Size and age of Stonecat in Lake Champlain; estimating growth at the margin of their range to aid in population management

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1   MANAGEMENT BRIEF

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3   **Size and age of Stonecat in Lake Champlain; estimating growth at the margin of their**

4   **range to aid in population management**

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16

17   *Abstract*

18   Little is known about Stonecat *Noturus flavus* populations, especially in the northeastern United

19   States, where they are at the edge of their range. In Lake Champlain tributaries, Stonecat are

20   listed as endangered in Vermont, but not in New York. Here we describe the growth of Stonecat

21   in two tributaries to Lake Champlain, one in Vermont (LaPlatte River), which was our primary

22   interest, and one in New York (Great Chazy River), with von Bertalanffy growth models fit to

23   lengths at the times of marking and recapture and to observed length and age data. We also

24   compared growth of Stonecat in these waters to results from other locations near the middle of

25   their distribution. Stonecat in the Great Chazy River were larger at ages 1-3, but similar in size

26   for ages 4 and 5, than Stonecat from the LaPlatte River. Stonecat in Lake Champlain tributaries

27   were generally larger at age than those from the middle of their range, except for those from

28   Lake Erie. From our mean length-at-age results and previous literature estimates of length at

29   maturity for Stonecat, it appears that Stonecat in Lake Champlain reach maturity by age 3,

30   though future research that directly estimates age at maturity would be more informative. These

31   results will help managers assess the effect of various environmental and human stressors that

32   Stonecat have experienced in the Lake Champlain basin in recent years. Furthermore, our results

33   expand the literature that lacks information about growth of this species. Finally, our mark-

34   recapture approach to estimating growth of Stonecat can be applied to other species, especially

35   where data are limited because of their status, and in other systems.

36

37   Stonecat *Noturus flavus* are widely distributed in the interior of North America, with

38 populations in Vermont at the northeastern edge of their range (Langdon et al. 2006). In 1994,

39 the Vermont Agency of Natural Resources listed the Stonecat as endangered because its known

40 distribution within the state was limited to two tributaries of Lake Champlain: the LaPlatte and

41 Missisquoi rivers (Langdon et al. 2006). There is concern over the continued survival of these

42 populations of Stonecat, especially given the modeling results that support a decreasing

43 population size in the LaPlatte River (Puchala et al. 2016) and only a small population in the

44 Missisquoi River (Puchala 2015).

45   Quist and Isermann (2017) stated that "age and growth investigations are critical for

46 providing information on the basic ecology of a species and guiding management and

47 conservation actions." This is especially important for species such as Stonecat that are of

48 conservation concern and often understudied (Burr and Stoeckel 2000). We are aware of only

49 five studies, none of which were from the Lake Champlain basin, that examined growth of

50 Stonecat (Gilbert 1953; Carlson 1966; Paruch 1979; Walsh and Burr 1985; Tzilkowski and

51 Stauffer 2004). The utility of these studies for better understanding the dynamics of Stonecat in

52 Lake Champlain or other populations is limited because they are either quite dated, from

53 populations near the middle of the distribution of Stonecat, or have other concerns such as small

54 sample size, varied methods to estimate age (e.g., pectoral spines, dorsal spines, and vertebrae),

55 and specimens combined across multiple populations.

56   Our primary objective is to describe the growth of Stonecat in the LaPlatte River. In

57 doing so, we demonstrate an underutilized modeling approach to estimate growth for species

58 where lengths at the times of marking and recapture are available from throughout the growth

59 season, but estimates of age (e.g., from calcified structures) are not available. Secondarily, we

60   compare these results to results from other Stonecat populations to better understand the growth

61   dynamics of LaPlatte River Stonecat. To augment previously published results, we also describe

62   growth of Stonecat from the Great Chazy River, which is a tributary to Lake Champlain in New

63   York. Inclusion of these results allows us to compare the LaPlatte River results to a

64   contemporary population in the same watershed. Our results, along with estimates of survival

65   and population change provided by Puchala et al. (2016), will be an important consideration in

66   the continued management of Stonecat populations in Lake Champlain for long-term stability.

67   These results also contribute significantly to the literature that lacks information about growth of

68   this species, especially from throughout its geographic range.

69

70   <A>Methods

71   *Study sites*.— The LaPlatte River is 24 km long, drains a 138 km^2 watershed (Pelton et al.

72   1998), and enters Lake Champlain in Shelburne Bay, Vermont (44.39959N; 73.23385W). The

73   Great Chazy River originates near Ellenburg, New York, and empties into northern Lake

74   Champlain (44.93236N; 73.38537W), is approximately 86 km long, and drains a watershed of

75   790 km^2.

76   *Data Collection*.— Stonecat were collected from the LaPlatte River from June to October

77   2012, May to October 2013, and June to October 2014 using backpack electrofishing (DC) and

78   minnow traps. Backpack electrofishing generally used 200 volts, 20-30 Hz, and a 20-40% duty

79   cycle and, because Stonecat are nocturnal, began no earlier than 0.5 h after sunset. Electrofishing

80   effort depended on the length of stream section and ranged from 26 to 247 minutes, with a mean

81   effort of 86 minutes (SD = 49.4). We repeatedly sampled two 200-m long sections over the

82   three-year period, and on two occasions, we sampled the entire 1.2 km of river between them.

83   Minnow traps were 42 cm long and 23 cm diameter with 2.5 cm openings at each end and 0.6 cm

84   square meshed sides. Minnow traps were set overnight (18-24 h soak time) in gangs of three or

85   four attached to a single weight. Details of the study sections are in Puchala et al. (2016).

86   Captured Stonecat not experiencing obvious distress (i.e., swimming normally) were

87   anesthetized in a 100 mg/L concentration of tricaine methanesulfonate (MS-222). Each

88   individual was measured for TL to the nearest mm and all Stonecat approximately 90 mm TL

89   and greater had a passive integrated transponder (PIT) tag (134-kHz, 8.4 x 1.4 mm; Biomark,

90   Boise, Idaho) inserted into the peritoneal cavity through a 2-mm incision in the upper abdominal

91   wall. The incision was then treated with iodine. Individuals were examined for the presence of a

92   PIT tag after the first sampling event. Spines were not removed from these fish to minimize the

93   traumatic impact of removal on other aspects of our overall study (Puchala et al. 2016).

94   Stonecat were collected from the lower 33 km of the Great Chazy River on 17-19

95   October 2012 as mortalities from a 3-trifluoromethyl-4-nitrophenol (TFM) lampricide treatment

96   conducted on 16-18 October 2012. During the post-treatment assessment, teams of two biologists

97   each visually scanned the banks, shallows, and portions of the river where the bottom was visible

98   to collect non-target mortalities, including Stonecat. Additional Stonecat were collected from the

99   Great Chazy River on 8-9 August 2011 and 15 November 2011 as part of a bioassay study

100 (Calloway 2012) and frozen as quickly as possible. Stonecat were thawed between 1 and 19

101 months later and measured for standard (SL) and total lengths (TL) to the nearest mm. For aging

102 purposes, the dorsal spine was removed from each individual by snipping the spine just above

103 the articulation point (Buckmeier et al. 2002; Manny et al. 2014; Fischer and Koch 2017).

104   Spines were placed in boiling water to remove excess skin and flesh and allowed to dry

105 before being set in epoxy, largely following the procedures of Koch and Quist (2007) but with

106 plastic straws similar to Bauerlien et al. (2018). One or two 0.5-mm sections were cut from the

107   spine using a Buehler^{TM} low-speed isomet saw (Buehler, Lake Bluff, Illinois). Thin sections

108   were glued to slides for viewing under an Olympus SZX9^{TM} dissecting microscope using fiber

109   optic transmitted light. Mineral oil was used to help with clarity of the structure. Three readers

110   blind to fish size independently estimated age by identifying annuli in the patterns of translucent

111   and opaque zones of the sectioned spine. The three readers attempted to reach a consensus age if

112   there were discrepancies among their estimated ages. If a consensus could not be reached then

113   the fish was removed from further analysis.

114   *Data analysis.*— Growth of Stonecats collected from the LaPlatte River could not be

115   summarized with a typical growth model because age for these fish could not be estimated.

116   Rather we summarized growth of Stonecats from the LaPlatte River with a von Bertalanffy

117   growth function (VBGF) modified by Francis (1988a) for use with mark-recapture data and

118   including a seasonal component:

$$\varDelta L = \left(\frac{L_2 g_1 - L_1 g_2}{g_1 - g_2} - L_m\right)\left(1 - \left[1 + \frac{g_1 - g_2}{L_1 - L_2}\right]^{\varDelta t + S_r - S_m}\right)$$

119   where

$$S_r = \frac{u \sin(2\pi[t_r - w])}{2\pi} \quad \text{and} \quad S_m = \frac{u \sin(2\pi[t_m - w])}{2\pi}$$

120   and $\varDelta L$ is the change in TL between marking and recapture, t_m and t_r are the marking and

121   recapture times (years), $\varDelta t$ is the change in time (years) between marking and recapture, L_m is the

122   TL at t_m, g_1 and g_2 are parameters that represent the mean annual growth rate or increment at L_1

123   and L_2 (which we chose to be 100 and 150 mm, respectively), w is a parameter that represents the

124   time of year when the growth rate is maximum, and u is a parameter that describes the extent of

125   the seasonal variation in growth (i.e., $u = 0$ represents no seasonal variability in growth). For fish

126   that were recaptured multiple times, we treated each interval between recaptures as independent

127   mark-recapture (M-R) events (Ogle et al. 2017). For example, if a fish was captured three times

128   then we considered the interval from marking to the first recapture as one M-R event and the

129   interval from the first to second recapture as a separate M-R event. Mark-recapture events based

130   on observations within 7 d of each other were excluded from further analysis under the

131   assumption that any growth that occurred in this short period was minimal and likely less than

132   measurement error. We modeled a seasonal component to growth with these data because fish

133   were collected on many dates within each year such that times-at-large might span different parts

134   of the growing season.

135   Growth of Stonecat collected from the Great Chazy River was summarized with the

136   traditional VBGF (Beverton and Holt 1957):

$$L_t = L_\infty\left(1 - e^{-K[t-t_0]}\right)$$

137   where L_t is the shrinkage-adjusted TL at time (or age) t, L_∞ is the asymptotic mean TL, K is the

138   Brody growth coefficient, and t_0 is the theoretical time when the mean TL is zero (Ogle et al.

139   2017). It is unknown if the total length of Stonecat become shorter after freezing. tThough

140   shrinkage has been reported for several species (e.g., Ogle 2009), including the related Channel

141   Catfish *Ictalurus punctatus* (Haubrock et al. 2018). Therefore, we adjusted for likely shrinkage

142   of our Stonecat using the average of 2.5% shrinkage in TL for the eight species reported in Ogle

143   (2009) and Haubrock et al. (2018), We used fractional ages in this model to adjust for our fish

144   being collected at various times throughout the growing season (Ogle et al. 2017). We assumed

145   that annual growth on the spine commenced on June 1, as shown for vertebrae by Carlson

146   (1966), and was completed by November 1. Thus, the adjusted age was equal to the number of

147   observed annuli for fish collected before June 1, was one more than the number of observed

148   annuli for fish collected after November 1, and was the number of observed annuli plus the

149   fraction of the growing season completed for fish captured between June 1 and November 1. We

150   chose not to use a growth function with a seasonal component (e.g., Somers 1988) for fish

151   collected from the Great Chazy River because sampling dates were concentrated on only a few

152   days in a year such that a seasonal component would not be well estimated.

153   Both growth models were fit with the nls() function in R v3.5.1 (R Core Team 2018)

154   using the "port" algorithm. The g_1, g_2, and u parameters were constrained to be positive and the

155   w parameter was constrained to be between 0 and 1. All other parameters were unconstrained in

156   model fitting. Three different starting values and two other algorithms (Gauss-Newton in the

157   nls() function and Levenburg-Marquardt in the nlsLM() function from the minpack.lm package

158   v1.2-1 [Elzhov et al. 2016]) were used to determine the robustness of parameter estimates to

159   starting values and model fitting algorithms (Ogle et al. 2017). Bootstrap confidence intervals for

160   model parameters were estimated from 999 bootstrapped samples using the nlsBoot() function

161   from the nlsTools package v1.0-2 (Baty et al. 2015) as described in Ogle (2016).

162   Parameter estimates could not be compared between the LaPlatte and Great Chazy rivers

163   because different growth models were required for each location. Thus, we compared growth

164   between locations by predicting mean lengths-at-age. Mean lengths-at-age were predicted

165   directly from the traditional VBGF for Stonecat from the Great Chazy River. However, mean

166   lengths-at-age cannot be predicted directly from the Francis model because it does not use age as

167   a variable. In this case, we estimated the mean length at age 1 from monthly length frequency

168   histograms of all Stonecat captured in the LaPlatte River. We then used the results from the

169   Francis model to predict the annual growth increment for fish of this length. This predicted

170   annual growth increment was added to the mean length at age 1 to predict the mean length at age

171   2. This process was repeated until mean lengths for all ages up to age 6 had been predicted. We

172   also compared predicted mean lengths-at-age for Stonecat from the LaPlatte and Great Chazy

173   rivers to mean lengths-at-age reported for Stonecat in the literature (Gilbert 1953; Carlson 1966;

174   Paruch 1979). Some of the literature results were converted from SL to TL using results from a

175   linear model fit to our measurements of SL and TL on fish collected from the Great Chazy River.

176

177   <A>Results

178   A total of 1,469 Stonecat were collected in the LaPlatte River, of which 1,311 were PIT

179   tagged. These fish ranged in length from 54 to 205 mm, with a mean of 131 (SD = 24.3) mm.

180   Our gears collected few fish under 90 mm, but some collections of these fish provided insight

181   into first year growth of Stonecat in the LaPlatte River (Figure 1). The mode of small fish in

182   September 2012 indicates that LaPlatte River Stonecat are approximately 55-80 mm near the end

183   of their first year. The mode of small fish in May 2013 and the lower mode of the bimodal

184   distribution in June 2012 suggested that age-1 fish in the LaPlatte River begin their second

185   growing season at approximately 70-80 mm TL.

186   Of the 133 Stonecat recaptured from the LaPlatte River, 111 fish (83%) were recaptured

187   once, 20 fish (15%) were recaptured twice, and 2 fish (2%) were recaptured three times. Thus,

188   157 paired M-R events were observed, though 9 (6%) of these were within 7 days of each other

189   and were removed from further analysis. Of the remaining 148 M-R events, 61% of recaptures

190   were in the same year as the original capture, 39% were in the following year, and 1% were two

191   years later (Figure 2). Stonecat recaptured from the LaPlatte River ranged from 87 to 185 mm

192   TL at marking, with a mean of 131 (SD = 20.5) mm. Parameter estimates (with 95% confidence

193   intervals) from fitting the modified VBGF to the LaPlatte River Stonecat (N=177) were 34.2

194   (32.6 – 35.7) mm for g_1 at L_1 = 100 mm, 18.0 (16.6 – 19.4) mm for g_2 at L_2 = 150 mm, 0.55 (0.52

195   – 0.58) year for w, and 2.52 (2.25 – 2.87) for u.

196   Of the 183 Stonecat from the Great Chazy River aged from spines, six (3%) were

197   removed from further analysis because the three readers could not agree on a consensus age.

198   Age-classes ranged from 0 (young-of-the-year) to 5 with most fish age 0 (49%) and only five

199   fish (3%) age 4 or older. Stonecat from the Great Chazy River ranged from 44 to 193 mm TL,

200   with a mean TL of 114 (SD = 41.5) mm. The SL-TL relationship was TL=1.239+1.166SL ($r^2 =$

201   0.996). Parameter estimates (with 95% confidence intervals) from fitting the traditional VBGF to

202   the Great Chazy River Stonecat were 177 (164 - 198) mm for L_∞, 0.79 (0.52 - 1.16) year^{-1} for K,

203   and 0.13 (-0.15 – 0.34) year for t_0 (Figure 3).

204   Stonecat from the LaPlatte River were smaller than those from the Great Chazy River for

205   the first three years, but similar in size for the fourth and fifth years of life. Stonecat from the

206   Lake Champlain tributaries were approximately the same size as Stonecat from Lake Erie at age

207   1 (Figure 4), but substantially smaller for LaPlatte River fish by age 2 and fish from both

208   tributaries after age 2. Stonecat from the Lake Champlain tributaries were longer at all ages than

209   Stonecat from other populations reported in the literature (Figure 4).

210

211   <A>Discussion

212   Stonecat in the Lake Champlain tributaries, at the northeast margin of their distributional

213   range, may grow faster than Stonecat from streams in the middle part of their distribution, but

214   not from those in Lake Erie. Gilbert (1953) suggested that Lake Erie Stonecat may exhibit

215   exceptional growth because of the availability of mayfly Ephemeroptera spp. nymphs as prey. It

216   is unclear why Stonecat in Lake Champlain grow faster than many of those in the middle of their

217   range, but it is plausible that density dependence has a role; i.e., lower abundance of Stonecat in

218   Vermont especially would contribute to individual fish growing faster. Additionally, our fish

219   were measured fresh or were adjusted for the effect of freezing on length, whereas lengths of fish

220   reported in the literature were either measured on preserved fish or the condition of the fish was

221   unknown. Regardless, knowing how fast individuals grow is important for agencies to be able to

222   predict and manage populations for sustainability.

223   We found it difficult to identify annuli, especially near the central lumen, on sectioned

224   spines from the Great Chazy River fish. Other authors have noted similar difficulties. Gilbert

225   (1953) commented on difficulties identifying the first annulus on Stonecat vertebrae and

226   Tzilkowski and Stauffer, Jr. (2004) noted that annular rings were often not discernible on

227   Stonecat pectoral spines. Given similar growth curves between the LaPlatte River (derived

228   independent of any calcified structure) and the Great Chazy River (derived from spines)

229   Stonecat, we feel that our age estimates from spines are reasonable. Similarly, our growth

230   estimates from capture-recapture data appear reasonable, which demonstrates that this method

231   may be used to assess growth for populations of Stonecat where calcified structures cannot be

232   collected. Nevertheless, future Stonecat age and growth studies would benefit from

233   understanding the precision and accuracy (i.e., validity) of various methods for assessing age of

234   Stonecat.

235   Stonecat in the Lake Champlain basin have been subjected to a variety of environmental

236   and human stressors in recent years. For example, several Stonecat were found dead after a

237   dewatering event in in the Missisquoi River in 2012 (Puchala 2015) and Stonecat in the LaPlatte

238   River were exposed to very low water levels and high temperatures in three of the four years

239   immediately after our sampling was completed. Our results contribute to a better understanding

240   of the growth dynamics of Stonecat, which may aid managers in understanding the effects of

241   these stressors on Stonecat populations. As a specific example, the LaPlatte River was first

242   treated with TFM in 2016, two years after our last sampling, to control larval Sea Lamprey

243   *Petromyzon marinus* abundance. Bioassay results on Stonecat between 122 and 200 mm TL

244   indicated that 10% mortality could occur at a TFM concentration of 1.2 times that needed to kill

245   99% of the larval Sea Lamprey present (Calloway 2012). The predominance of age-0 fish in our

246   Great Chazy River samples, which largely came from mortalities collected following a TFM

247   treatment, suggests that this mortality may primarily affect age-0 fish. Tributaries to Lake

248   Champlain are treated with TFM on a rotating basis every four or more years, which could pose

249   a risk for Stonecat populations if most fish matured after age 4. In Pennsylvania, female Stonecat

250   matured at 102-141 mm SL, or approximately 120-166 mm TL (Tzilkowski and Stauffer, Jr.

251   2004). These lengths correspond to age-2 to age-4 Stonecat in the LaPlatte River. Thus, it

252   appears that most female Stonecat in the LaPlatte River would mature within the minimum TFM

253   treatment interval. While this result is useful to managers planning TFM treatments in Lake

254   Champlain tributaries, future research that directly estimates age at maturity would be

255   informative.

256   Here, with Stonecat from the LaPlatte River, we demonstrated the use of a growth model

257   with mark-recapture data collected across much of the growing season. While this model has

258   been used in other studies (e.g., Francis 1988b; Wilde and Sawynok 2005; Afeworki et al. 2014),

259   it is used rarely and those studies have been primarily with marine species that were largely of

260   commercial or recreational interest. We showed that the model can be used to derive useful

261   estimates of growth rates and growth model parameters for an imperiled species for which

262   individuals cannot be legally or ethically sacrificed to remove calcified structures for estimating

263   age. This approach may be useful to others studying imperiled species under similarly

264   constraining conditions.

265

266   <A>Acknowledgments

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279   <A>References

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Figure headings

Figure 1. Histograms of total length of Stonecat captured in the LaPlatte River by month during

2012-2014. Note that no sampling occurred in May or August 2012, June 2013, or May 2014.

Collections from October are not shown because sample sizes were small.

Figure 2. Histogram of times-at-large for Stonecat recaptured from the LaPlatte River, Vermont

in 2012-2014. Each bar in the histogram is fourteen days wide. Note that nine mark-recapture

events where the time between marking and recapture was less than seven days are not included.

Figure 3. Fit (solid line), with 95% confidence bounds (dashed lines), of the traditional von

Bertalanffy growth function to total lengths and ages estimated from spines of Stonecat collected

from the Great Chazy River, New York in 2011 and 2012. Ages have been adjusted to represent

the number of observed annuli on the spine plus the fraction of growth completed in the year the

fish was collected. Observations are plotted with a semi-transparent color such that darker points

represent more observations.

Figure 4. Mean total lengths-at-age for the two locations of this study (LaPlatte R. [VT]) and

Great Chazy R. [NY]) and for four previous studies (Lake Erie (OH) [Gilbert 1953], Wisconsin

streams [Paruch 1979], Vermillion River (SD) [Carlson 1966], and Ohio streams [Gilbert 1953]).

The LaPlatte River results were predicted from the fit of the von Bertalanffy growth function

modified by Francis (1988) assuming a mean length at age 1 of 75 mm. The Great Chazy River

results were predicted from the fit of the traditional von Bertalanffy growth function. The results

from the other locations were either observed or back-calculated lengths-at-age.
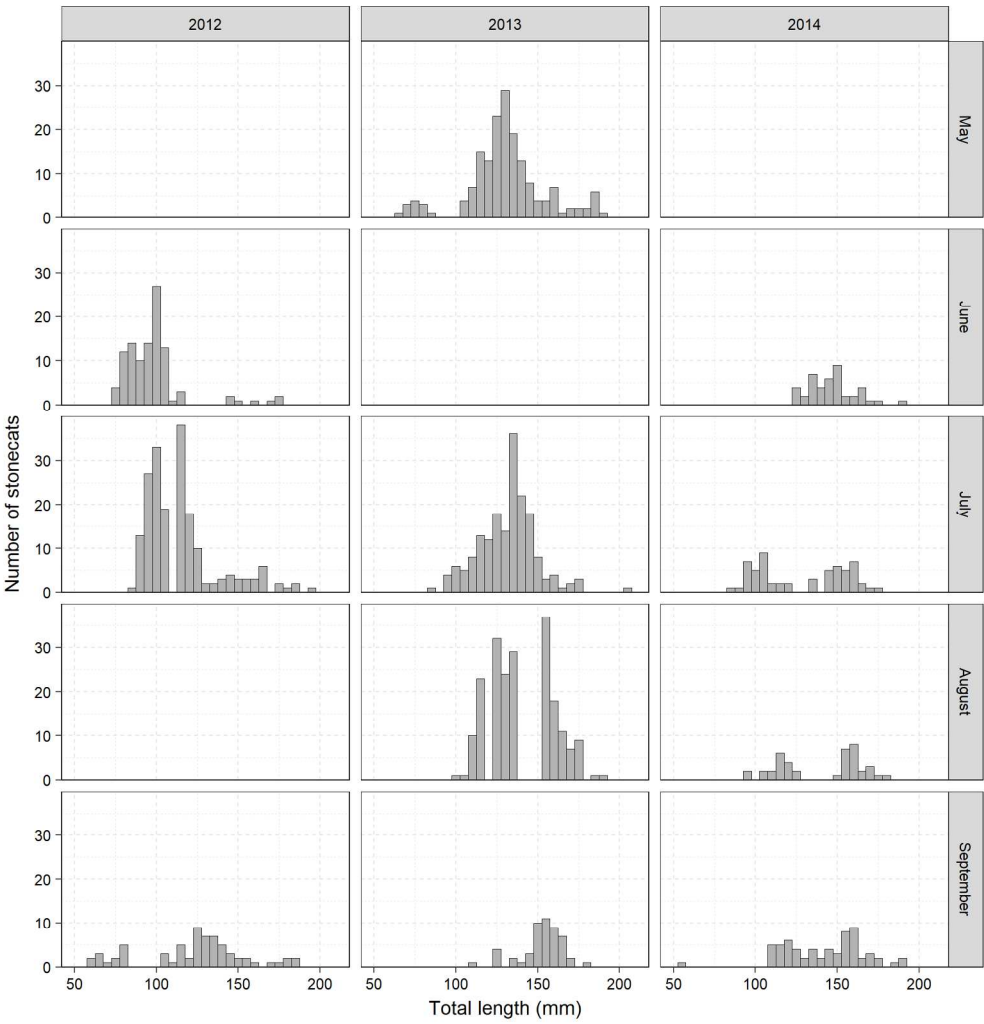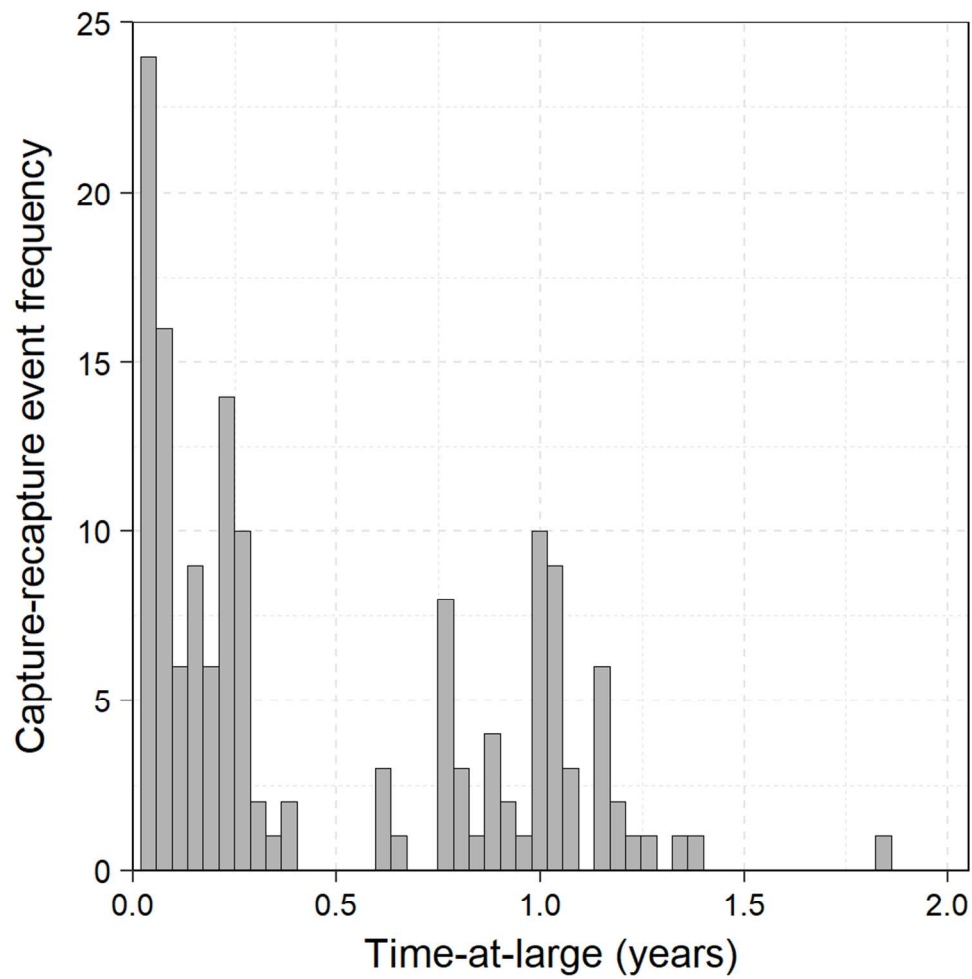
Figure 1.

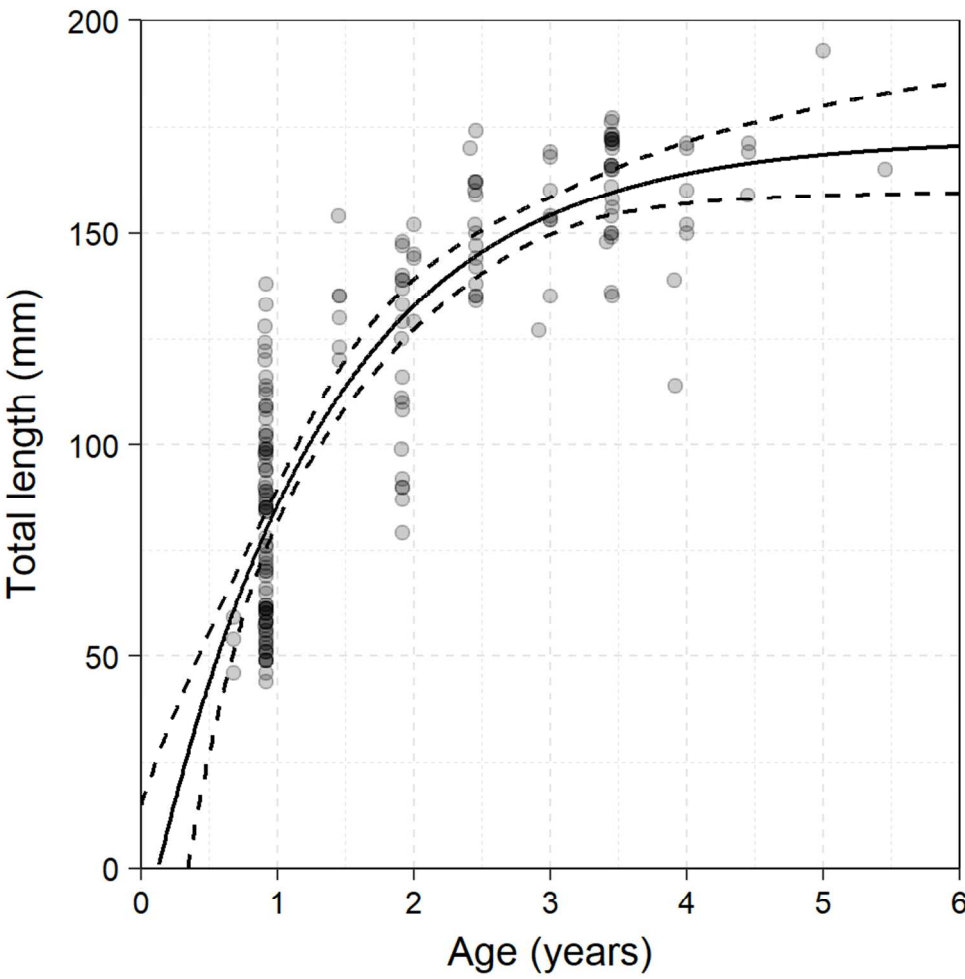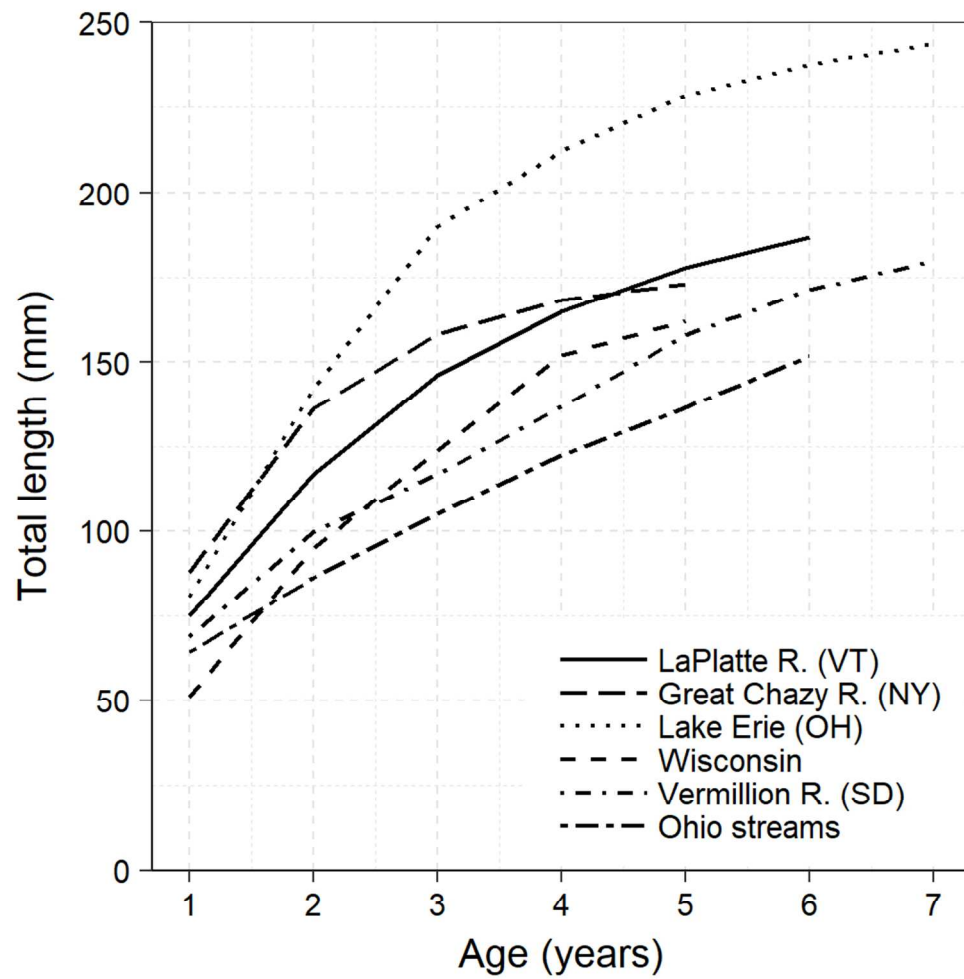184x190mm (300 x 300 DPI)

Figure 2.

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Figure 3.

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Figure 4.

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