from the Great Chazy River were used to create the growth curve in the von Bertalanffy model. Stonecats ranged from 44 to 193 mm total length (Table 1). The estimated growth curve for Stonecats from dorsal spines was: t= 175.14 ± (8.73) (1-e^(-0.65 ± (0.14) (t--0.92± (0.15)))) (Mean ± SE) (Figure 1; Table 1). Recaptured Stonecats (N=157) collected in Vermont were used to analyze a growth curve using Fabens model. Stonecats ranged in total length from 87 to 186 mm and were at large from 1 to 805 days (median=84). The growth curve for Stonecats using Fabens model was: t= 199.61 ± (9.55) (1-e^(-0.48 ± (0.08) (t-0))) (Figure 1; Table 1). The asymptotic total length using von Bertalanffy was 175 mm and Fabens was 200 mm with K values of 0.48 for von Bertalanffy and 0.65 for Fabens.

The percentage deviations between the predicted total length from the von Bertalanffy model and the recapture data in the Fabens model were slightly skewed in a positive direction (Figure 2). This would indicate that the von Bertalanfy model predicted slightly higher individual growth than what was observed using Fabens model.

**DISCUSSION**

Knowing age and length of individual fish in a population is important in understanding the stability of the population. We were unable to collect spines from Stonecats in Vermont because of they are listed as endangered. However, we could use mark-recapture data from Stonecats collected in Vermont to estimate growth using Fabens model. We used Stonecat dorsal spines collected from the Great Chazy River, NY to create a von Bertalanffy growth equation, which we compared to Fabens model. These two independent methods give more support for our estimated age-length relationship for Stonecats than either would alone.

Both growth models have different strengths and weaknesses. The data required for Fabens model offers less uncertainty in the metrics because changes in total length and the number of days at large have little error as long as accurate records are kept. However, the model assumes t0=0, which is a modeling artifact since is not possible for a fish to be 0 mm in total length upon hatching. The growth curve estimated by the von Bertalanffy model can be inaccurate because of errors associated with age estimation. We recognize that our results have not been validated (Campana 2001). We were unable to PIT tag and recapture individuals < 90 mm TL because they were too small to tag. Limitations of our threatened and endangered species permit did not allow rearing for the common procedures of validating ages such as raising Stonecats in the laboratory to observe when the first annulus was formed or tagging young-of-year Stonecats and killing them upon recapture the following year to check for the first annulus.

Growth curves are location specific and our estimated curves are the only ones available for this geographic region. It is not uncommon for fish of the same species to grow at different rates when they occupy different systems given that predation pressure, thermal constraints, and food availability are variable. Asymptotic lengths (L∞) of the two models differed by 25 mm and they differed in growth rate coefficients (K; Table 1). However, the most common sizes we collected did not approach asymptotic lengths (i.e., most were <150 mm TL) and they were estimated to be less than 4 years old. These estimated growth curves illustrate the variability of length-at-age estimates. However, there is overlap with the estimated total length for different ages within the same model. The ranges in total lengths for each age estimate would likely be smaller if we had recaptured a greater number of individuals and had more confidence in the age estimates from the dorsal spines.

Although we followed recommended procedures to estimate the ages of Stonecats from spines (Clugston and Cooper 1960; Paruch 1979) and from another madtom (Manny et al. 2014) and an ictalurid (Buckmeier et al. 2002), there was often disagreement and uncertainty in determining ages. Only ages agreed upon by three individuals were used in the analysis, but the wide range of total lengths possible for ages 0 and 1 was likely because we had difficulty seeing the first annulus.

We were particularly interested in how our results from Stonecat populations near the edge of their range compare to those near the middle. Data from much older studies (Table 2), indicate that Stonecats in New York and Vermont grow faster than those in Ohio, Illinois, and Missouri (Gilbert 1953, Walsh and Burr 1985). Unfortunately, these are the only data we could find for comparisons and they are limited in sample size (Walsh and Burr 1985) and do not report size ranges.

Although our age estimates and growth curves are imperfect, they offer region specific estimates. Given the restrictions on aging Vermont fish, using independent samples to estimate growth curves with the two methods was an effective approach. The growth models offered similar sizes at ages 3 and 4, which is when many Stonecats reach maturity (REF?). Knowing the number of individuals that are of this size can provide a more accurate picture of the number of breeding individuals in the population. The estimated ages provide managers a better idea of the current Stonecat demographics and sheds more light on this cryptic endangered species.

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Table 1. Growth parameter estimates for Stonecats from two different data sources. Von Bertalanffy model estimates were derived from dorsal spines that were aged and were collected in 2011 and 2012 in the Great Chazy River, New York. Fabens model estimates were derived from capture-recapture data from Stonecats collected in 2012, 2013, and 2014 sampling seasons in both the LaPlatte and Missisquoi rivers, Vermont. Standard errors are in parentheses. n=number of individual fish in parameterizing each model. Other abbreviations are defined in text.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Model | Equation | K | L∞ | t0 | n | Total Length Range (mm) |
|  |  |  |  |  |  |  |
| von Bertalanffy | Lt= L∞ (1-e^-K(t-t0) | 0.65 | 175.14 | -0.92 | 177 | 44-193 |
|  |  | (0.14) | (8.73) | (0.15) |  |  |
| Fabens | Ri= Mi +(L∞- Mi)(1-e ^ (-K∆ti)) | 0.48 | 199.61 |  | 157 | 87-186 |
|  |  | (0.07) | (9.55) |  |  |  |
|  |  |  |  |  |  |  |

Table 2. Total length (TL, mean + 95% CI) of Stonecats for ages 0 to 5 and number (n) of individuals from this and other studies. Fabens model (VT streams) estimates were derived from capture-recapture data from Stonecats collected in 2012, 2013, and 2014 sampling seasons in both the LaPlatte and Missisquoi rivers, Vermont. Von Bertalanffy model (NY streams) estimates were derived from aged dorsal spines from fish collected in 2011 and 2012 in the Great Chazy River, New York. NA=not available.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Location | Ages | | | | | | Source |
| Age 0 | Age 1 | Age 2 | Age 3 | Age 4 | Age 5 |  |
| Ohio streams | |  |  |  |  |  | Gilbert 1953 |
| Average | 53.6 | 72.6 | 89.0 | 104.1 | 116.4 | 128.9 |  |
| n | 47 | 34 | 29 | 23 | 16 | 10 |  |
|  |  |  |  |  |  |  |  |
| IL and MO streams | |  |  |  |  |  | Walsh and Burr 1985 |
| Average |  | 48.6 |  | 100.0 | 123.3 | 177.0 |  |
| n |  | 1 |  | 17 | 7 | 2 |  |
|  |  |  |  |  |  |  |  |
| NY streams | |  |  |  |  |  | This study |
| Average | 78.9 | 125.0 | 149.0 | 161.5 | 168.0 | 171.4 | Spine data |
| 95% CI | 51.2- 83.6 | 84.7- 138.4 | 108.4- 163.2 | 125.3-174.5 | 137.2- 179.6 | 145.7- 181.9 |  |
|  |  |  |  |  |  |  |  |
| VT streams | |  |  |  |  |  | This study |
| Average | NA | 76.3 | 123.5 | 152.6 | 170.6 | 181.7 | Recapture data |
| 95% CI |  | 63.4- 89.5 | 105.7- 140.7 | 133.8- 169.9 | 152.6- 186.7 | 165.1- 196.3 |  |
|  |  |  |  |  |  |  |  |

**Figure headings**

Figure 1. Model growth estimates from Fabens (gray) and Von Bertalanffy (black). Mean is solid line and 95% CI are dashed lines. Black circles are individual age estimates from each dorsal spine that was used to estimate the Von Bertalanffy model. Grey circles are from the Fabens model estimates derived from capture-recapture data from Stonecats collected in 2012, 2013, and 2014 sampling seasons in the LaPlatte and Missisquoi rivers, Vermont. Von Bertalanffy model estimates were derived from individuals collected in 2011 and 2012 in the Great Chazy River, NY and aged dorsal spines. Circles are aligned vertically between ages even though they were collected throughout the sampling seasons.

Figure 2. Percentage deviations between the predicted total length from the von Bertalanffy model and that of capture-recapture data used in the Fabens model. Data used in von Bertalanffy were derived from aged dorsal spines of Stonecats collected in 2011 and 2012 in the Great Chazy River, New York. The capture-recapture data were from Stonecats collected in 2012, 2013, and 2014 in the LaPlatte and Missisquoi rivers, Vermont.

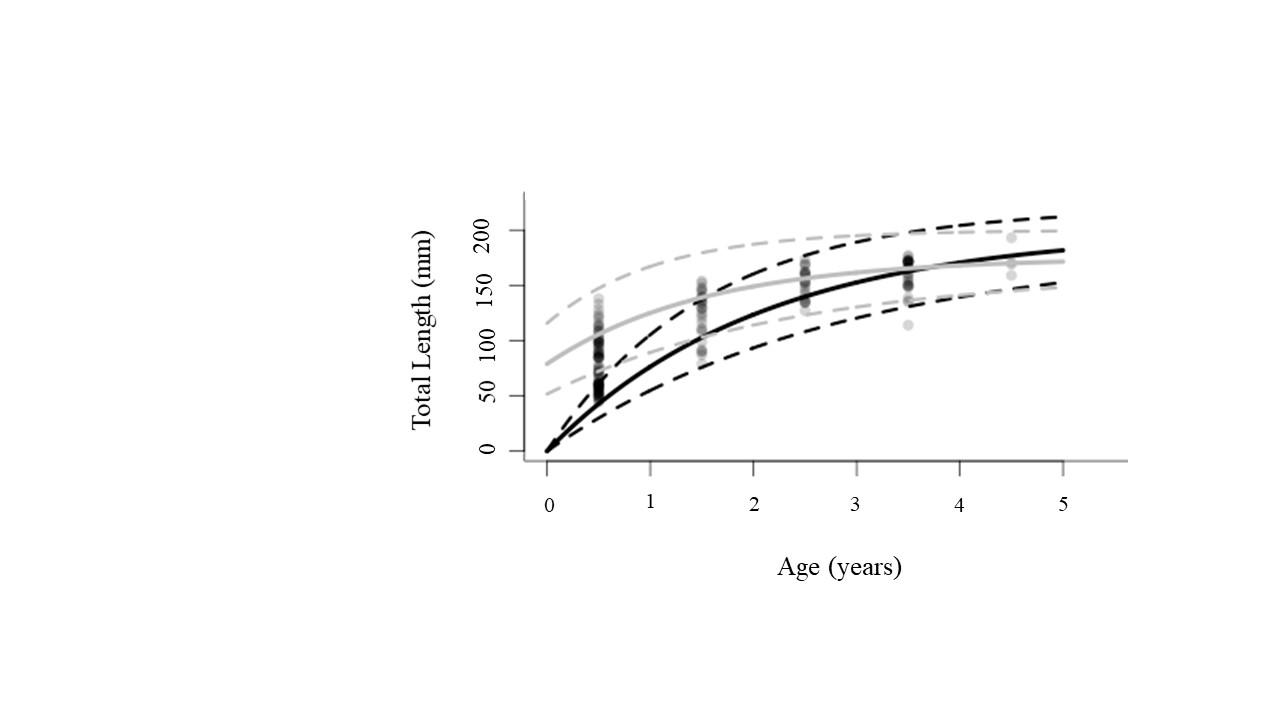
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