

## **Bite and Suction Forces of the Adductor Muscle in Four Sculpin Species**

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## ABSTRACT

To prevent constant competition across species, different species may develop different morphologies to increase their ability to attain a certain food source within a niche. By dissecting the adductor muscle and taking measurements in four sculpin species we can begin to assess how their feeding styles and niches influence their jaw morphology. Many parts of the jaw, such as the mandible, grow with the individual size of the organism, contributing to an ability to consume bigger prey. The advantages of more bite force for crushing harder prey, such as in *Enophrys bison*, are compared to the advantages of higher velocity and fluid flow in the buccal cavity, such as in the suction using *Myoxocephalus polyacanthocephalus*. We also found that bigger adductor muscles does not actually lead to larger gape angles, but in fact decreases the maximum gape angles.

## INTRODUCTION

The world's oceans are full of an incredible diversity of creatures that survive in a wide variety of habitats. All of these different niches (e.g. snail-eating or high-speed swimming) demand specific, specialized mechanical performance from each individual to be successful. These specializations are often evident in musculoskeletal anatomy and morphology (Alfaro et al., 2014). Organisms can adapt to their environment by modifying many aspects of their life history and body plan. Feeding specializations are uniquely important for animal survival and food items come in many shapes and sizes. Food and/or prey are highly variable; anything from small phytoplankton, sessile algae, and hard-shelled snails to other fish, and the predator's feeding performance must match these demands. If the prey is slow, then the predator can also be slow. But if the prey is

fast, the predator also has to be fast, or at least able to strike quickly (Westneat, 1991). With smaller food an organism can filter or ram feed (Bloodworth et al., 2005). For bigger food organisms many have to use suction feeding or have a strong bite (Gidmark et al., 2013).

The concept of form correlating with function arose from observations based on these different morphologies. Non-useful or unnecessary morphologies are usually weeded out by natural selection (Westneat, 2014), and therefore only the “useful” morphologies – ones that increase fitness – are left. Therefore we expect that all morphologies in a species have a purpose. For example, a fish that feeds on plankton would have no use for sharp teeth. An organism’s jaw morphology can tell you a lot about their habitat and life history.

For my research, I focused on the story that a sculpin’s jaw muscles tell about their eating habits. The family *Cottidae* may not have the biggest number of species but they are great examples of a variety of morphologies based on different habitats and feeding styles (Boschung, 1995). One can make inferences about sculpin specimens based on knowing a few key things about their habitat. For example: tidepool sculpins, *Oligocottus maculosus*, are commonly found in tide pools, therefore it can be inferred that they do not grow very large, or else they would outgrow their habitat. Following this thought process; I evaluated the jaw muscles in four sculpin species that are local to the San Juan Archipelago. This research will be used to answer questions of whether or not a feeding style and/or prey type is correlated with specific jaw muscle lever ratios, head shapes, or muscle shapes in sculpins. Specifically, we hypothesize that species which

prey on harder prey items will maintain larger adductor muscles, larger mechanical advantages, and longer jaws.

## Methods

**Specimens:** Eight great sculpin, *Myoxocephalus polyacanthocephalus*, two spiny headed sculpin, *Dasycottus setiger*, two buffalo sculpin, *Enophrys bison*, and two scalyhead sculpin, *Artedious harringtoni*. All the specimens studied here varied in size, ranging between 10 and 40 cm, with *M. polyacanthocephalus* occupying the higher end of the scale and *A. harringtoni* occupying the lower end. Specimens were collected proximal to the San Juan Islands (Friday Harbor Area).



Figure 1. Skinned *Myoxocephalus polyacanthocephalus* showing exposed muscle and bone anatomy.

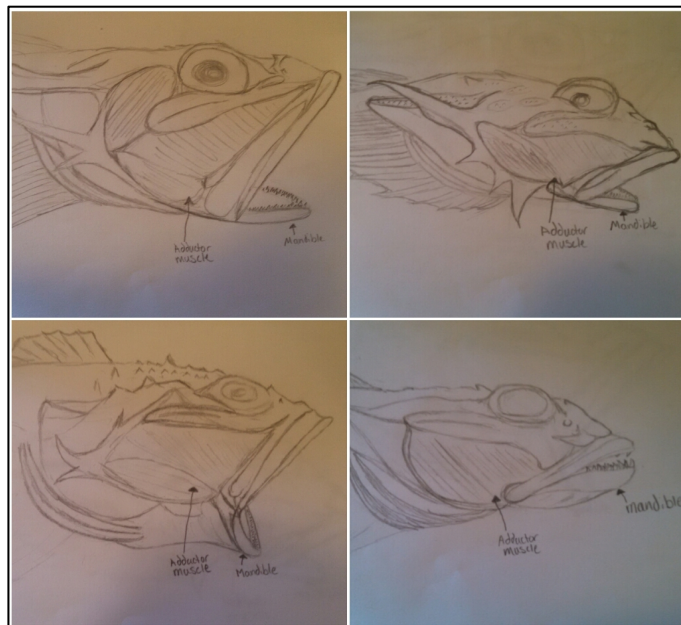


Figure 2. Drawings of dissections, showing the musculoskeletal anatomy. Clockwise from top right, buffalo, scalyhead, spiny headed, great.

**Dissection:** The head of the sculpin was skinned and the right jaw muscle was dissected (Figure 1). Measurements of the length of the head and body, width of the head, maximum gape, angle of maximum gape, maximum horizontal gape were taken and the

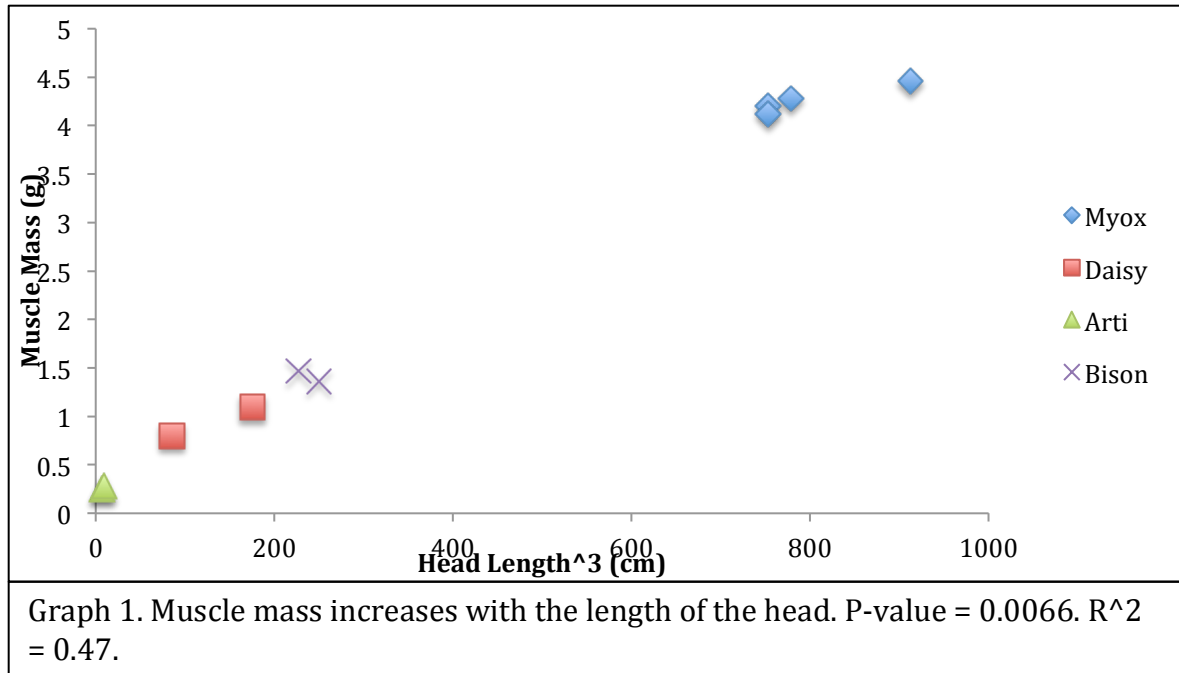
mass, length and width of the mandibular adductor muscle was taken. I also measured adductor muscle pennation angle and the distance from the jaw joint to the point of muscle insertion. On the jawbone, measurements of the length from the jaw joint to posterior-most tooth and anterior-most tooth (mandible length) were taken. Sketches were made of each species jaw bones and muscles after dissection (Figure 2). Photos were also taken to correct for

any scaling error. Measurements were taken manually with rulers, calipers, scale, and protractor (Figure 3). Fish were defrosted overnight in a tide table in Lab 8. All dissections and measurements were done in Lab 8 at Friday Harbor Laboratories.

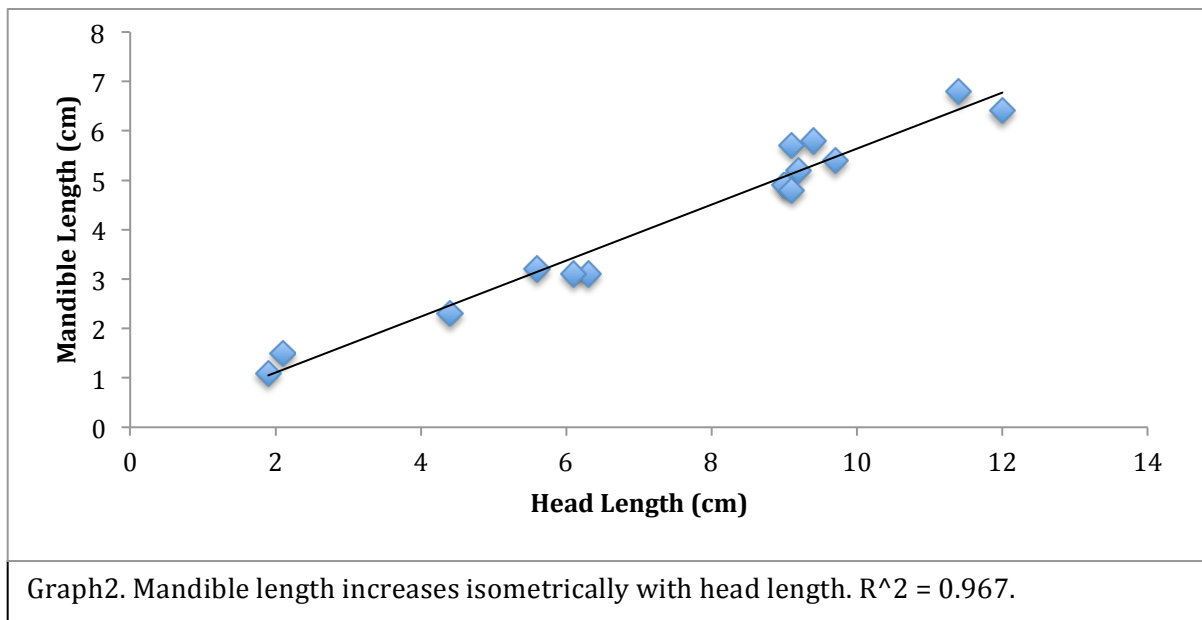


Figure 3. Example of measurements taken on every specimen, shown above is *Myoxocephalus polyacanthocephalus*.

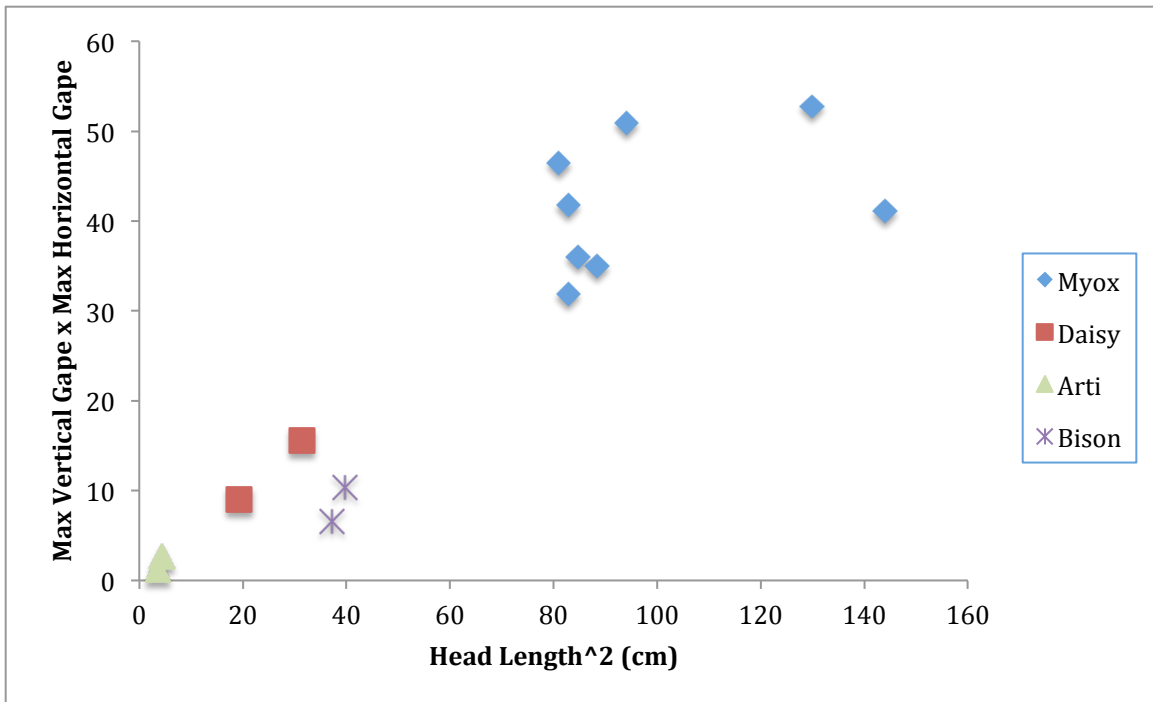
## RESULTS



A number of the measured components change with the size of the organism. As the head length increases, there was a strong correlation with increased muscle mass (Graph 1) p-value=0.0066. Mandible length increases isometrically with increasing head length (Graph 2) r<sup>2</sup>=0.967. The volume of the buccal cavity was calculated by the

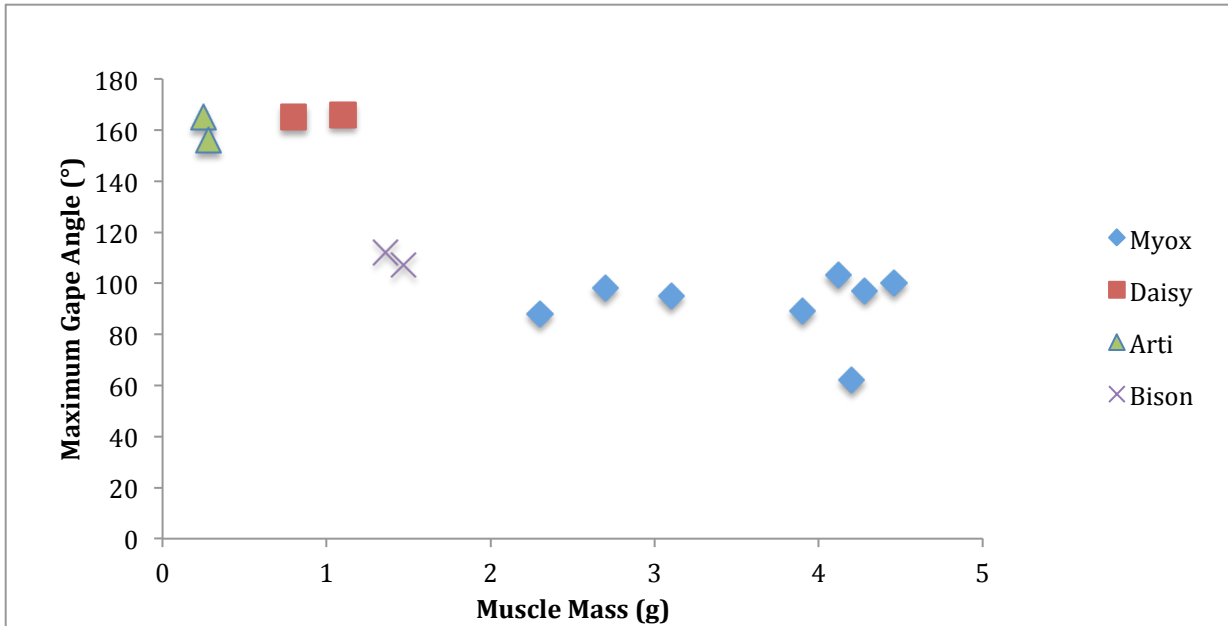


relationship between the head size squared and the maximum horizontal gape times maximum vertical gape (Graph 3)  $p\text{-value}=8.205 \times 10^{-6}$  or 0. Buccal cavity increased with the size of the organism in a linear manner. The outlier is *E. bison* which even though it had a bigger head length, it has a smaller buccal cavity than *D. setiger*.



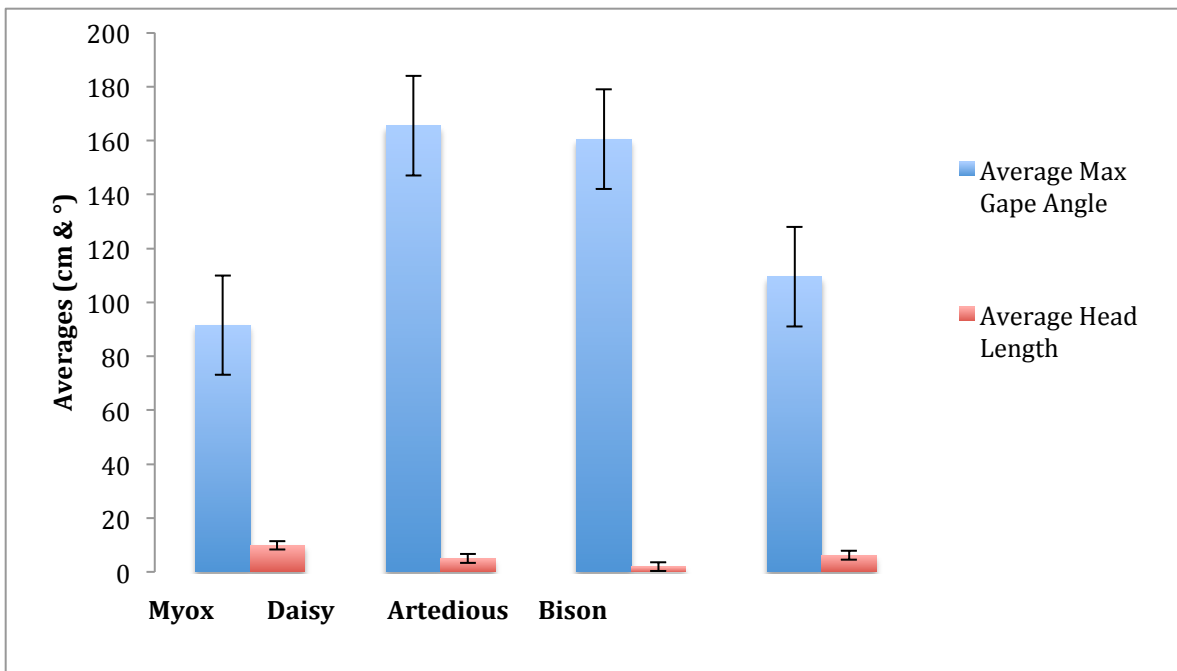
Graph 3. Buccal cavity volume. Calculated by maximum horizontal gape times maximum vertical gape then compared against the head length squared.  $P\text{-value} = 0$ .  $R^2 = 0.82$ .

Some components changed negatively with size. Adductor muscles with more mass have smaller maximum gape angles (Graph 4)  $p\text{-value}=0.00036$ . More massive muscles correlate with smaller maximum gape angles. The relationship of average head length to average maximum gape angle between species shows that bigger heads yield smaller gapes (Graph 5).



Graph 4. Negative correlation across species of adductor mass and maximum gape angle. P-value= 0.0036. R<sup>2</sup>= 0.67.

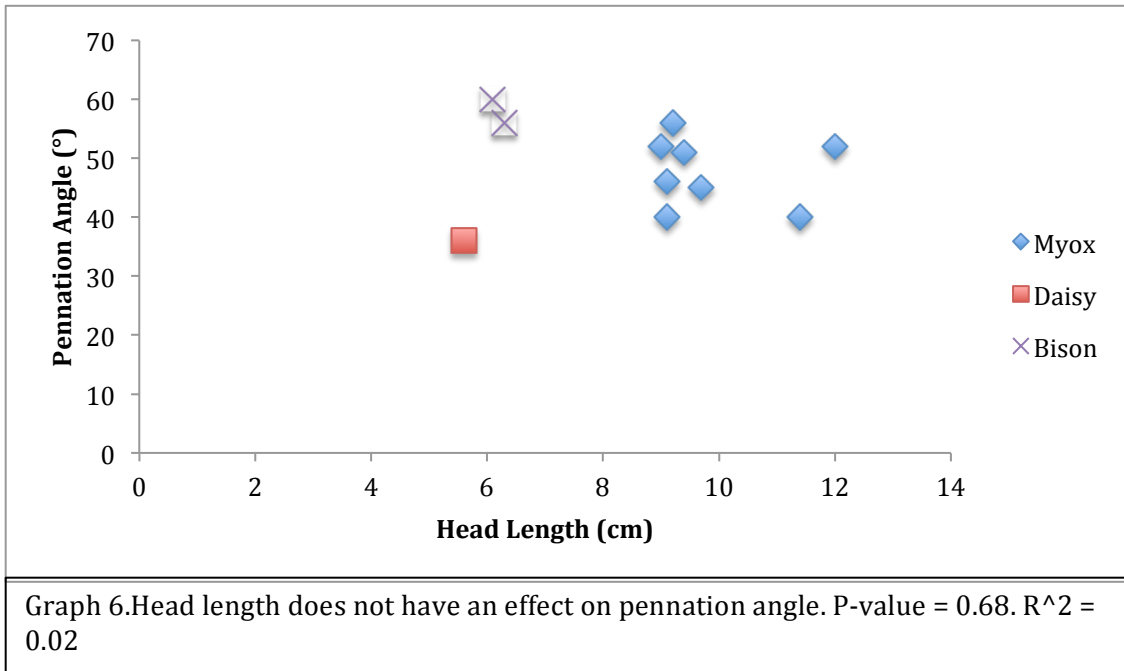
Size doesn't change everything though. Increased in head length did not correlate with changes in pennation angle of any species (Graph 6) p-value=0.68. Head length did not affect the leverage systems between the muscle insertion point and the posterior-most tooth or anterior-most tooth with p-values of 0.94 and 0.35 respectively (Graph 7 & 8



Graph 5. Averages of maximum gape angle and head length.

respectively).

ANOVA and  $R^2$  was used for all statistical tests.



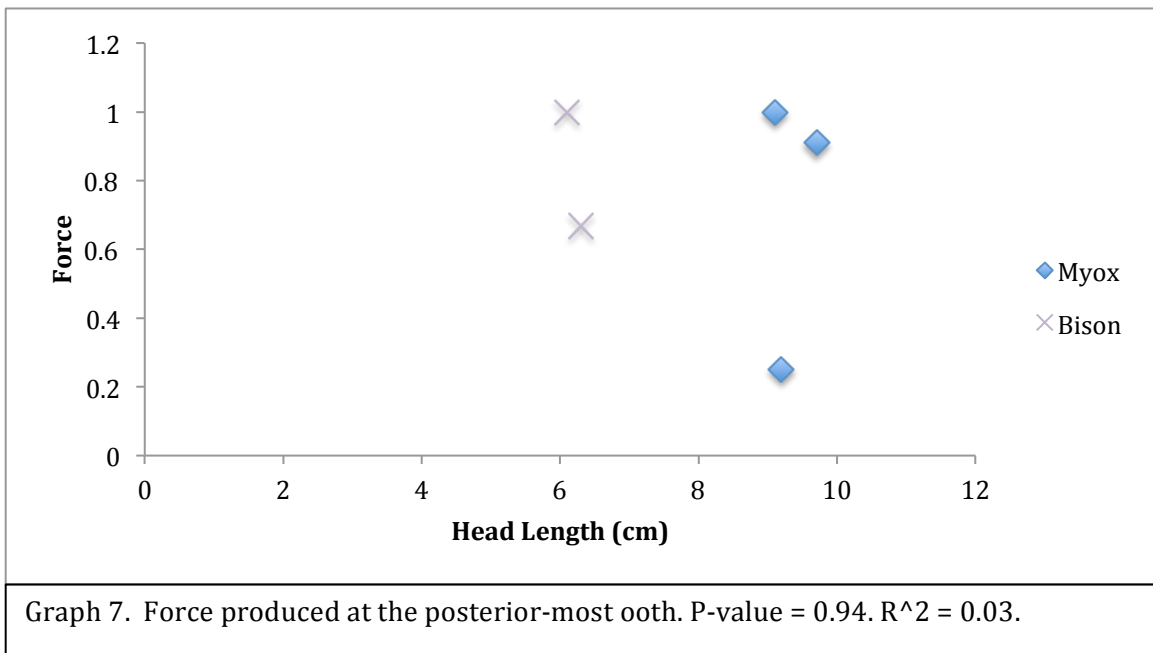
## DISCUSSION and CONCLUSIONS

Size does seem to have an effect on the jaw mechanisms of these four sculpin species.

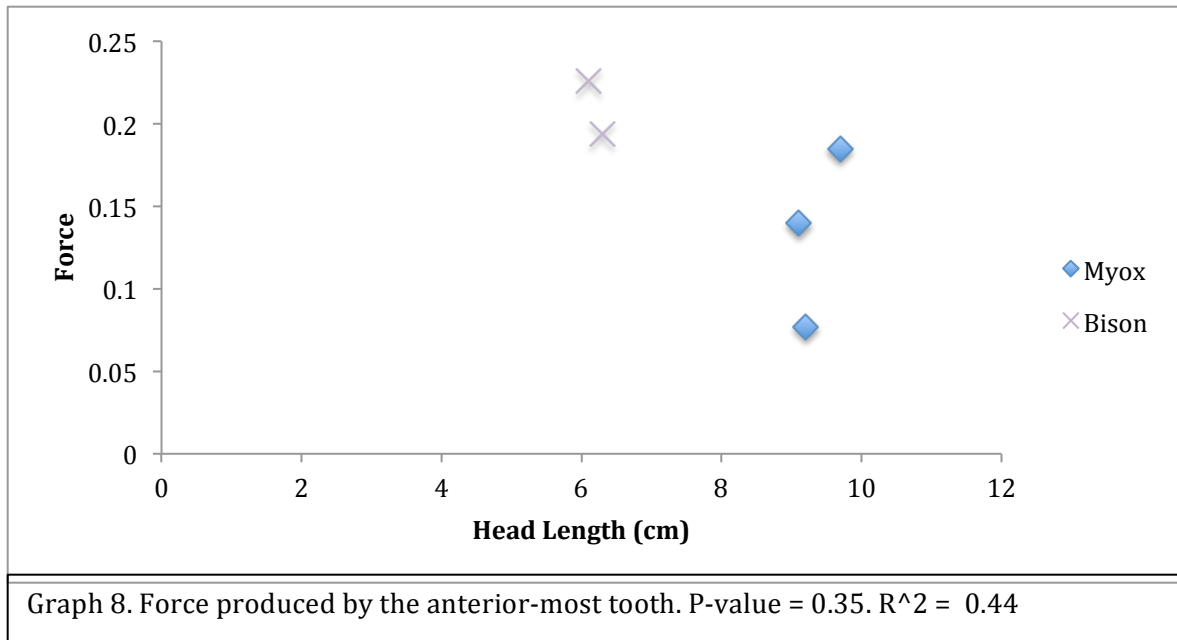
The bigger the adductor muscle, the smaller the gape angle a jaw is able to achieve. There is only so much space available in a jaw. So, the more mass the adductor muscle has, the less space all that muscle can contract into when opening the jaw. Also, the more mass the muscle has, the more difficult it becomes to stretch the muscle, thus reducing dexterity. Therefore, having a larger bite force correlates to not being able to stretch your jaw as far. When a head gets bigger or longer, the muscles also get bigger. One reason is that adductor muscles increase with the head length because as the head grows, so does the mandible. If the muscles don't grow with the bone that they maneuver, they won't be

able to do their job and help the sculpin eat. If the sculpin can't eat, then the sculpin increases their chance of dying without reproducing.

Sculpins don't rely on just bite though; the use of suction to feed is common in many sculpin species. Buccal cavity is one way to measure a specimen's potential to suction feed. Higher fluid flow potentials increase the chances they prey will not escape, by swimming against the incurrent flow into the organism's mouth. Higher fluid flow and the space available in your buccal cavity can also correlate to an increase in the size of the prey you are able to bring into your mouth. The volume of buccal cavity increases greatly with size, the bigger you are, the higher volume of water you can pull through your mouth. The outlier in this example though is the *E. bison*, for their size, they have a smaller buccal cavity and a medium sized maximum gape angle. This is because *E. bison* strike quickly to catch their prey (Boschung, 1995). What they lack in volume, they make



up for in jaw force. In Graph 7 you notice the *M. polyacanthocephalus* and *E. bison* have fairly similar force capabilities in the back of their mandible. In Graph 8 though, *E. bison* has more force capabilities in the front of their mandible. Meaning they snap down harder with the front of their jaw, they don't rely on suction like *M. polyacanthocephalus*. This could be an indication of a prey niche that *E. bison* occupies where the force applied by



the front of their jaw is more beneficial than the amount of flow through their buccal cavity. To really support this finding more *E. bison* specimens would need to be dissected and analyzed, and more specimens of other species would help to further support the finding.

The pennation angle seems to have no relation to head size because this angle is not dependent on the size of the organism. The angle is similar across all species meaning that the sculpin species are feeding on prey with similar proportions to their size. The implication of this finding is that there is an optimal fiber angle that works across species and sizes. This could be a morphological system that was figured out early on in the species development and doesn't need to keep changing to adapt to goals.

All of these findings together help us start to piece together a picture of the different type of feeding niches that have correlated with different jaw morphologies. When you want to study a fishes diet, a good starting place would be analyzing their jaw morphology to help understand the type of prey they are capable of consuming. Bigger fish may be able to consume bigger prey, but its not all dependent on how wide they can open their jaws. These results are a stepping-stone to understanding more about how form correlates with function.

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