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THE ECOLOGY AND LIFE HISTORY OF †*HIODON ROSEI* FROM THE MCABEE AREA

2018 | MITCHELL DARIN JOHNSON

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THE ECOLOGY AND LIFE HISTORY OF †*Hiodon rosei* FROM THE McABEE AREA

by

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ABSTRACT

Although †*Hiodon rosei* (Hussakof), an extinct species of mooneye, has been known of for over a century, little in the way of its ecology or life-history has been studied. It is a common fossil in the McAbee site, a lakebed dated to the Eocene epoch. Various fossils collected from the sites around the Eo-Thompson basin (including McAbee) were analyzed for standard length in an attempt to generate age classes. Missing standard lengths were extrapolated from proxies determined by regression analysis. The distribution of sexes among the various fossil localities was also analyzed. Furthermore, to support hypothesis development about the ecology of †*H. rosei*, a literature review was undertaken. The fossils from the Eo-Thompson basin range from less than 1 year to over 4 years of age, with the majority being between 1 and 3 years of age. There was no difference in the distribution of sexes within the McAbee site or between the sites of the Eo-Thompson sites studied. †*Hiodon rosei* appears to be an opportunistic insectivore, probably feeding at night. It may have spawned in rivers or shallow water, and matured around 1 year of age. Much research is still needed and a promising start is to collect further samples at the Eo-Thompson sites.

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DEDICATION

This work is dedicated to Dr. Rob Higgins, who took a chance on a first year undergraduate student and helped propel him into the field of research, as well as providing him with one of the coolest and most informative jobs ever, and then continued to support and help him through his other research endeavours. I greatly appreciate all you have done for me.

Table of Contents

Table of Figures

Table of Tables

INTRODUCTION

†*Hiodon rosei* (Hiodontidae) is a prehistoric species of fish from the Paleocene and Eocene epochs (66 to 50 Ma; Fossilworks 1998), that is closely related to the mooneye (*Hiodon tergisus*, Lesueur) and goldeye (*Hiodon alosoides*, (Rafinesque)) of today (Hilton and Grande 2008). Discovered in 1912 by Dr. Rose in the Tranquille beds near Kamloops Lake, it was originally placed in the genus *Leuciscus* in the Cyprinidae family and dated to the Miocene epoch (Hussakof 1916). The fish remained *Leuciscus rosei* until 1966 when ash layers in the Tranquille beds were radiometrically dated to the Eocene epoch. Since no member of the Cyprinidae family had been positively identified before the Miocene, the K-A date of 49 Ma raised doubts of the identification and the species was relisted under the newly created †*Eohiodon* genus (Hiodontidae, Cavendar 1966). A study in 2008 found that the main character that separated the genus †*Eohiodon* from the extant *Hiodon* genus, a posterodorsal projection on the opercle bone, was present in specimens of †*Eohiodon* and the genus was grouped within the genus *Hiodon* (Hilton and Grande 2008). Though †*Hiodon rosei* has been known for over a century very little study in the way of its ecological or life history has been done (e.g., Wilson 1977, Wilson and Williams 1993). This research is therefore among the first to look solely at †*Hiodon rosei* ecology and life history.

This study focuses on the specimens of †*Hiodon rosei* from the McAbee area (in the Eo-Thompson basin, after the paleo-valley of the same name in Read and Hebda (2009), Figure 1), specifically McAbee, the Perry Ranch, and Cache Creek (a designation used for some of the RBCM fossils that came from the Eo-Thompson area but could not be specifically placed in one of the other sites). The McAbee beds are an Eocene lake deposit that consists of diatomaceous shale interbedded with volcanic tephra (Mustoe 2005), part of the Tranquille formation of the Kamloops group (Read and Hebda 2009). The McAbee site has two general areas from which fossils are collected: the Zugg 1 claim and the Old Quarry (occasionally referred to as the Kitty Litter Quarry (e.g. Read and Hebda 2009), Figure 1). Biotite from the tephra at McAbee was dated at 52.90 ± 0.83 Ma (Archibald et al. 2010), putting it in the Ypresian age of the Eocene epoch. Along the Thompson valley there are two other fossiliferous beds: the Perry Ranch deposit (3 km west of McAbee) and the Battle Creek deposit (0.5 km east of McAbee). The most comprehensive look at the geology of the whole area (Read and Hebda 2009) does not specifically mention the date of the other sites. However, it does imply the 3 sites were deposited at the same general time (Late Early Eocene, Table 1 in Read and Hebda 2009) and are therefore likely also around 53 Ma. Both Perry Ranch and Battle Creek contain the same fossiliferous layer (designated ETpft) found in McAbee (Read and Hebda 2009), and are therefore likely part of the same lake as the McAbee beds, or were at least connected to the McAbee lake by rivers at the time. The lake (or lakes) system likely formed when volcanism or a landslide dammed up a paleo-valley system allowing water to fill the area (Read and Hebda 2009). There are roughly 3 different "zones" of the lake represented at the different sites. The Battle Creek site and an area east of the Zugg site are very near shore (<150 m away) and in very shallow water (<15 m deep), the Perry Ranch and Zugg sites (as well as a few areas around the Old Quarry) are near shore (<400 m away) and in shallow water (<20 m deep), and the Old Quarry is near shore (<300-400 m away) and in moderately deep water (<75 m deep (Read and Hebda 2009)). Fossils from the site include arthropods, birds, fish, and plants of various taxa (Wilson 2008, Greenwood et al. 2004). Organisms are preserved as compression fossils (Mustoe 2005, Wilson 2008, Read and Hebda 2009, Greenwood et al. 2004, Archibald et al. 2011) and the details are excellent (Wilson 2008, Read and Hebda 2009, Archibald et al. 2010, Archibald et al. 2011), likely owing to mucous-like secretions from diatoms that created a coating on the dead organisms, preserving fine detail and protected them from scavengers

(Mustoe 2005, Archibald et al. 2010). Fossils were likely deposited in anoxic waters where scavengers could not reach them (Wilson 2008, Archibald et al. 2010). It is likely that the fish died during winter overturn as they exhibit many of the same characteristics as the specimens of †*Amyzon aggregatum* Wilson that Wilson (1984) reported: specifically, there was a lack of preserved gut contents and evidence of tetany among the fossils of †*H. rosei*. Wilson (1984) also stated that specimens of †*Amyzon aggregatum* are found in many layers of sediment and individuals are rarely found in close proximity. This is true for many of the specimens of †*H. rosei*, however there are also specimens that were found on the same matrix (for example, specimens L-018 F-1386a and L-018 F-1386b, RBCM.EH2009.020.0052.001, RBCM.EH2009.020.0052.002, RBCM.EH2009.020.0052.003 and specimens RBCM.EH2017.050.0307.001, RBCM.EH2017.050.0307.002, and RBCM.EH2017.050.0307.003) which could either imply mass mortality (Wilson 1984) or semi-social behaviour, like that observed in *Hiodon alosoides* (Fernet and Smith 1976).

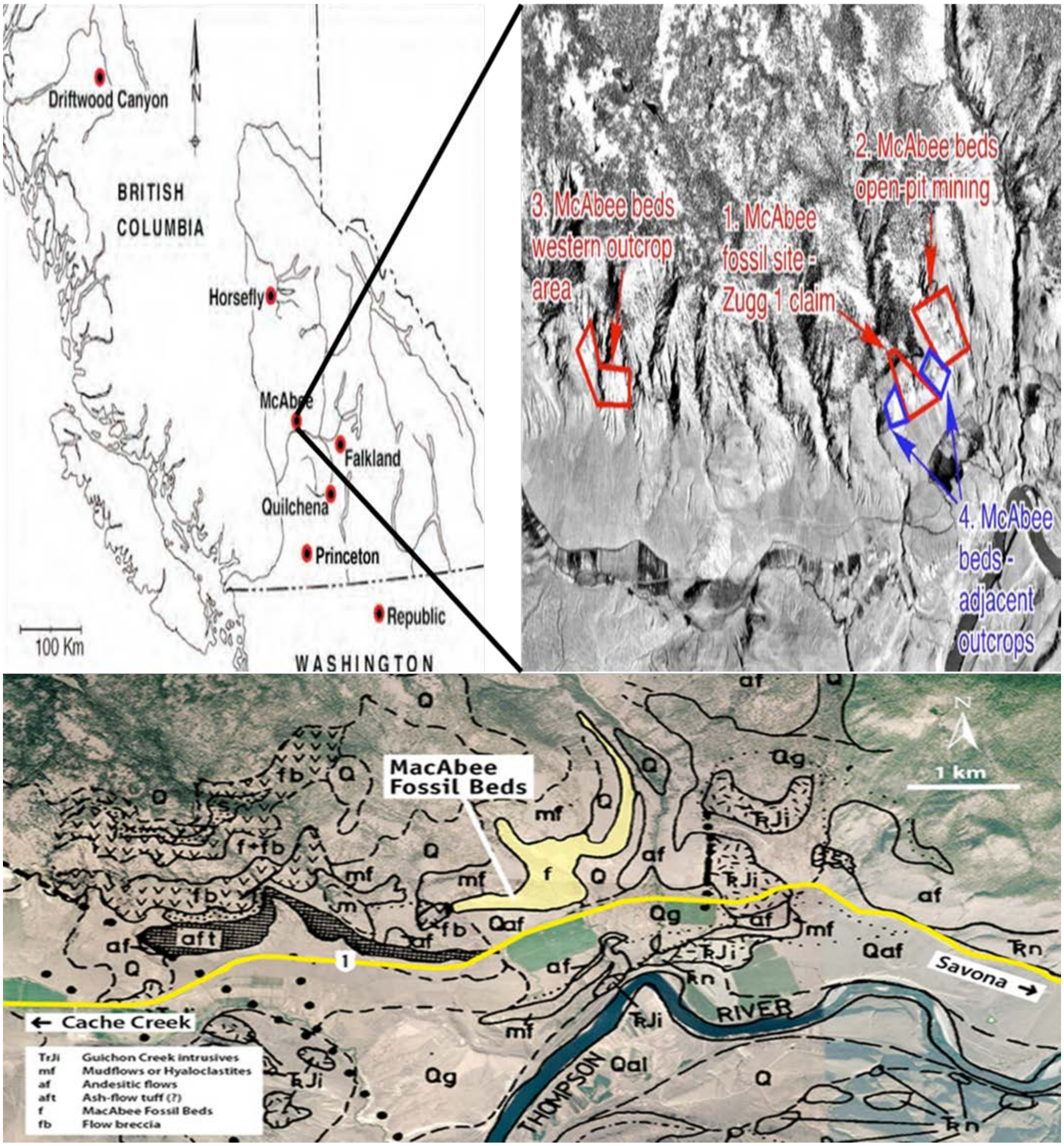

Figure 1: The location of the Eo-Thompson basin. McAbee consists of the polygons labelled 1, 2, and 4, Perry Ranch is the polygon labelled 3. Battle Creek is the dark line along the right side of the photo and the Battle Creek fossil deposit would be located west (left) of there (Read and Hebda 2009). The bottom map shows the geology of the area. The unit labelled 'f' looks like it crosses all the sites in the Eo-Thompson basin. Right map was taken from Figure 1 in Archibald et al. 2011; left photo taken from Figure 2 in Wilson 2008; bottom map from Figure 17 in Ewing 1981.

This study set out to create proxies for extrapolating standard length from incomplete fossils, to be used by future researchers in further studies (Table B2, Appendix C). It uses the extrapolated lengths in combination with measured lengths to look at the age classes of †*H. rosei* within the Eo-Thompson. The gender distribution of †*H. rosei* within the McAbee site and between other sites in the Eo-Thompson basin was also examined to see if there was any partitioning of males, females, and juveniles due to the different water depths at each fossil site. It is expected that there will be more juvenile fossils in the shallower sites. Finally, ecology, life history, and behaviour was suggested for †*H. rosei* based on ecological research done on living *Hiodon* species.

METHODS AND MATERIALS

Fossils labelled as †*Hiodon rosei* from the Thompson Rivers University (TRU) and the Royal British Columbia Museum (RBCM) collections were measured for various characters. Measurements for fins were made using a digital microscope where possible. However, since much of a typical fossil would not fit in the field of view, many metrics were measured using a ruler and a piece of string. In instances where the fossil was curved or otherwise bent away from a straight profile a piece of string was used to follow the curve and marked as needed for the measurement. It was then stretched out along a ruler and measured to get a straight line measurement. In figures 3 – 18, the measurements are shown for illustration (characters involving curves were measured as defined above). When both the part and counterpart of the same individual were present the measurements were averaged (if there were two measurements for a particular metric) as measurements sometimes varied due to the way the fossil split. If there was only a single measurement for the pair, then that measurement was kept and not averaged. This created one combined fish to avoid replication in the calculations, and the fossils are reported as the two IDs combined in some way. The definitions given below are how each character (see also Appendix A) was defined in this study and may vary from other published definitions. References are provided when possible; otherwise the characters are defined as used in this study.

Sex: †*Hiodon rosei* has a sexually dimorphic anal fin (Cavendar, 1966), with mature males having thicker anal rays and a more rounded anal fin profile (Figure 2).

Figure 2: Sexual dimorphism in †*H. rosei*. Arrows point to the dimorphic anal fin. A) Male (fin is more rounded and has thicker rays, image of TRUP2014.0081.001) B) Female (fin is more triangular and has thinner rays, image of L-018 F-1383 [slightly distorted]).

Standard Length (SL): Length of the fish from the tip of the snout to the end of the vertebral column (McClane 1978, Figure 3). Since the tips of the caudal fin could be hidden by overlying rock or improperly fossilized (pers. obs.), all calculations were performed with standard length measurements.

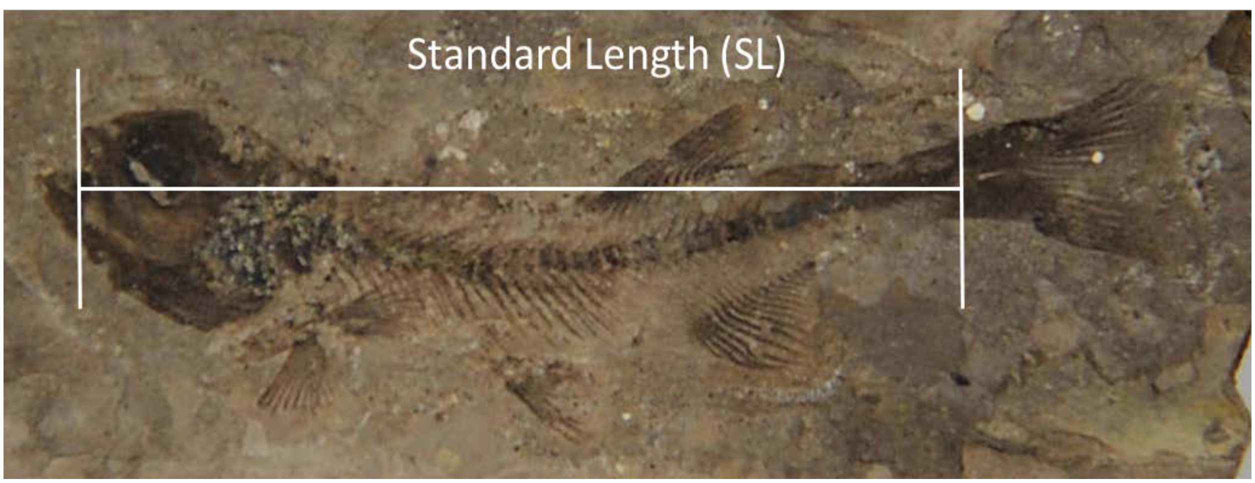

Figure 3: Standard Length (SL). The curve of the spine would have been followed with a string and the end points marked. The string would then be stretched along a ruler to get a straight line measurement. Image of TRUP2014.0085.001.

Total Length (TL): length of the fish from the tip of the snout to the tip of the caudal fin (McClane 1978, Figure 4). This was used only to visually compare regression outputs, not for any calculations.

Post-Opercle Urostyle Length (POUL): a measurement created for this study. It is defined here as the distance from the caudal-most point of the operculum (opercle bone) to the beginning of the urostyles (Figure 5). It was measured using a ruler and string as stated above.

Body Depth (BD): defined as the greatest depth of the body measured at right angles to the long axis of the body (McClane 1978, Figure 6).

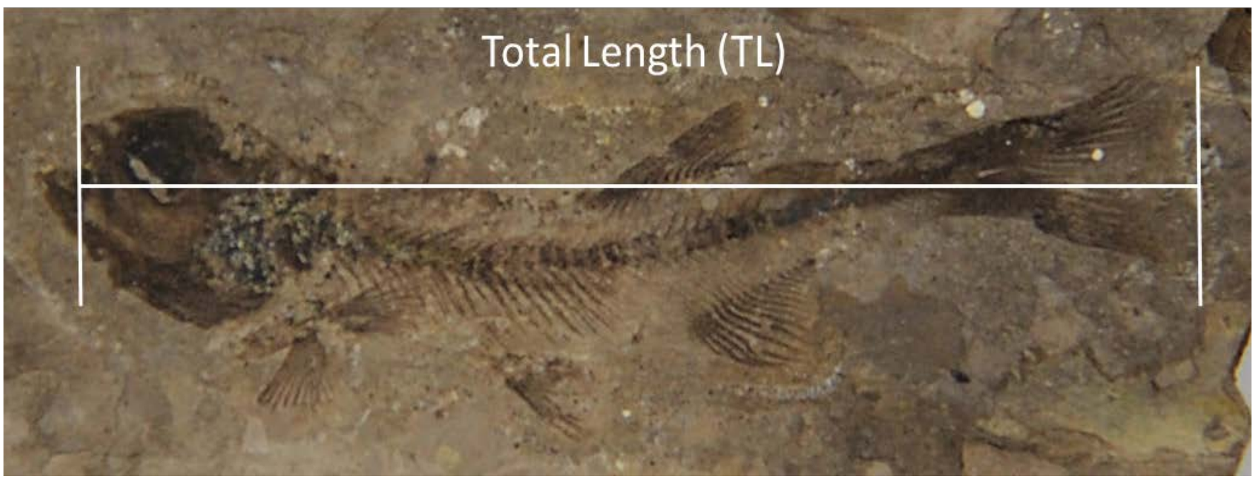

Figure 4: Total Length (TL). The curve of the spine would have been followed with a string and the end points marked. The string would then be stretched along a ruler to get a straight line measurement. Image of TRUP2014.0085.001.

Figure 5: Post-Opercle Urostyle Length (POUL). A measurement developed for this study. The curve of the spine would have been followed with a string and the end points marked. The string would then be stretched along a ruler to get a straight line measurement. Image of TRUP2014.0085.001.

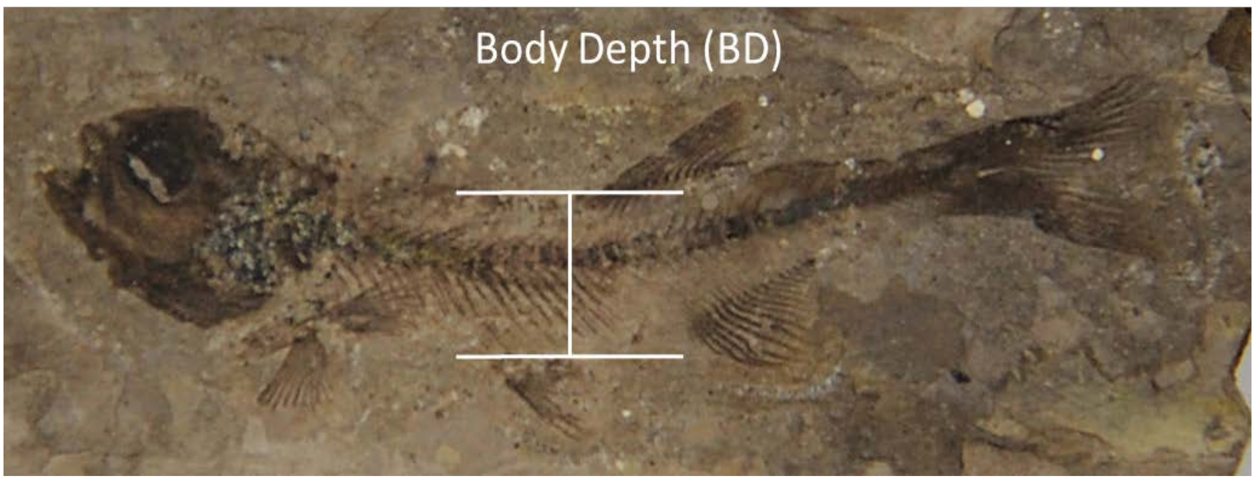

Figure 6: Body Depth (BD). Image of TRUP2014.0085.001.

Caudal Peduncle Length (CPL): defined as the length of the narrow part of the body between the posterior ends of the dorsal and anal fins and the base of the caudal fins (Fishbase 2018, Figure 7). It was measured from the posterior end of the dorsal fin rather than the anal fin in this report.

Caudal Peduncle Depth (CPD): defined as the vertical measurement at the narrowest point of the caudal peduncle (Fishbase 2018, Figure 8).

Head Length (HL): defined as the straight-line measurement of the head from the upper lip to the posterior end of the operculum (Fishbase 2018, Figure 9).

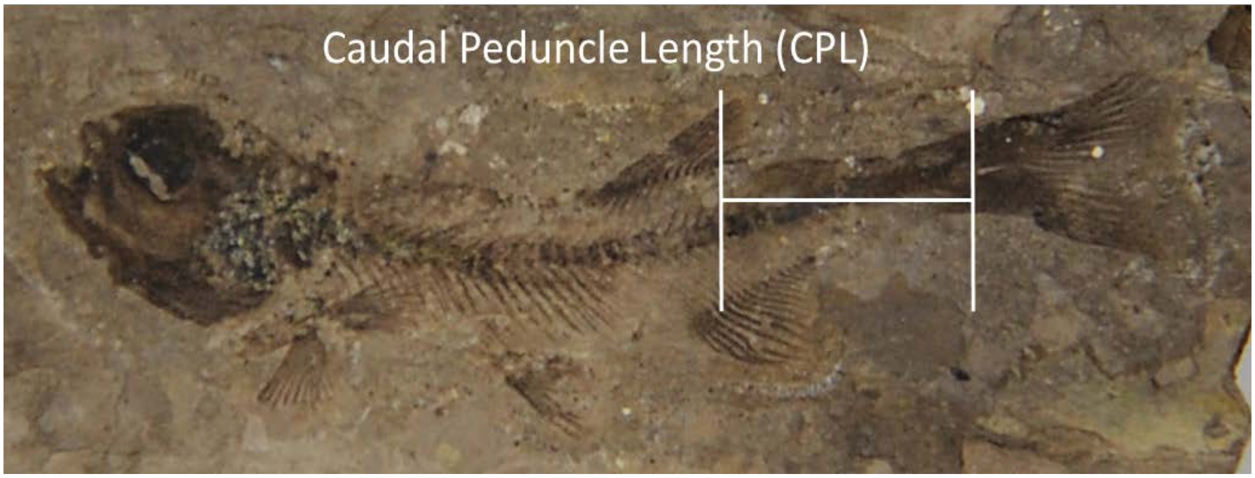

Figure 7: Caudal Peduncle Length (CPL) as measured in this study. The curve of the spine would have been followed with a string and the end points marked. The string would then be stretched along a ruler to get a straight line measurement. Image of TRUP2014.0085.001.

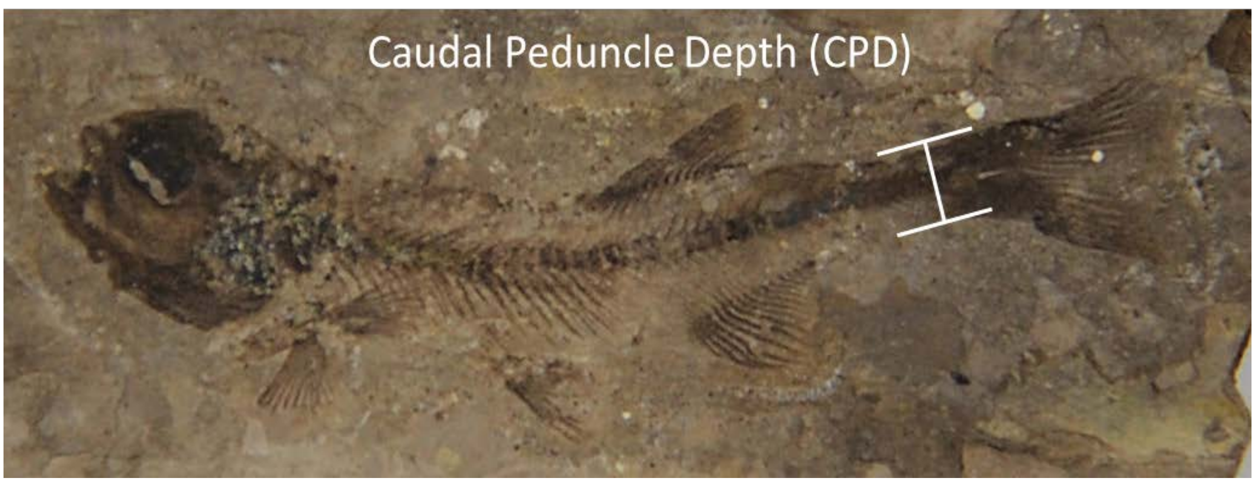

Figure 8: Caudal Peduncle Depth (CPD). Image of TRUP2014.0085.001.

Figure 9: Head Length (HL). Image of TRUP2014.0085.001.

Head Depth (HD): defined here as the width of the skull across the opercle bone to its base (Figure 10). This was to avoid inaccurate measures due to extended brachiostegal rays.

Eye Diameter (ED): defined here as the diameter across the eye (or across the narrowest diameter if the eye is not circular, Figure 11).

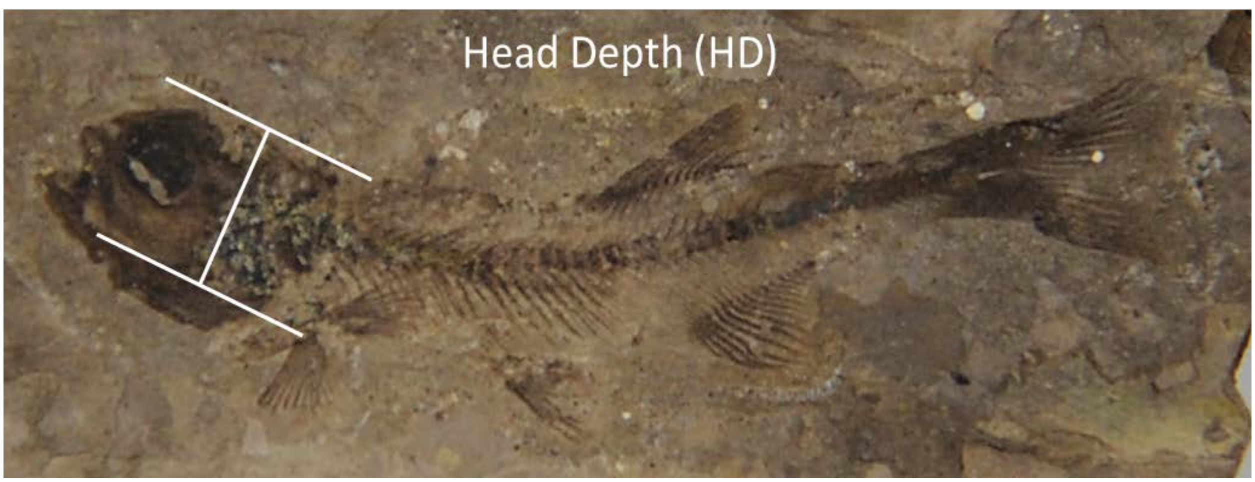

Figure 10: Head Depth (HD) as measured in this study. Image of TRUP2014.0085.001.

Figure 11: Eye Diameter (ED) as measured in this study. Image of TRUP2014.0085.001.

Pectoral fin Length (PcL): the length of the pectoral fin from the origin to the distal tip of the fin (Fishbase 2018, Figure 12). Determined by taking the average length of the three longest visible fin rays when lengths could be measured by digital microscope; otherwise a single measurement was taken of the longest fin ray using a ruler and string as described above.

Pelvic fin Length (PvL): measured and defined the same way as the pectoral fin ray length (Figure 13).

Figure 12: Pectoral fin Length (PcL). Image of TRUP2014.0085.001.

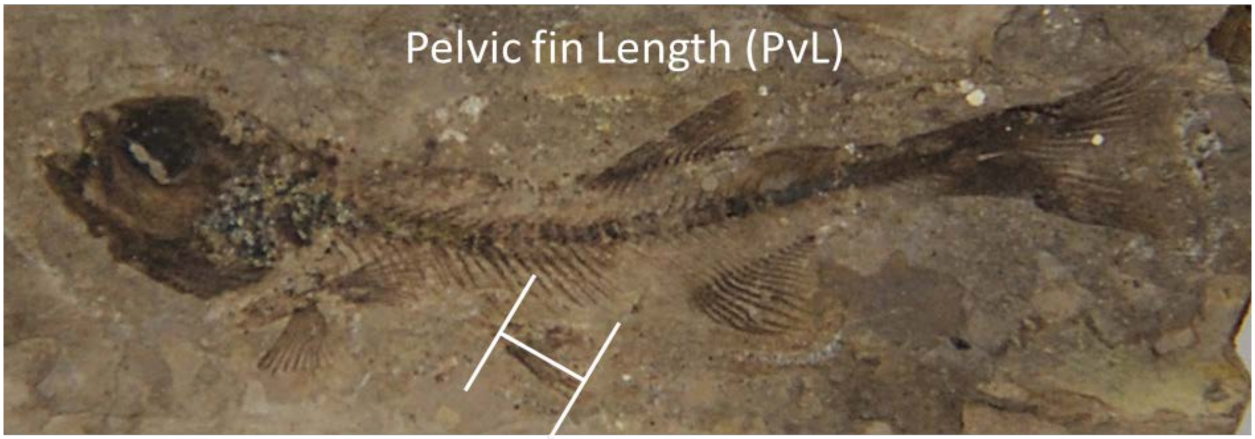

Figure 13: Pelvic fin Length (PvL) as measured in this study. Image of TRUP2014.0085.001.

Dorsal fin Base Length (DBL): defined here as the straight line measurement from the base of the front-most ray or spine to the base of the last ray (Figure 14).

Dorsal fin Ray Length (DRL): defined here as the average length of the three longest rays of the dorsal fin measured from the longest rays when possible to do so with a microscope, otherwise a single measurement was taken with a ruler and string as described above (Figure 15).

Anal fin Base Length (ABL): measured the same as dorsal fin base length along the anal fin (Figure 16).

Figure 14: Dorsal fin Base Length (DBL) as measured in this study. Image of TRUP2014.0085.001.

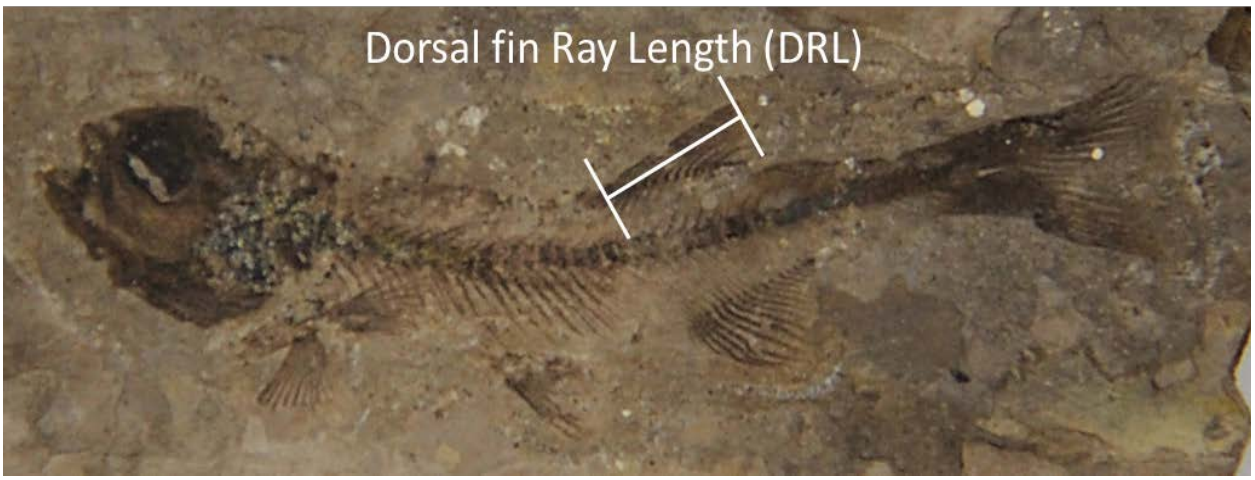

Figure 15: Dorsal fin Ray Length (DRL) as defined in this study. Image of TRUP2014.0085.001.

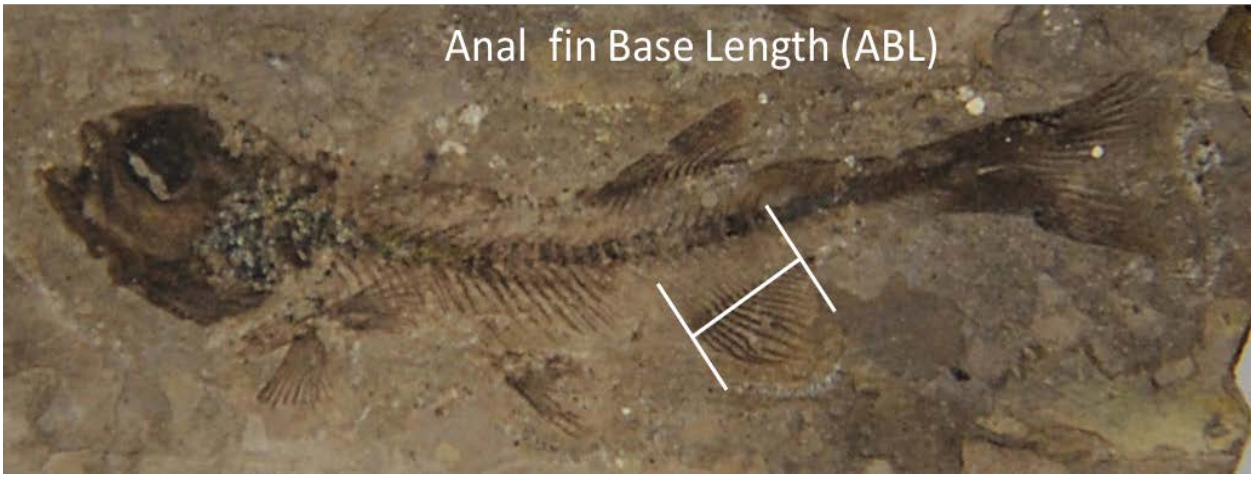

Figure 16: Anal fin Base Length (ABL) as measured in this study. Image of TRUP2014.0085.001.

Anal fin Ray Length (ARL): measured the same as dorsal ray length (Figure 17).

Caudal Fin Length (CFL): the average length of the longest lobe of the caudal fin from the distal most tip to the beginning of the urostyles (Figure 18) when measured with a microscope, or a single measurement with a ruler and string as described above.

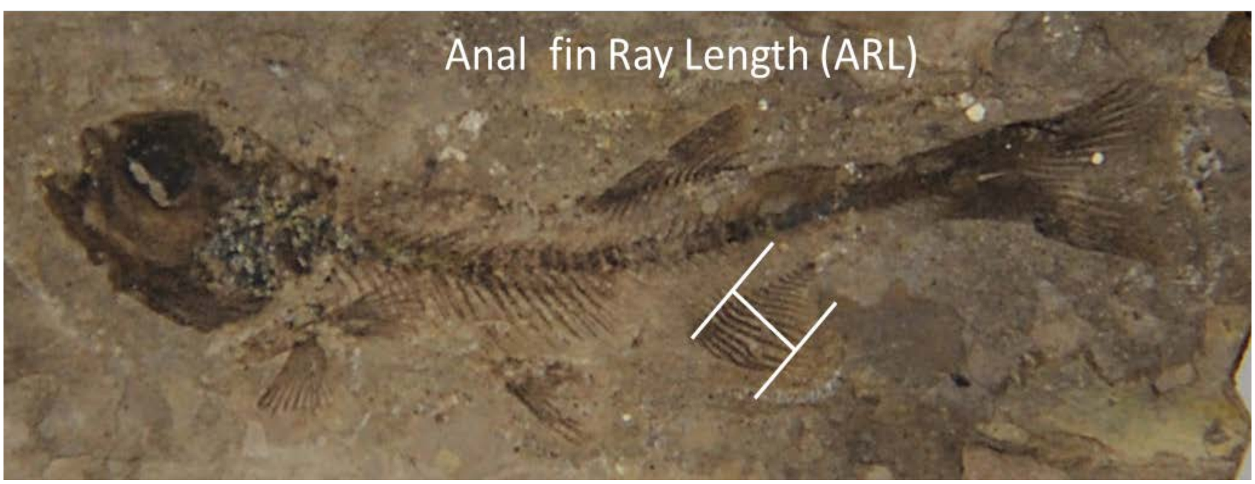

Figure 17: Anal fin Ray Length (ARL) as measured in this study. Image of TRUP2014.0085.001.

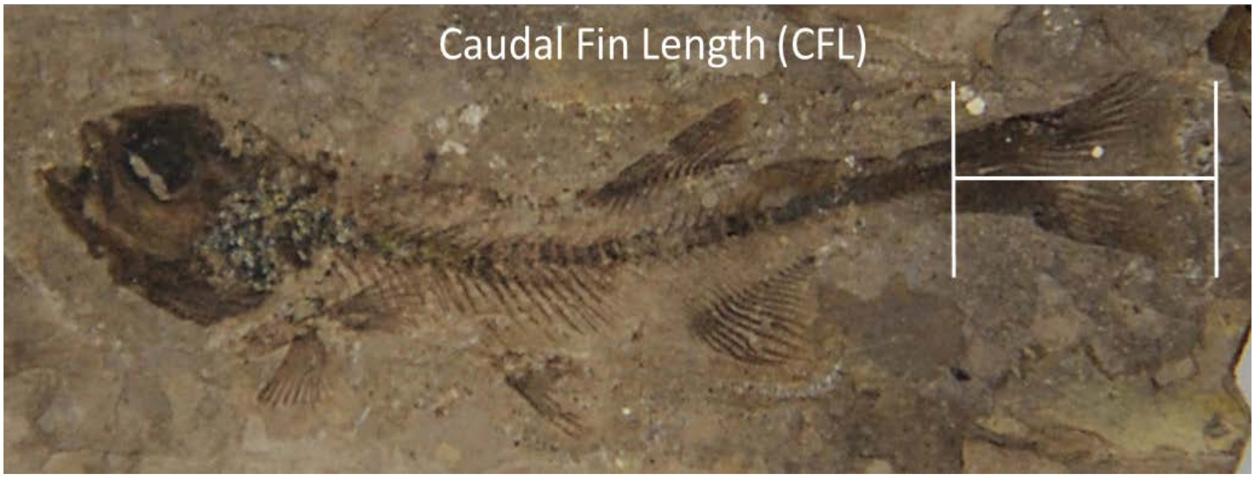

Figure 18: Caudal Fin Length (CFL) as measured in this study. Image of TRUP2014.0085.001.

Species identification was verified primarily by using counts of the anal fin rays and pterigiophores as †*H. rosei* has fewer of these characters versus †*H. woodruffi* or †*H. falcatus* (see Table 1 in Hilton and Grande 2008 for a summary of the different counts associated with various *Hiodon* species). Previous identification varied among the fossils. Some were misidentified or identification was unclear; these fossils were excluded from the study. Some identifications was highly probable (i.e., counts were in the range of overlap between †*H. rosei* and †*H. woodruffi*, or only one fin could be counted but these counts aligned with the range for †*H. rosei*). These fish were excluded from only the final regression calculations, but included in other analyses such as distribution within and between sites of the Eo-Thompson basin in order to increase sample size (it is noted when they were included). Fossils confirmed as †*H. rosei* were included in all analyses and calculations. Many fossils were incomplete, showing either the anterior or posterior half of the fish, or some medial portion. To render them useable, regressions were plotted relating standard length to all other mensural characters using complete fossils of †*Hiodon rosei*. Missing standard lengths were determined by using the proxy with the highest, significant R^2 value that was available for a particular individual (Table 1, Table B 2, appendix C). Regression was tested for significance using an ANOVA. Age classes were created by plotting the frequencies of the standard lengths and identifying specific peaks visually. Sex distributions were tested using X^2 analysis. Statistical tests and figures were done in Minitab 14 (student release version, Waveland Press, Inc.). Significance was set at $\alpha = 0.05$, except for the regression analyses to which a Bonferroni correction was applied making $\alpha = 0.003$.

RESULTS

A total of 153 individual fossils were examined, of which 52 individuals were confirmed as †*Hiodon rosei*. An additional fifteen individuals were highly likely †*H. rosei* (hereafter probable †*H. rosei* or probable group. When the two groups are referenced together they are the ‘confirmed + probable group). Twenty six fish of the 52 had measureable SLs and were used in the regression analysis (Table 1), omitting the any fish in the probable group. All R^2 values were significant except for Eye Diameter (ED). Anal fin Base Length (ABL) and Body Depth (BD) were not used to determine Standard Length (SL) because these metrics have been shown to be sexually dimorphic in *Hiodon* (Li and Wilson 1994). Pectoral fin Length (PcL) and Pelvic fin Length (PvL) could not be used for extrapolations because these fins are often damaged or even missing in these fossils. Significance for the regressions was set at $P > 0.003$ using a Bonferroni correction, otherwise significance is set at $P > 0.05$.

Table 1: Summary of proxies used to extrapolate Standard Length (SL). Proxies marked with an '*' indicate ones that were not used to extrapolate SL. Abbreviations: POUL = Post-Opercle Urostyle Length, CPL = Caudal Peduncle Length, CFL = Caudal Fin Length, DRL = Dorsal fin Ray Length, ARL = Anal fin Ray Length, CPD = Caudal Peduncle Depth, ABL = Anal fin Base Length, HD = Head Depth, PvL = Pelvic fin Length, HL = Head Length, BD = Body Depth, DBL = Dorsal fin Base Length, PcL = Pectoral fin Length, ED = Eye Diameter.

Proxy Measurement	Regression Equation	N	R^2 Value	P value
POUL	SL = 3.15 + 1.33(POUL)	22	0.976	<0.001
CPL	SL = 4.81 + 3.33(CPL)	24	0.941	<0.001
CFL	SL = 5.79 + 3.42(CFL)	23	0.926	<0.001
DRL	SL = 11.1 + 4.69(DRL)	14	0.922	<0.001
ARL	SL = 14.2 + 5.68(ARL)	16	0.920	<0.001
CPD	SL = 18.3 + 7.86(CPD)	21	0.902	<0.001
ABL*	SL = 16.2 + 4.35(ABL)	23	0.897	<0.001
HD	SL = 5.33 + 4.08(HD)	19	0.853	<0.001
PvL*	SL = 28.0 + 4.26(PvL)	10	0.842	<0.001
HL	SL = 7.24 + 3.02(HL)	22	0.834	<0.001
BD*	SL = 22.0 + 2.61(BD)	21	0.831	<0.001
DBL	SL = 18.4 + 5.13(DBL)	21	0.785	<0.001
PcL*	SL = 32.2 + 3.99(PcL)	17	0.565	0.002
ED*	SL = 29.6 + 6.36(ED)	9	0.289	0.169

Standard Lengths (SLs) were plotted for †*Hiodon rosei* following the example of Wilson (1984) which used size-frequency distributions to suggest possible age classes for †*Amyzon aggregatum*. Figures 19 and 20 show the results of the size frequency distribution. With the bars of the histogram set at 10 mm intervals (as is suggested by Neumann and Allen (2007) for fish up to 300 mm in length), two modes were seen at 60 mm and 130 mm SL in the confirmed group (Figure 19A). Adding the probable group gave a third mode at 110 mm SL (Figure 20A). The bars at 5 mm intervals showed far more groupings: ones at approximately 35mm, 60 mm, 90 mm, 110 mm, and a grouping around 135 mm SL in both the confirmed (Figure 19B) and confirmed + probable groups (Figure 20B).

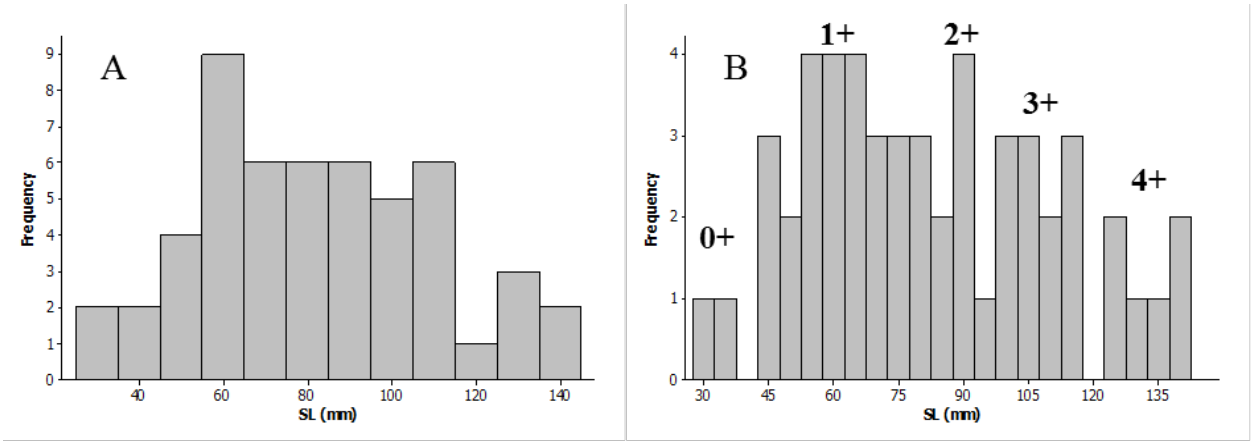

Figure 19: Size-frequency distributions for confirmed †*H. rosei*. SL = Standard Length. A) Bar midpoints at 10 mm intervals. There are 2 possible modes, one at 60 mm and one at 130 mm SL. Since this resolution is not discussed further, the age classes are not shown. B) Bar midpoints at 5 mm intervals. Here there are 5 possible modes at approx. 32.5 mm, 60 mm, 90 mm, 110 mm, and 132.5 mm SL respectively.

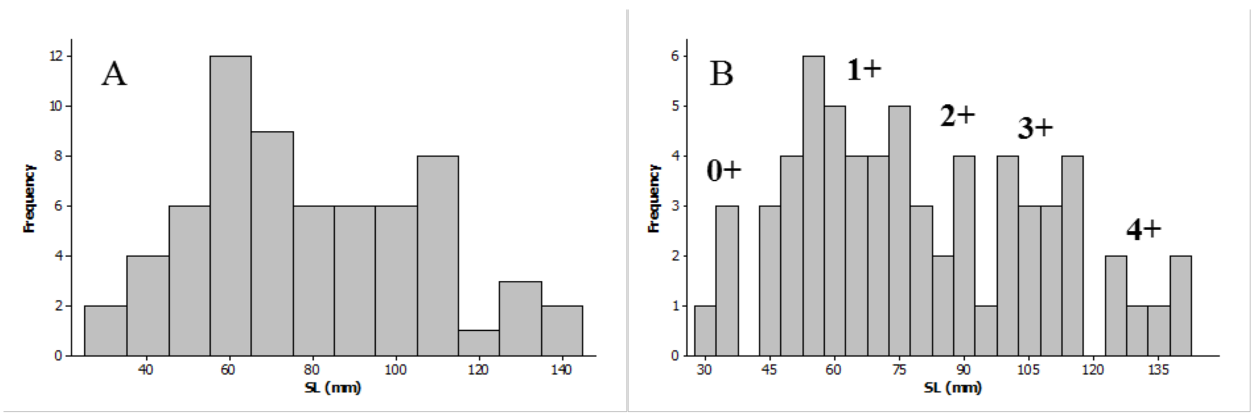

Figure 20: Size-frequency histograms of confirmed + probable †*H. rosei*. SL = Standard Length. A) Bars at 10 mm intervals. There are 3 possible modes at 60 mm, 110 mm, and 130 mm SL respectively. Since this resolution is not discussed further, the age classes are not shown. B) Bars at 5 mm intervals. There are 5 possible modes at approx. 35 mm, 55 mm, 90 mm, 107.5 mm, and 132.5 mm SL respectively.

The distribution of sexes was examined both within the McAbee site (Table 2) and between the McAbee site and other possible sites in the Eo-Thompson basin (Table 3). There was no difference between the frequency of males, females, or juveniles within McAbee (X^2 = 0.707, DF = 2, P > 0.50) or between the sites of the Eo-Thompson basin (X^2 = 8.128, DF = 4, P > 0.50) for confirmed †*H. rosei*. Neither was there a significant difference for the confirmed + probable †*H. rosei* within McAbee (X^2 = 0.675, DF = 2, P > 0.50). However, there was a significant difference in distribution of sexes for the confirmed + probable †*H. rosei* between the sites in the Eo-Thompson basin (X^2 = 14.244, DF = 4, P < 0.01), but see the discussion for caveats.

Table 2: Comparison of the sex groups between the two main sites of McAbee. Numbers in parentheses indicate how many individuals belonged to the probable group for each sex. Unsure sex was not tested in the X^2 analysis.

Site	Number of Males	Number of Females	Number of Juveniles	Number of Unsure Sex	Total
Zugg 1	4 (1)	5 (2)	1 (0)	2 (1)	12 (4)
Old Quarry	2 (0)	6 (0)	1 (0)	0 (0)	9 (0)

Table 3: Comparison of the sex groups between the sites of the Eo-Thompson basin. Numbers in parentheses indicate how many individuals belonged to the probable group for each sex. Unsure sex was not included in the X^2 analysis. Cache Creek is a group likely relating to the McAbee area but not specifically assigned to either Perry Ranch or McAbee.

Site	Number of Males	Number of Females	Number of Juveniles	Number of Unsure Gender	Total
McAbee	11 (3)	20 (4)	2 (1)	3 (1)	36 (9)
Perry Ranch	0 (0)	2 (0)	2 (1)	0 (0)	4 (1)
Cache Creek	4 (3)	6 (0)	1 (0)	1 (0)	12 (3)

DISCUSSION

This study was successful in creating proxies for extrapolating SLs in incomplete †*Hiodon rosei* fossils. Every character was significantly related to standard length except for ED, and this is likely because the eyes did not fossilize well and therefore there was a smaller sample of this character compared to other characters. The eyes may also have remained the same size throughout the fish's life but this cannot be verified from these data.

From the complete and extrapolated Standard Lengths (SLs), frequency histograms were created in order to visualize possible age classes in confirmed †*H. rosei* (Figure 19), and confirmed + probable †*H. rosei* (Figure 20). There appear to be between 2 and 5 modes visible depending on the bar size used in the histogram, generally around 35 mm, 60 mm, 90 mm, 110mm, and/or 135 mm SL. The majority of fossil fish appear to be grouped around the mode at 60 mm SL. The combined grouping at 135 mm SL appears to have 2 peaks, but this is likely an artifact due to sample size. Because Eocene Hiodontids grow to about 150 mm long at maximum (Wilson 1996; maximum measured length for this study = 113.25 mm SL [RBCM.EH2017.050.0309.001], maximum estimated length for this study = 140.51 mm SL [L-019 F-056-061]; maximum reported length = 143 mm SL [Wilson 1977]), and because of the better resolution of modes the histograms with 5 mm interval bars, it was assumed that the 5 mm bars are likely the most accurate (Bars of 5 mm were used in age analysis of *Phoxinus phoxinus* (Linnaeus) (Frost 1943)) and will be discussed for the remainder of this section. The first mode at approximately 30-35 mm SL is likely representative of juvenile †*H. rosei*, as fish with SLs shorter than 50 mm are likely less than one year old (Wilson and Williams 1993). It follows then, that the modes at 60 mm, 90 mm, 110 mm, and 135 mm SL are probably ages 1+ through 4+ respectively, with the majority of fossils being around ages 1+ to 3+. Additional samples are needed to infer the proper bounds for the age classes. Newbrey et al. (2005) provide evidence that species of †*Eohiodon* (= †*Hiodon*) lived to be 11 years of age, though they did not specify as to whether or not this could apply to †*H. rosei* alone. There are several possible reasons as to why the histograms of †*H. rosei* presented here do not show a 11 year age maximum as suggested by Newbrey et al. (2005). Firstly, most fossil †*Hiodon* found are less than 100 mm in length (Wilson and Williams 1993), suggesting a skew towards younger age classes (age 1+ and onwards) but the presence of juvenile fish (i.e. age 0+) is rare (see Tables 2 and 3, and discussion on spawning habits below). Additionally, there may be less of a noticeable size difference in fish older than 4 years (assuming that †*H. rosei* reaches 11 years of age at maximum) than there is among the younger year classes. It has been shown that older mooneyes grow more slowly than younger mooneyes (Glenn 1975a). Secondly, the fossils may not be an accurate representation of the population. Both old and young †*H. rosei* are found together in McAbee (Table 2) and the other sites of the Eo-Thompson basin (Table 3), and there was no evidence of sex segregation within McAbee or between the sites of the Eo-Thompson. Thirdly, a small sample size could also affect results by failing to capture all age classes present in the sites.

Coprolites believed to be piscivorous from the McAbee site show traces of insect cuticle and even bits of plant material such as *Metasequoia* needles (pers. obs.). Modern mooneyes feed primarily on insects, but also appear to be opportunistic eaters consuming occasional plant material (Glenn 1975b). †*Hiodon rosei* had sharp teeth (Cavendar 1966) and likely had a similar diet to modern mooneyes. †*Hiodon rosei* was likely a critical component of the food web in the Eo-Thompson basin. Fossilized regurgitates from the McAbee site contain †*Hiodon* sized skeletons (pers. obs.). These regurgitates are likely from birds (Greenwood et al. 2004), but it is logical that the much larger †*Eosalmo* would also consume †*H. rosei* since modern mooneyes have been recorded in the stomachs of striped bass (Katechis et al. 2007). A very large eye is seen in fossil †*H. rosei* and given that it is consumed by other, larger predators it would make sense to forage at night to avoid predation. Juvenile mooneyes appear to follow this same behaviour (Wallus and Buchanan 1989). It has been suggested that the large eye of modern *Hiodon* is likely an adaptation to its feeding habits (Cavendar 1966).

Little is known about the spawning behaviour of the mooneye, but they do migrate into clearer waters to spawn (Paulson and Hatch 2002). Therefore, †*H. rosei* may also have migrated from the lake to nearby rivers (see the geology in Read and Hebda 2009) to spawn. The low number of juvenile fish observed among the various sites in the Eo-Thompson basin and could imply that those that are observed are nearing the end of their first year and have migrated into the lake upon approaching maturity. Alternatively, †*H. rosei* may have spawned in shallower waters closer to shore, an environment that may have not been well preserved (see Read and Hebda 2009). One very small, likely †*H. rosei* fossil was observed in a personal collection, but this juvenile could have been washed into the lake in a storm or similar event (the thin tuffaceous layers at the site are thought to have been washed in during storms (Mustoe 2005)). A probable †*H. rosei* (L-018 F-1386b) was identified as male at 50 mm SL in this study. Since fossil fish less than 50 mm SL are likely less than 1 year of age (Wilson and Williams 1993), †*H. rosei* may reach sexual maturity by their first year. Modern mooneyes mature at ages 4 and 5 for males and females respectively (Glenn 1975a). Upon reaching sexual maturity, male mooneye and goldeye develop their characteristic anal fin modifications (Cavendar, 1966). The sexually dimorphic fin does not appear in †*H. rosei* until 50 mm SL (Wilson 1977, see also Figure 5 in Wilson and Williams 1993). It isn't possible to be sure when female †*H. rosei* mature, as there does not appear to be any noticeable age-related dimorphism in their fossils aside from the anal fin, however, it may be that the females mature one year after the males as in modern mooneyes (Glenn, 1975a).

This report focused on the ecology and life history of †*Hiodon rosei*. It successfully created proxies for estimating standard length. It has shown that the fossils from within the McAbee site likely range from > 1yr of age (class 0+) to <4 yrs of age (class 4+). Unfortunately, the lack of fossils collected from the other sites in the Eo-Thompson basin did not allow for a significant between-site analysis. Within the Eo-Thompson basin there appeared to be no difference in the distribution of males, females, and juveniles. By comparing †*H. rosei* to its living relative *H. tergisus* we could hypothesize about some of its ecological behaviour. For example, †*H. rosei* was likely a nocturnal feeder and fed opportunistically on insects. It may have migrated into rivers to spawn. Many future avenues of research remain available. More collecting at the various sites of the Eo-Thompson basin, but especially at Perry Ranch and Battle Creek, will be needed.

LITERATURE CITED

Archibald SB, Bossert WH, Greenwood DR, Farrell BD. 2010. Seasonality, the latitude gradient of diversity, and Eocene insects. Palaeobiology. 36(3): 374-398.

Archibald SB, Greenwood DR, Smith RY, Matthews RW, Basinger JF. 2011. Great Canadian Lagerstätten 1. Early Eocene Lagerstätten of the Okanagan Highlands (British Columbia and Washington State). Geoscience Canada. 38(4): 155-164.

Cavendar T. 1966. Systematic position of the North American Eocene fish, “*Leuciscus*” *rosei* Hussakof. American Society of Ichthyologists and Herpetologists (Courtesy of JSTOR). 1996(2): 311-320.

Ewing, T. E., 1981, Geology and tectonic setting of the Kamloops Group, South-Central British Columbia, PhD Thesis, University of British Columbia, 238 p.

Fernet DA, Smith RJF. 1976. Agnostic behavior of captive goldeye (*Hiodon alosoides*). Journal of the Fisheries Research Board of Canada. 33: 695-702.

Fishbase [Internet]. Froese R, Pauly D, Editors. 2018. Version (02/2018). World Wide Web electronic publication; [cited 2018 Jun 03]. Available from: www.fishbase.org

Fossilworks [Internet]. 1998. Macquarie University, NSW, Australia: Macquarie University; [cited 2018 May 18]. Available from: http://fossilworks.org/cgi-bin/bridge.pl

Frost WE. 1943. The natural history of the Minnow, *Phoxinus phoxinus*. Journal of Animal Ecology (Courtesy of JSTOR). 12(2): 139-162.

Glenn CL. 1975a. Annual growth rates of Mooneye, *Hiodon tergisus*, in the Assiniboine River. Journal of the Fisheries Research Board of Canada. 32: 407-410.

Glenn CL. 1975b. Seasonal diets of Mooneye, *Hiodon tergisus*, in the Assiniboine River. Canadian Journal of Zoology. 53: 232-237.

Greenwood DR, Archibald SB, Mathewes RW, Moss PT. 2004. Fossil biotas from the Okanagan Highlands, southern British Columbia and northeastern Washington State: climates and ecosystems across an Eocene landscape. Canadian Journal of Earth Sciences. 42: 167-185.

Hilton EJ, Grande L. 2008. Fossil Mooneyes (Teleostei: Hiodontiformes, Hiodontidae) from the Eocene of western North America, with a reassessment of their taxonomy. Geological Society, London, Special Publications. 295: 221-251.

Hussakof L. 1916. A new Cyprinid fish *Leuciscus rosei*, from the Miocene of British Columbia. American Journal of Science. 42: 18-20.

Katechis CT, Sakaris PC, Irwin ER. 2007. Population dynamics of *Hiodon tergisus* (Mooneye) in the lower Tallapoosa River. Southeastern Naturalist. 6(3): 461-470.

Li GQ, Wilson MVH. 1994. An Eocene species of *Hiodon* from Montana, its phylogenetic relationships, and the evolution of the postcranial skeleton in the Hiodontidae (teleostei). Journal of Vertebrate Paleontology (courtesy of JSTOR). 14(2): 153-157.

McClane AJ, editor. 1978. Field guide to freshwater fishes of North America. New York (NY): Henry Holt and Company, Inc.

Mustoe GE. 2005. Diatomaceous origin of siliceous shale in Eocene lake beds of central British Columbia. Canadian Journal of Earth Sciences. 42: 231-241.

Neumann RM, Allen MS. 2007. Size structure. In: Guy CS, Brown ML, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland. p. 375-416.

Newbrey MG, Wilson MVH, Ashworth A. 2005. Growth characteristics of North American Hiodontidae (Teleostei) from the Late Cretaceous to Recent. Journal of Vertebrate Paleontology. 25: 96A.

Paulson N, Hutch JT. [Internet]. 2002. Mooneye *Hiodon tergisus* LeSueur, 1818 member of the Mooneye Family (Hiodontidae). Minneapolis (MN): University of Minnesota; [updated 2002 Jan 28; cited 2017 May 15]. Available from: http://academics.cehd.umn.edu/hatch/research/fish/fishes/mooneye.html#reproduction

Read PB, Hebda R. 2009. Geological setting and paleontology of the fossiliferous Eocene beds near McAbee, southwestern British Columbia. Unpublished report. 71p. . Available from: http://www2.gov.bc.ca/gov/content/industry/natural-resource-use/land-use/fossil-management/mcabee under the “assessment” hyperlink.

Wallus R, Buchanan JP. 1989. Contributions to the reproductive biology and early life history of Mooneye in the Tennessee and Cumberland River. The American Midland Naturalist (Courtesy of JSTOR). 122(1): 204-207.

Wilson MVH. 1977. Middle Eocene freshwater fishes from British Columbia. Life Science contributions, Royal Ontario Museum. 113: 1-61.

Wilson MVH. 1984. Year classes and sexual dimorphism in the Eocene Catostomid fish *Amyzon aggregatum*. Journal of Vertebrate Paleontology (Courtesy of JSTOR). 3(3): 137-142.

Wilson MVH. 1996. The Eocene fishes of Republic, Washington. Washington Geology. 24(2): 30-31.

Wilson MVH. 2008. McAbee fossil site assessment, revised August 5, 2007 and October 24, 2008; unpublished report. British Columbia Ministry of Agriculture and Lands. 60p. Available from: http://www2.gov.bc.ca/gov/content/industry/natural-resource-use/land-use/fossil-management/mcabee under the "assessment" hyperlink.

Wilson MVH, Williams RRG. 1993. Phylogenetic, biogeographic, and ecological significance of early fossil records of North American freshwater Teleostean fishes. Phylogenetics and Fossils. In: Mayden RL, editor. Systematics, historical ecology, and North American freshwater fishes. Stanford: Stanford University Press. P. 224-244.

APPENDIX A: Abbreviations

TL = Total Length

SL = Standard Length

POUL = Post-Opercle Urostyle Length

BD = Body Depth

CPL = Caudal Peduncle Length

CPD = Caudal Peduncle Depth

HL = Head Length

HD = Head Depth

ED = Eye Diameter

PcL = Pectoral fin Length

PvL = Pelvic fin Length

DBL = Dorsal fin Base Length

DRL = Dorsal fin Ray Length

ABL = Anal fin Base Length

ARL = Anal fin Ray Length

CFL = Caudal fin Length

TRU = Thompson Rivers University

RBCM = Royal British Columbia Museum

FLNRO = Forest, Lands, Natural Resources & Rural Development

APPENDIX B: Fossils Examined

Table B 1: List of fossils measured for this paper. All fossil IDs that begin with RBCM are from the Royal BC Museum. All other fossils are from TRU. Fossils identified as ‘probably’ in the ‘*H. rosei*?’ column are ones in the ‘probable group’ of this paper. Fields with a ‘?’ have uncertain values associated with them. The included value is a best estimate. Note: fossil 1386b refers to one of the 2 fish fossils on this specific matrix and any fossil with an ‘*’ is an averaged specimen.

Fossil ID	*H. rosei*?	Location	Sex	Standard Length (mm)
TRUP2017.004.0021.001	yes	Zugg 1	Female	51.50
L-018 F-1382	yes	Zugg 1	Female	56.00
TRUP2014.001.0098.001	yes	Zugg 1	Female	64.50
L-018 F-1383	yes	Zugg 1	Female	79.00
TRUP2014.001.0097.001	yes	Zugg 1	Female	79.50
TRUP2014.001.0085.001	yes	Zugg 1	Juvenile	46.00
TRUP2014.001.0088.001	yes	Zugg 1	N/A	33.50
L-019 F-062	yes	Old Quarry	Female	67.50
L-019 F-035-052*	yes	Quarry	Female	61.75
TRUP2017.005.0001.001	yes	Quarry	Female	113.00
TRUP2017.005.0002.001	yes	Quarry	Female	130.00
L-019 F-039	yes	Quarry	Juvenile	42.50
L-018 F-1385	yes	Zugg 1?	Male	86.50
L-018 F-1386b	probably	Zugg 1	Male	50.00
RBCM.EH2017.050.0307.003	yes	Zugg 1?	Female	62.00
RBCM.EH2017.050.0307.002	yes	Zugg 1?	Female	74.25
RBCM.EH2009.027.0001A.001A	yes	Zugg 1?	Female	76.00
RBCM.EH2017.050.0309.001	yes	Zugg 1?	Female	113.25
RBCM.EH.2004.001.1927B.001B	yes	Zugg 1?	Male	61.50
RBCM.EH2017.050.0307.001	yes	Zugg 1?	Female	102.00
RBCM.EH2017.050.0306.001	yes	Zugg 1?	Female	110.50
RBCM.EH2017.050.0308.001	yes	Zugg 1?	Female	112.50
RBCM.EH2009.020.0052.001	yes	Perry Ranch	Juvenile	43.25
RBCM.EH1997.005.0037.001	yes	Cache Creek	Juvenile	48.50
RBCM.EH.2004.001.1927A.001A	probably	Zugg 1?	Male?	61.50
RBCM.EH2009.020.0052.002	probably	Perry Ranch	Juvenile	36.50

Table B 2: List of fossils extrapolated for this paper. All fossil IDs that begin with RBCM are from the Royal BC Museum. All other fossils are from TRU. Fossils identified as 'probably' in the '*H. rosei*?' column are ones in the 'probable group' of this paper. Fields with a '?' have uncertain values associated with them. The included value is a best estimate. Note: RBCM.EH2009.020.0036.AB is an averaged part-counterpart hybrid. Fossil 1386a refers to one of the 2 fish fossils on this specific matrix and any fossil with an '*' is an averaged specimen.

Fossil ID	*H. rosei*?	Location	Sex	Standard Length (mm)	±SE	Proxy used for Extrapolation
L-019 F-037	yes	Quarry	Male?	60.34	0.97	POUL
L-019 F-056-061*	yes	Quarry	Female?	140.51	3.99	CPL
L-019 F-059	yes	Quarry	Female?	56.35	0.98	POUL
TRUP2014.001.0066.001	yes	Zugg 1	Male	65.66	0.96	POUL
TRUP2014.001.0069.001	yes	Zugg 1	N/A	69.75	1.42	CPL
TRUP2014.001.0081.001	yes	Zugg 1	Male	54.76	1.74	CPL
TRUP2014.001.0080.001	probably	Zugg 1	Female	57.07	3.15	HL
TRUP2014.001.0086.001	yes	Zugg 1	Male	124.69	3.19	CPL
TRUP2014.001.0092.001	probably	Zugg 1?	Female	113.45	4.54	HD
TRUP2014.001.0093.001	yes	Zugg 1?	Female	82.29	0.96	POUL
L-018 F-1384	yes	Zugg 1?	Male?	87.61	0.97	POUL
L-018 F-1386a	probably	Zugg 1	N/A	51.70	0.99	POUL
L-018 F-1500	yes	Zugg 1	Male	88.06	1.64	CPL
L-018 F-1504	probably	Zugg 1	Female	72.98	0.95	POUL
RBCM.EH1997.005.0018.001	yes	Cache Creek	Female	93.05	3.09	HD
RBCM.EH1997.005.0022.001	yes	Cache Creek	Male?	63.92	1.50	CPL
RBCM.EH1997.005.0023.001	yes	Cache Creek	Female	138.96	8.37	DBL
RBCM.EH1997.005.0025.001	yes	Cache Creek	Female	91.39	1.75	CPL
RBCM.EH1997.005.0026.001	probably	Cache Creek	Male	98.88	2.02	CPL
RBCM.EH1997.005.0027.001	yes	Cache Creek	Male	103.88	2.22	CPL
RBCM.EH1997.005.0032.001	yes	Cache Creek	Female	90.56	1.72	CPL
RBCM.EH1997.005.0034.001	yes	Cache Creek	Female	126.13	6.90	DBL
RBCM.EH1997.005.0038.001	yes	Cache Creek	Female	66.42	1.46	CPL
RBCM.EH1997.005.0041.001	probably	Cache Creek	Male	71.41	1.42	CPL
RBCM.EH1997.005.0059.001	yes	Cache Creek	Male	134.90	5.34	ARL
RBCM.EH1997.005.0064.001	yes	Cache Creek	N/A	84.45	1.83	CFL
RBCM.EH1997.005.0078.001	probably	Cache Creek	Male	108.69	2.92	CPD
RBCM.EH1997.005.0079.001	yes	Cache Creek	Male	112.18	3.71	ARL
RBCM.EH.2004.001.1903.001	yes	Zugg 1?	N/A	70.32	0.95	POUL
RBCM.EH.2004.001.1916.001	yes	Zugg 1?	Male	105.08	3.25	ARL
RBCM.EH.2004.001.1917.001	probably	Zugg 1?	female	56.80	2.58	ARL
RBCM.EH.2004.001.1918.001	probably	Zugg 1?	Male	74.74	1.42	CPL
RBCM.EH2009.020.0035A.001A	yes	Perry Ranch	Female	100.24	1.02	POUL

RBCM.EH2009.020.0036AB.001AB*	yes	Perry Ranch	Female	57.02	0.97	POUL
RBCM.EH2009.020.0044.001	yes	Quarry	Male	97.92	4.00	DBL
RBCM.EH2009.020.0052.003	yes	Perry Ranch	Juvenile	29.09	1.12	POUL
RBCM.EH2009.027.0056.001	yes	Zugg 1?	Male	102.56	3.06	DRL
RBCM.EH2009.027.0057.001	probably	Zugg 1?	Juvenile	35.07	1.08	POUL
RBCM.EH2017.050.0003.001	yes	Zugg 1?	Female	75.29	1.87	CPD

APPENDIX C: Regression Graphs

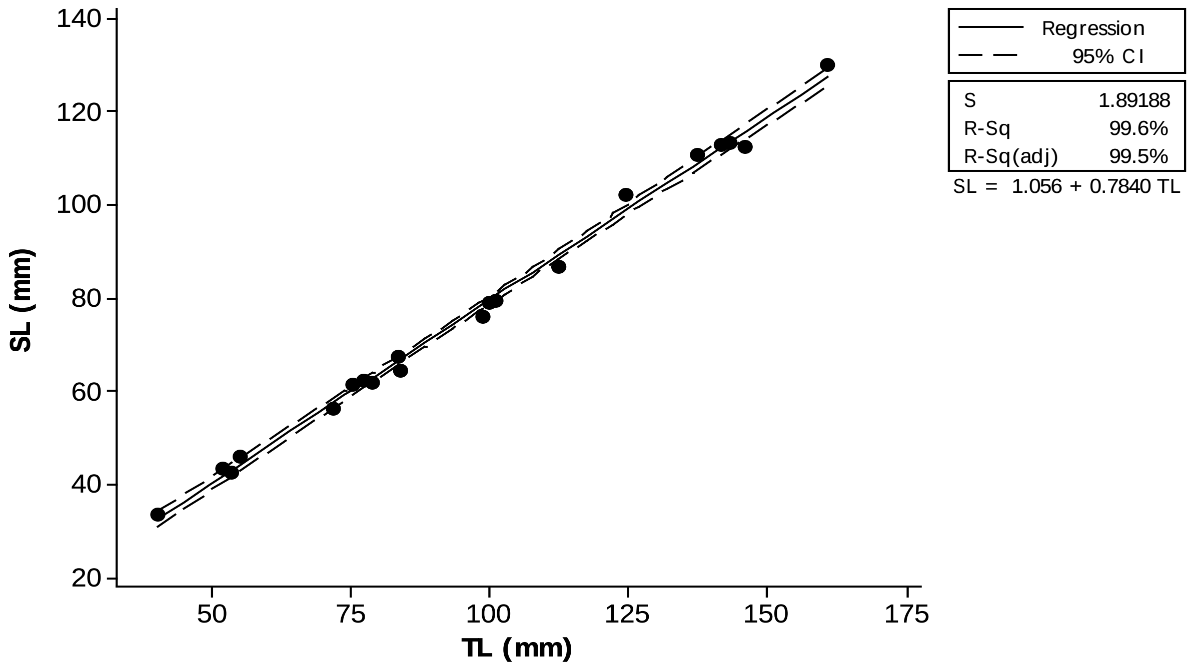

Figure C 1: Graph of Standard Length (SL) vs. Total Length (TL) with 95% confidence intervals and regression output.

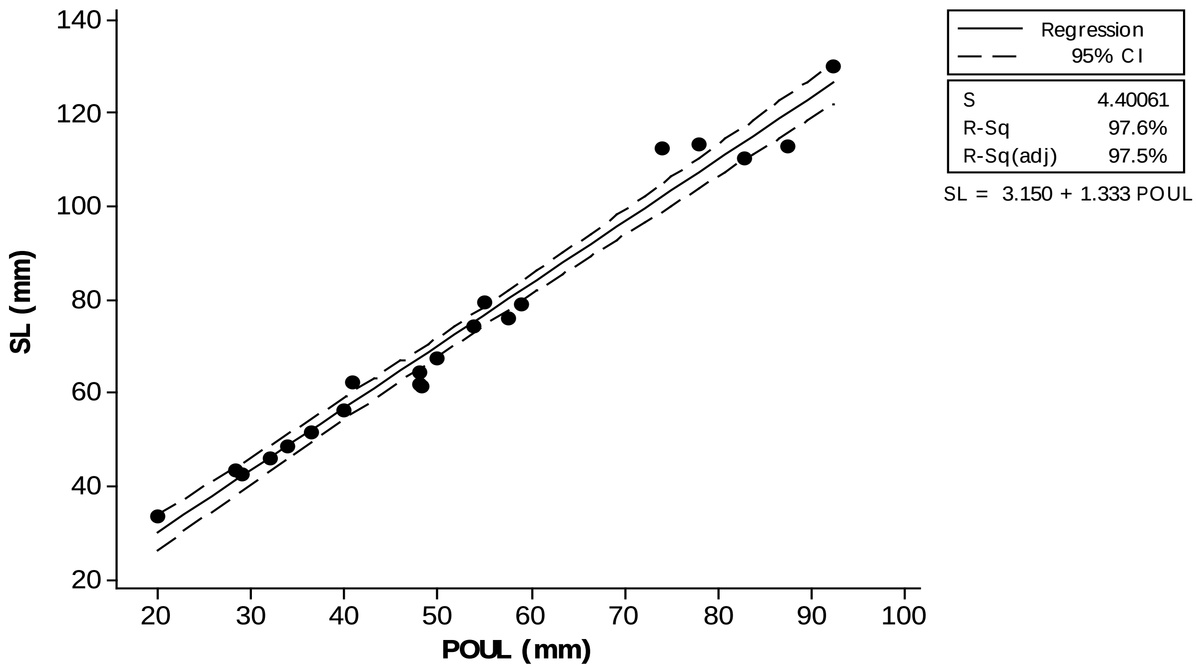

Figure C 2: Graph of Standard Length (SL) vs. Post-Opercle Urostyle Length (POUL) with 95% confidence intervals and regression output.

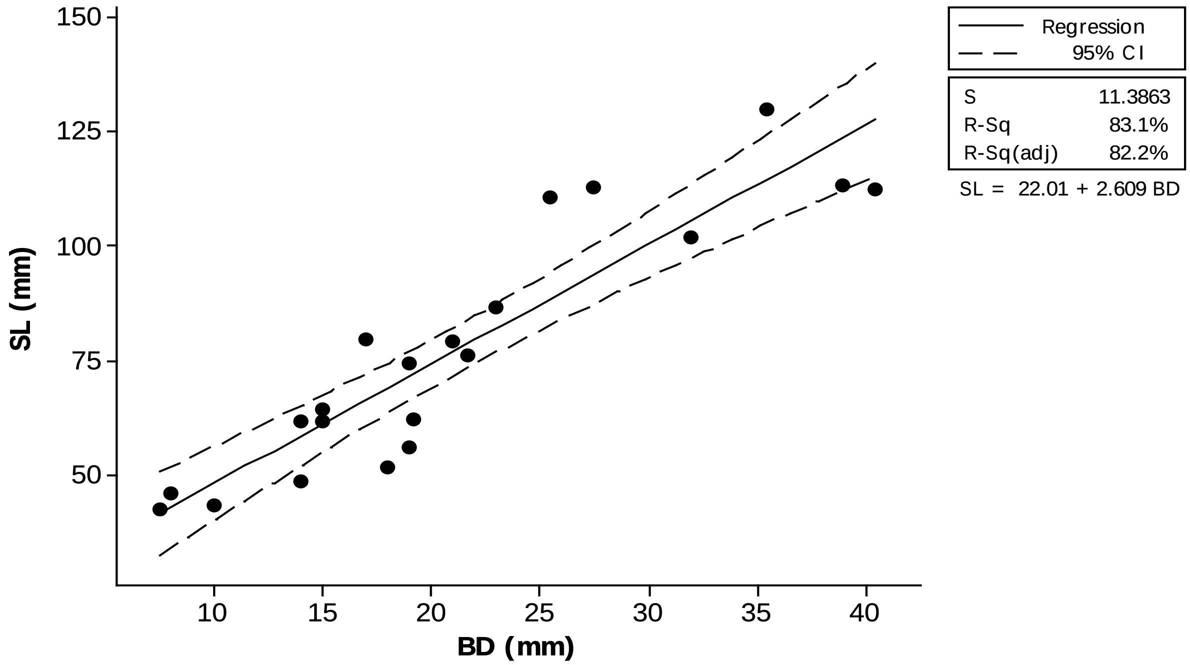

Figure C 3: Graph of Standard Length (SL) vs. Body Depth (BD) with 95% confidence intervals and regression output.

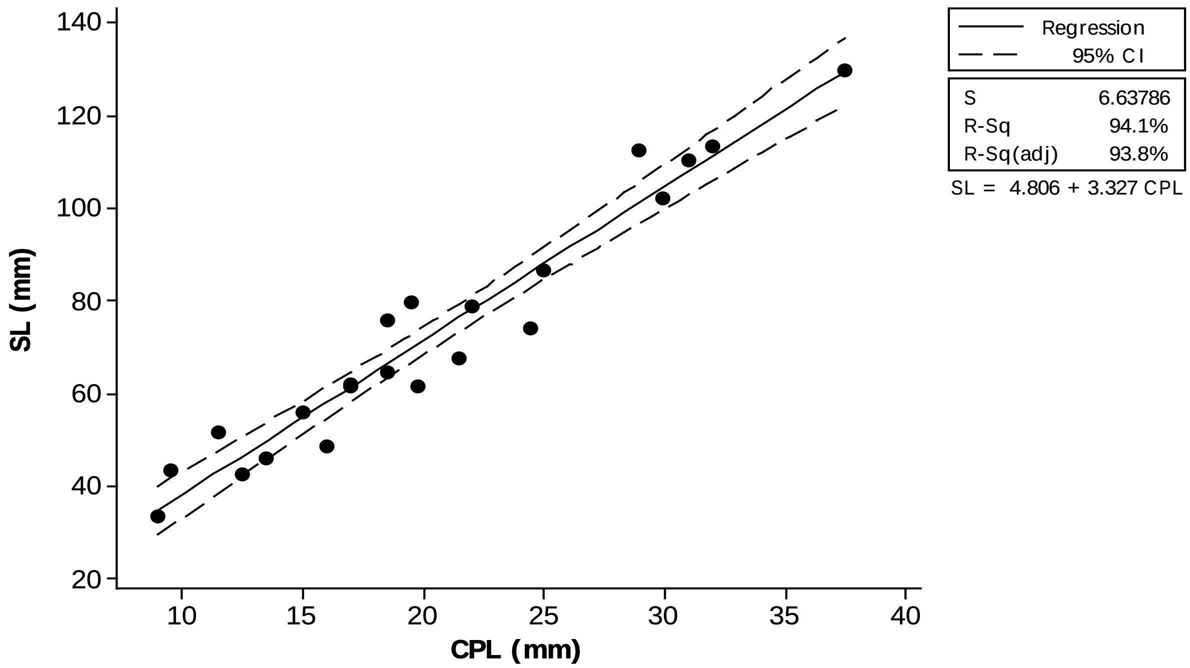

Figure C 4: Graph of Standard Length (SL) vs. Caudal Peduncle Length (CPL) with 95% confidence intervals and regression output.

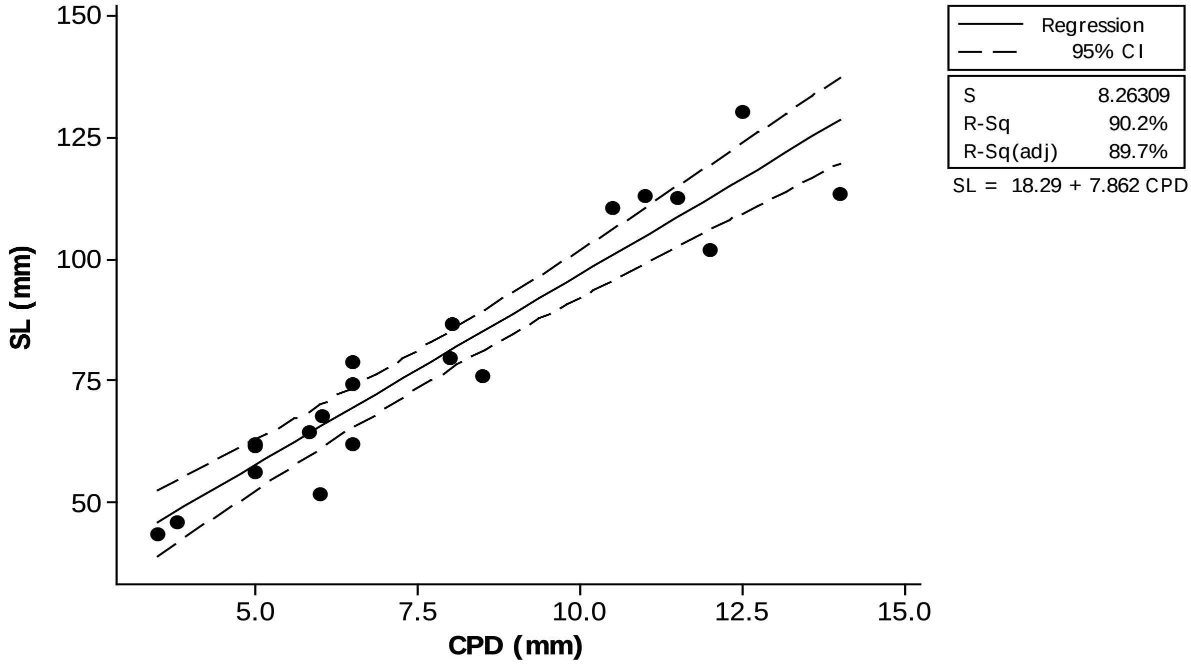

Figure C 5: Graph of Standard Length (SL) vs. Caudal Peduncle Depth (CPD) with 95% confidence intervals and regression output.

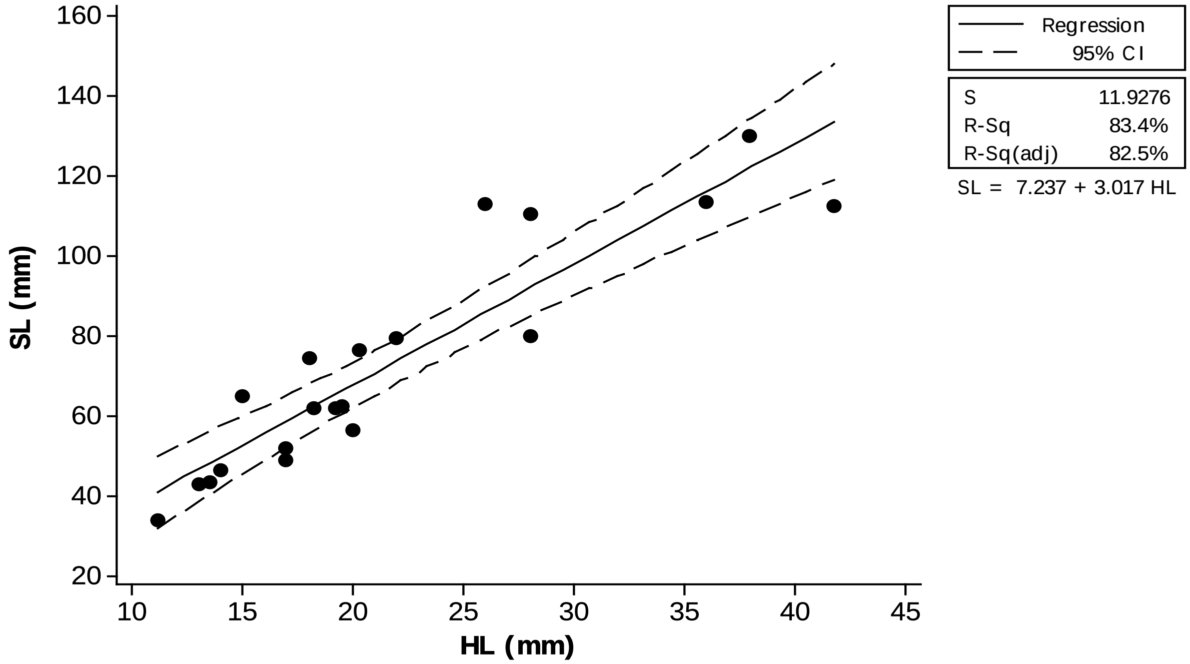

Figure C 6: Graph of Standard Length (SL) vs. Head Length (HL) with 95% confidence intervals and regression output.

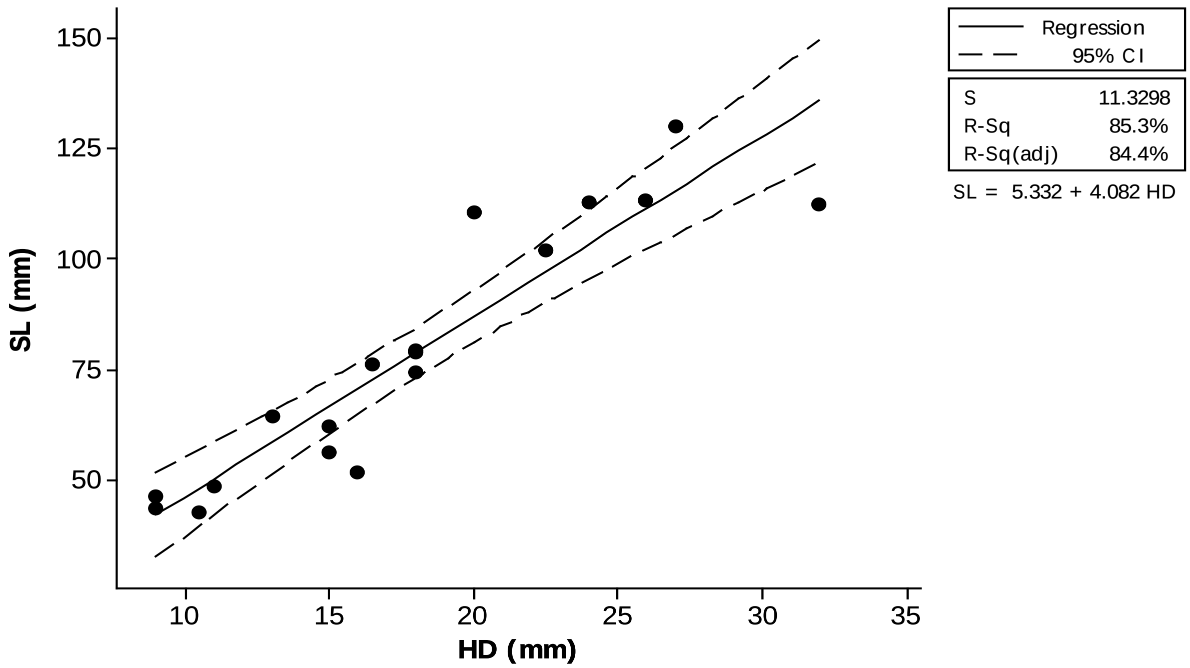

Figure C 7: Graph of Standard Length (SL) vs. Head Depth (HD) with 95% confidence intervals and regression output.

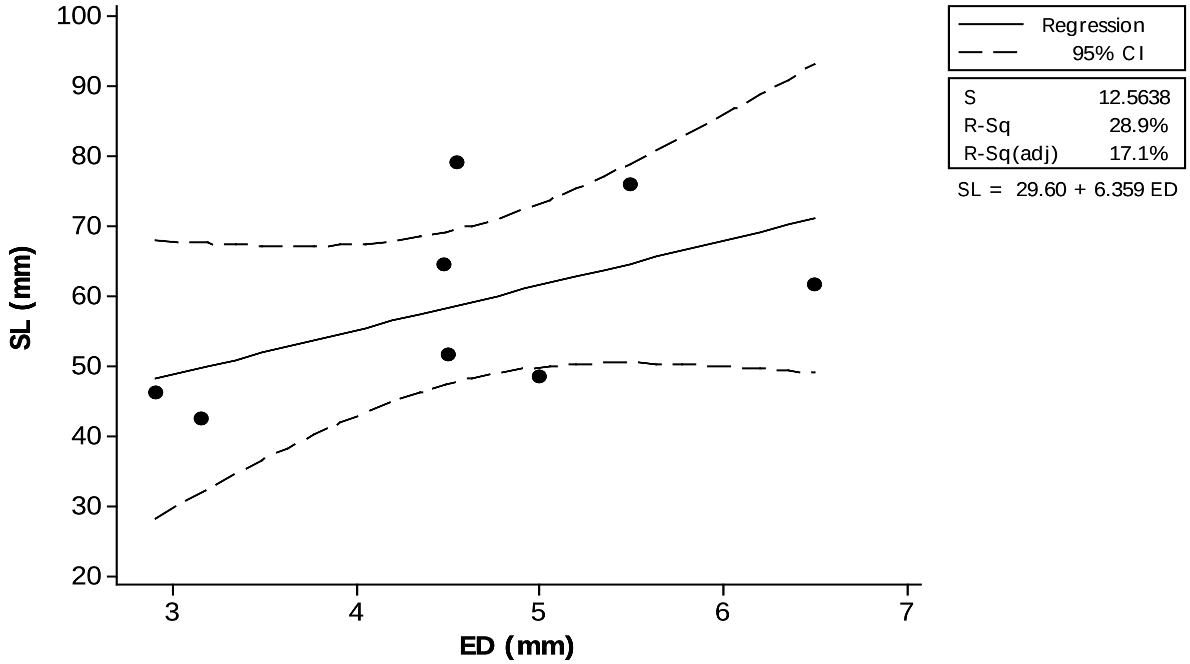

Figure C 8: Graph of Standard Length (SL) vs. Eye Diameter with 95% confidence intervals and regression output.

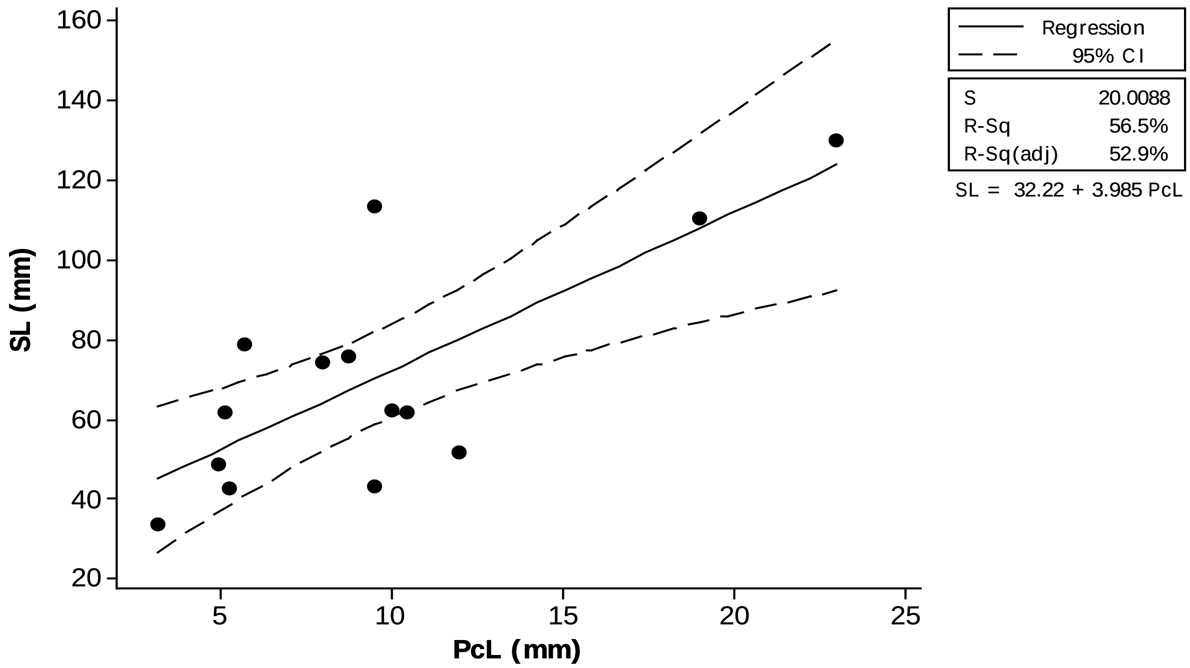

Figure C 9: Graph of Standard Length (SL) vs. Pectoral fin Length (PcL) with 95% confidence intervals and regression output.

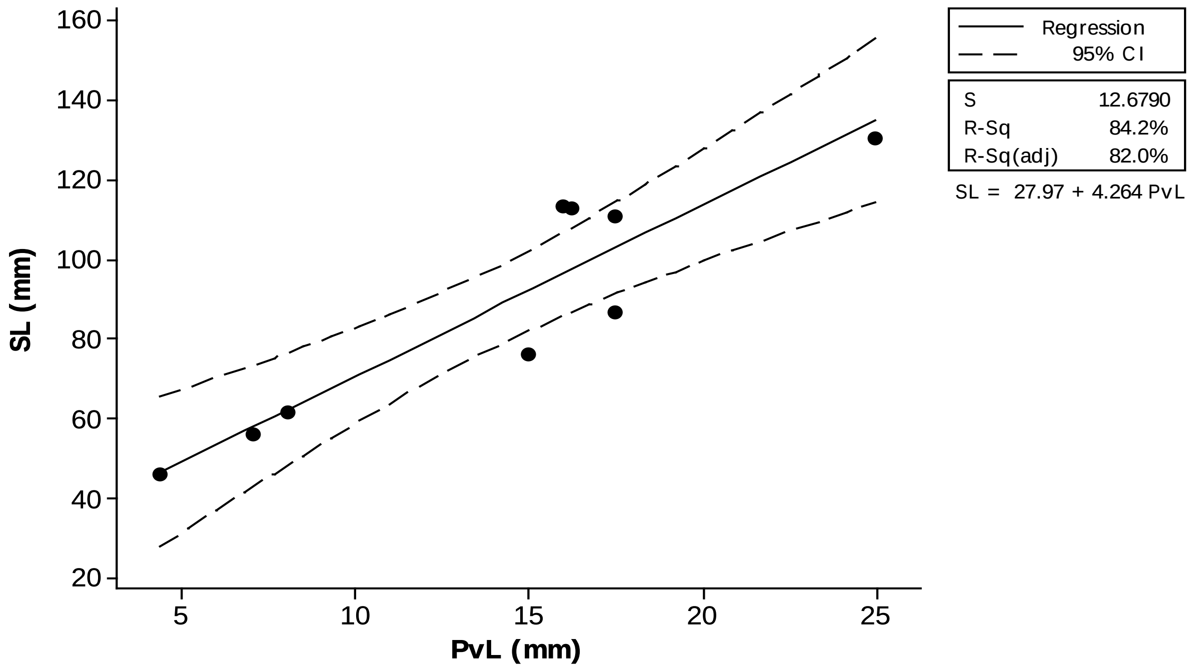

Figure C 10: Graph of Standard Length (SL) vs. Pelvic fin Length (PvL) with 95% confidence intervals and regression output.

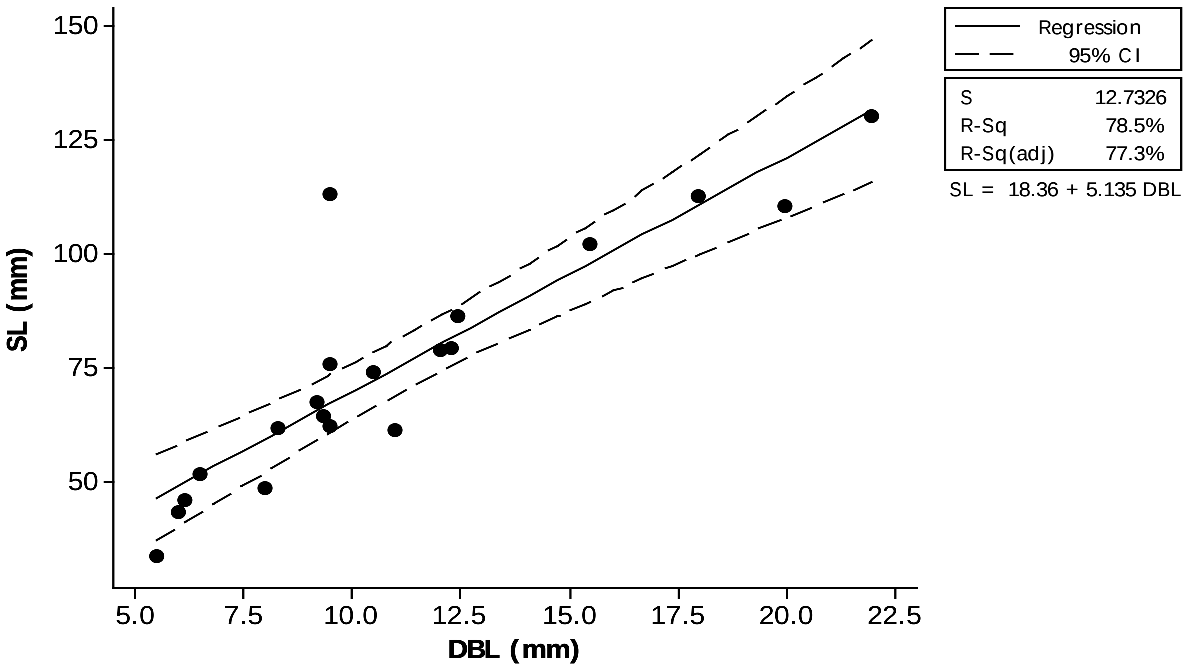

Figure C 11: Graph of Standard Length (SL) vs. Dorsal fin Base Length (DBL) with 95% confidence intervals and regression output.

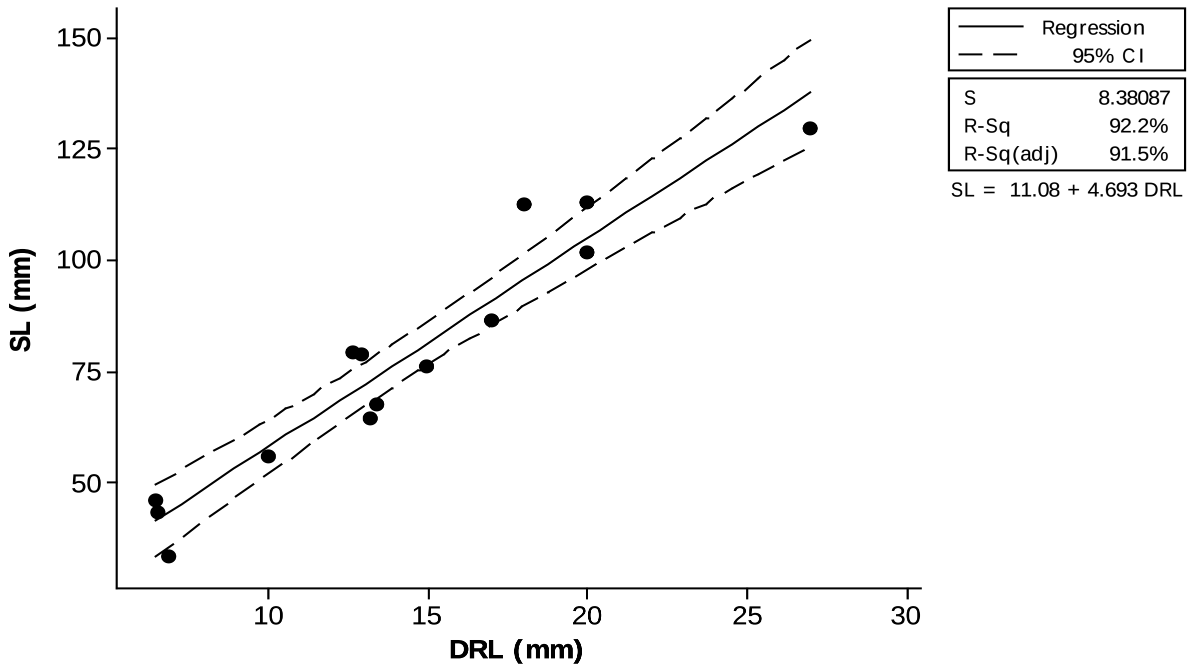

Figure C 12: Graph of Standard Length (SL) vs. Dorsal fin Ray Length (DRL) with 95% confidence intervals and regression output.

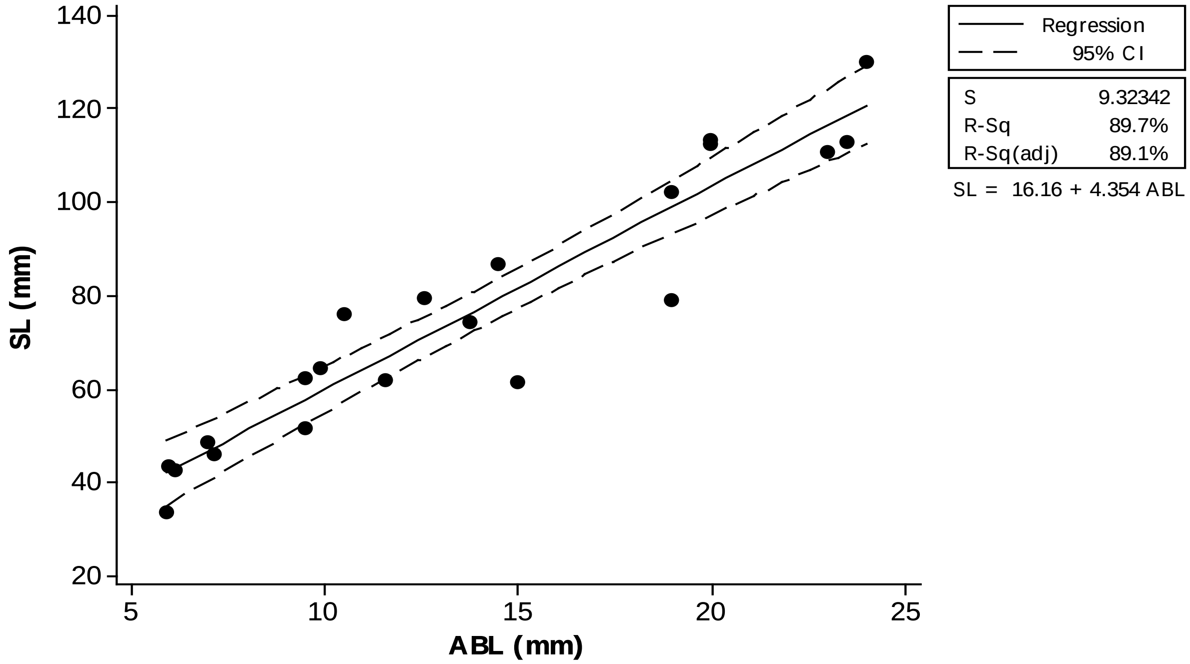

Figure C 13: Graph of Standard Length (SL) vs. Anal fin Base Length (ABL) with 95% confidence intervals and regression output.

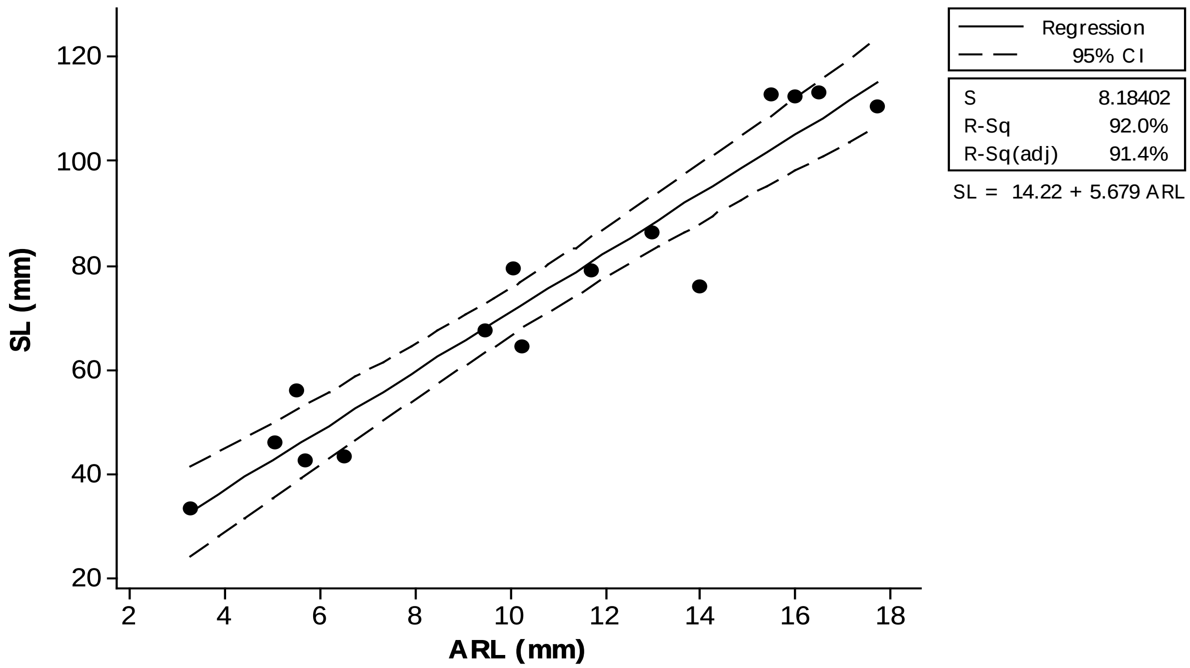

Figure C 14: Graph of Standard Length (SL) vs. Anal fin Ray Length (ARL) with 95% confidence intervals and regression output.

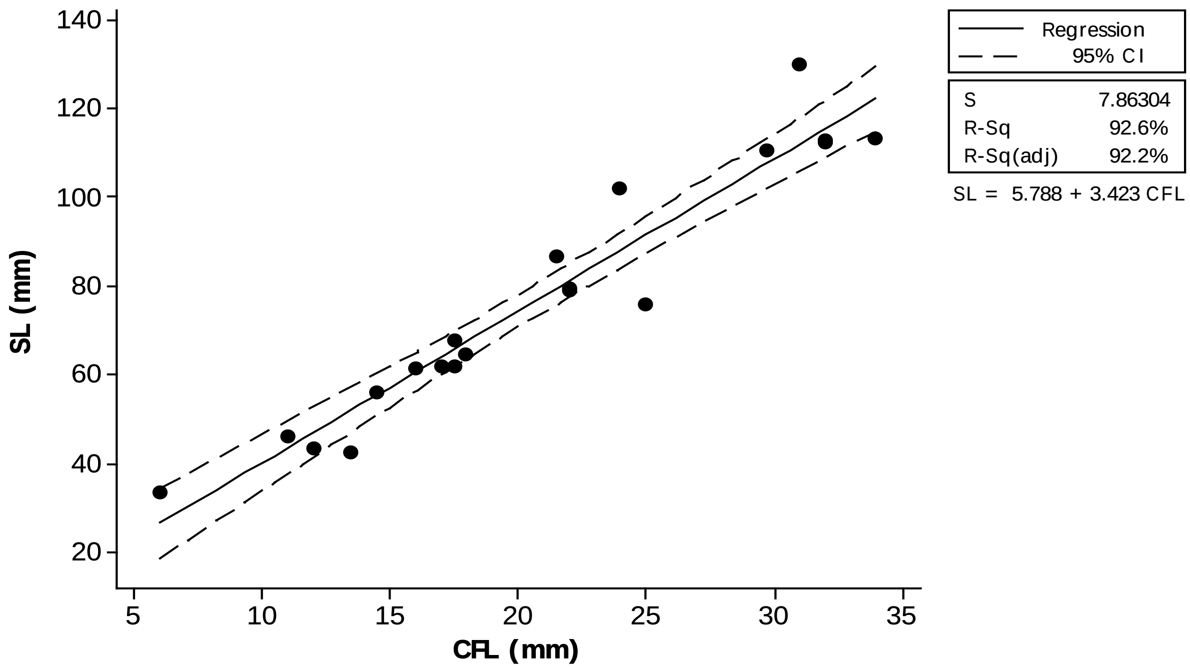

Figure C 15: Graph of Standard Length (SL) vs. Caudal Fin Length (CFL) with 95% confidence intervals and regression output.