

Characteristics of the Habitat of the Northern Clingfish

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Abstract

The Northern Clingfish, *Gobiesox maeandricus*, has many well-studied morphological adaptations to help it cope with the harsh environment that it lives in: the intertidal zone. Lab studies have shown that this fish can adhere to smooth and rough surfaces as well as slippery and non-slippery surfaces. Now, the aim of the current study is to define the habitat of the Northern Clingfish and compare habitat parameters with these previous lab studies. We show that the clingfish is presented with a challenging, slippery habitat. We find that nearly 90% of the rocks present in the habitat of the clingfish are covered in biofilm and are consequently slippery. Clingfish cope with their habitat by seeking shelter under rocks within a specific size range (15-45 cm in width) and they are most commonly found under rocks that have gravel as the main substrate. Rocks that clingfish were found under possessed a wide range of aufwuchs (periphyton) cover. Rock size did not correlate to fish length, but a bimodal distribution was found in the transect area.

Introduction

The intertidal zone is a harsh environment that exists as both an underwater and an above ground sanctuary and offers a heterogeneous array of macro scale niches for invertebrates and fishes to occupy. The intertidal zone is further complicated by the furious energy that crashing waves can provide and the daily tidal pattern that is coupled with long periods of emersion and exposure to the terrestrial landscape (Lewis, 1964). Not only do intertidal animals require equipment to handle wave energy and desiccation, but they also need to utilize mechanisms to avoid predation from both aquatic and terrestrial predators. Habitat selection and behavior—rather than simply morphology alone—are important factors to consider when examining an animal's adaptation to this intense environment.

For example, in addition to the evolved morphological adaptations to extreme conditions, some intertidal hermit crabs (*Clibanarius cubensis* and *Calcinus laevimanus*) are able to prevent desiccation by staying near the water line as the tide recedes or they can use their shell as a temporary shelter during times of high stress (Reese, E.S., 1969). Another behavioral modification to the burden of low tide is seen in the bivalve *Donax incarnatus*. This wedge clam is able to avoid predation during times of emersion by completing a series of burrowing movements that results in constant proximity to the water line (Ansell and Trevallion, 1969).

Fish in the family Gobiosocidae have evolved modified pelvic fins to create a suction disc that acts as a morphological aid in resisting dislodgement among crashing waves in the intertidal zone. Wainwright et al. (2013) found that clingfish are able to withstand pull forces that are equal to 80-230 times the body weight of the fish itself and they are actually able to cling to rough surfaces better than smoother surfaces. Furthermore, Ditsche (2014) looked at how well equipped clingfish were for the combination of periphyton and surface roughness and found that fish tenacity was impressively high on both unfouled rough surfaces and fouled rough surfaces, and that fouling did not affect tenacity on smooth rocks. Though these morphological adaptations to the stressful environment are generally well documented, interactions with the habitat are less known. One of the few habitat studies shows that a Brazilian clingfish, *Gobiesox barbatulus*, has preferences for the parameters of the rocks under which they are found: little to no periphyton cover and a range of rock sizes between 5-30 cm.

The Northern Clingfish (*Gobiesox maeandricus*) is offered an assortment of rocks to select as protection during emersion and protection from both terrestrial and aquatic

predators. It is evident just with the human eye that some rocks have a high concentration of algae, invertebrates and biofilm on them, while others are bare. The undersides of rocks also contain a high degree of roughness variability that is apparent just by touching them. Behavioral modifications to the stressful intertidal environment have been documented in other clingfish species (*Lepadogaster lepadogaster purpurea* and *Lepadogaster candollei*) that spend little time moving between shelters, which is a behavior that has been adopted to alleviate the strain of the turbulent environment by expending less energy (Goncalves, et al, 1998).

In the present study, we aim to describe the habitat use of *G. maeandricus* in relation to stress management strategies by answering these questions: 1) What is the range of rock sizes that clingfish prefer? 2) What range of periphyton cover (aufwuchs) and biofilm do we find clingfish in? 3) What substrates are found under stones where clingfish are found? 4) Are different sized clingfish using similar resources?

Methods

Study Site and Transect Preparation

This study took place at Ruben Tarte County Park on the Northeast side of San Juan Island, WA, USA between June-August 2014. While other study sites were considered, this site was chosen because of its accessibility, it experiences longer period of exposure during low tide, and during preliminary site selection this area had the highest occurrence of clingfish when compared to other sites that were explored. The study site has relatively calm waters due to its location in a partially protected cove.

Clingfish were observed during low tide when the rocks under which they are found were exposed. Rocks were turned systematically within a transect with meter squares lettered -C-S going from the shoreline to the beach and numbered 1-12 going perpendicular to the former line (Figure 1). The letter 'O' was skipped because of its resemblance to the number zero. These two lines created a total of 216-1x1 m transect squares. After a clingfish was found, it was photographed beside a ruler and its body length was later calculated using ImageJ (Rasband, 1997). The rock under which they were found was also measured by its length, width, height, and circumference and was recorded. Substrate type (sand, gravel, pebbles, or rocks), whether the underside of the rock was slippery, and the amount of algae, barnacles, and biofilm (aufwuchs) that was accumulated on the entirety of rock was also estimated.

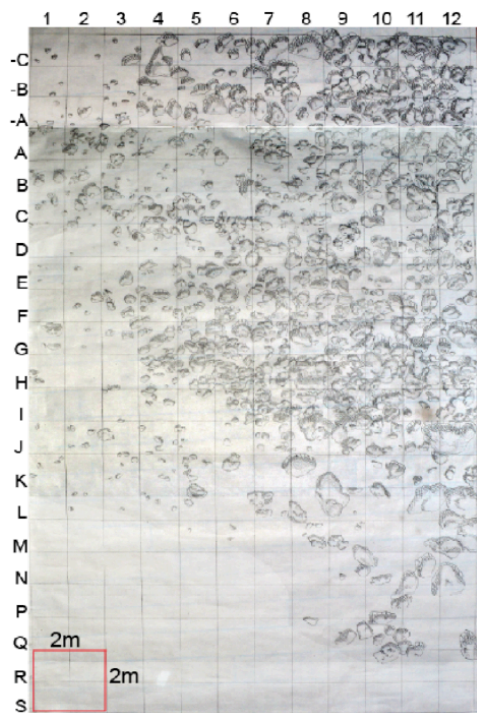


Figure 1: Hand-drawn representation of the sampling area within Reuben Tarte County Park. Letters -C-S begin at the water line and end at the beach and numbers 1-12 occur perpendicular to the former line. Each square represents one meter square.

Rock Sampling and Data Analysis

For transects lettered -C-H (the only transect columns where clingfish were found), samples of the distribution of rock size were taken randomly for 4 of the 12 squares. The number of rocks between 2-6 cm and 6-10 cm in width were counted, while any rocks that were larger than 10 cm in width were completely measured by their length, width, height and circumference. A linear regression was used to look for a relationship between fish size and rock size and a G test was used to test for differences in rock size preferences. All statistical analyses were completed using R statistical software (Team, 2012).

Rock Roughness

We preliminarily measured the range of rock roughness that clingfish experience in their habitat (n=13). To do this, we took casts of stones where clingfish were found using dental casts. First, the casts were cut into 5 rows that were then sectioned into 5-1 cm segments for a total of 25-1 cm segments per cast. We then measured the heights of the peaks and the depths of the valleys using a light microscope and its built in scale. The maximum distance between valley and peak was called R_{\max} . Values of R_{\max} were compared to the grain sizes used in a previous study that examined clingfish tenacity on smooth to rough surfaces (Ditsche *et al.*, 2014). To do this, the method described above was used to measure the known grain sizes that were used in Ditsche *et al.* (2014) in order to assure accuracy in the comparison.

Results

Habitat Structure

Clingfish preferred rock sizes ranging from 15-45 cm, though the rock sizes available ranged from small pebbles (>2 cm) to boulders (> 70 cm) (Figure 2). A G-test revealed that the difference between available rock sizes and rocks selected by clingfish was significant ($p < 0.001$), and this test included only available rocks that were >5 cm wide. Gravel was the substrate that was most frequently found under rocks used by clingfish ($n=48$) while rocks, pebbles and sand were all used less frequently ($n < 7$ each) (Figure 6). Fish were found under a wide range of aufwuchs cover, from bare to fully camouflaged (Figure 3). Water level under rocks was also casually observed. All rocks were at least damp, but some contained pools of water ranging from 1-6 cm in depth.

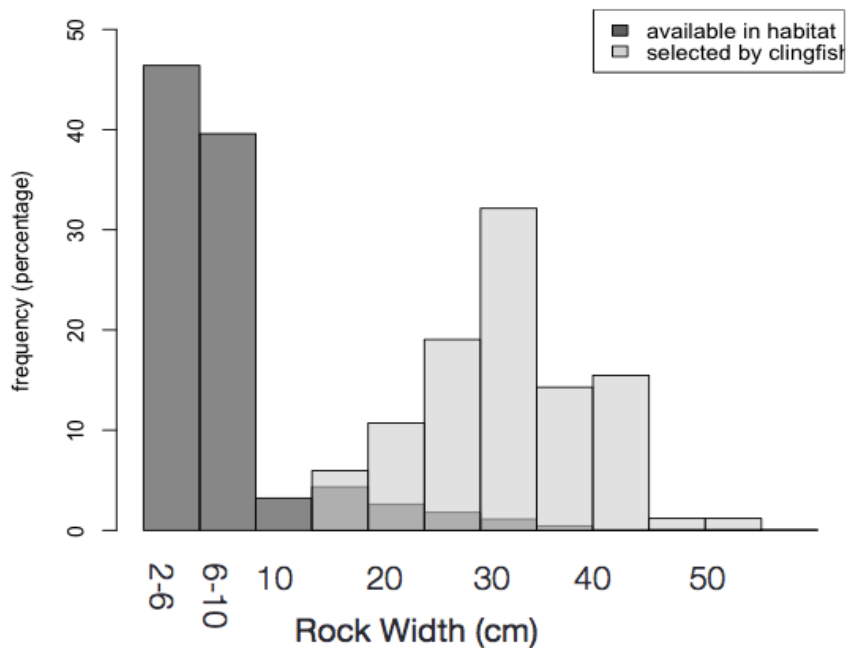


Figure 2: Percentage frequency of available rock sizes vs. actual rock width sizes (in cm).

Available rock widths are all rocks present over the whole transect; actual rock widths are rocks that clingfish were found under.

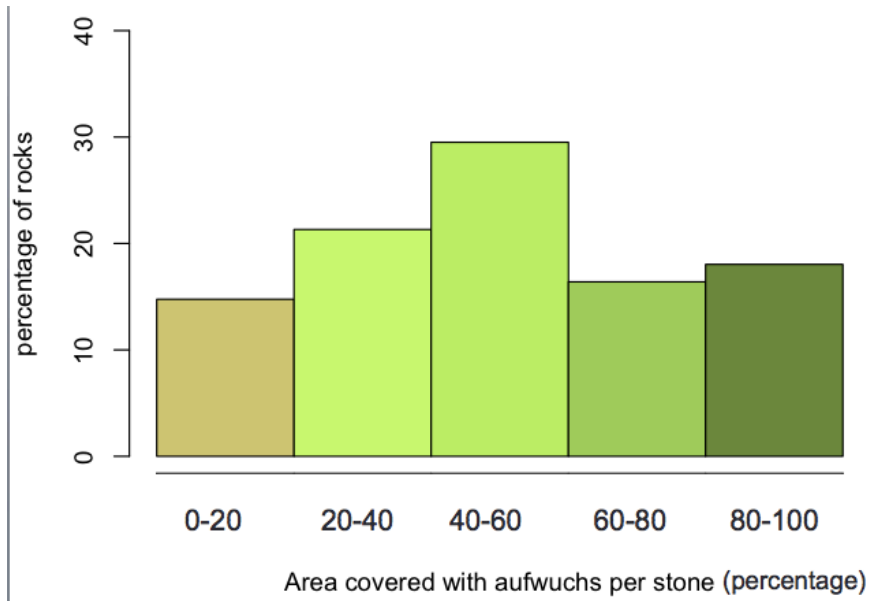


Figure 3: Frequency percentage of aufwuchs cover where fish were found.

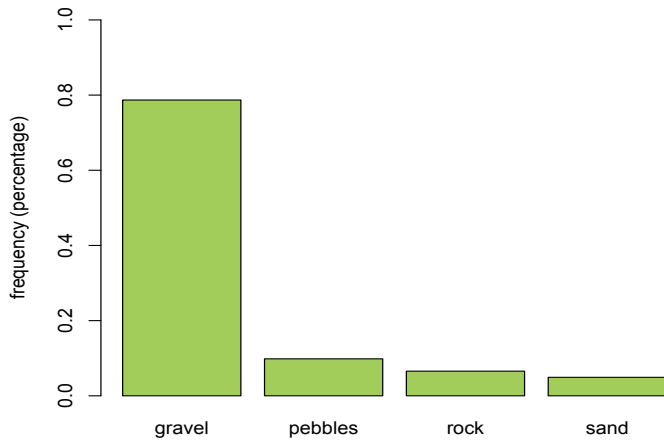


Figure 4: Frequency of substrate type where clingfish were found.

To determine the role of biofilm in the clingfish's habitat, rocks were qualitatively classified as either slippery or not, and we found that fish were most commonly found under rocks that were slippery to at least some extent nearly 90% of the time. The type of substrate found under rocks where clingfish were found was quantified and categorized

as sand, gravel, pebbles, or rocks. Clingfish were found on gravel substrates nearly 80% of the time (Figure 4).

Clingfish Size

Fish in the field ranged from 4-12 cm long. A linear regression model yielded no correlation between rock size (width in cm) and fish length (cm) ($R^2=0.0048$) (Figure 5).

A bimodal distribution of clingfish body length was found among the transects; one being a distribution of small sized fish between 4-6 cm, and the other being a distribution of larger sized fish between 7-11 cm (Figure 6).

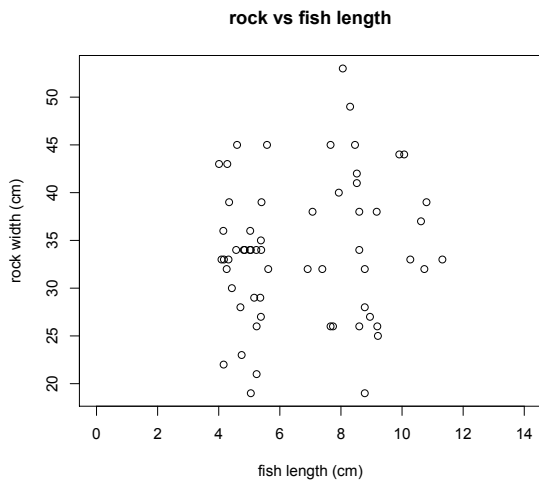


Figure 5: Rock width (cm) of rocks where fish were found vs. fish length (cm). No correlation was found ($R^2=0.005$).

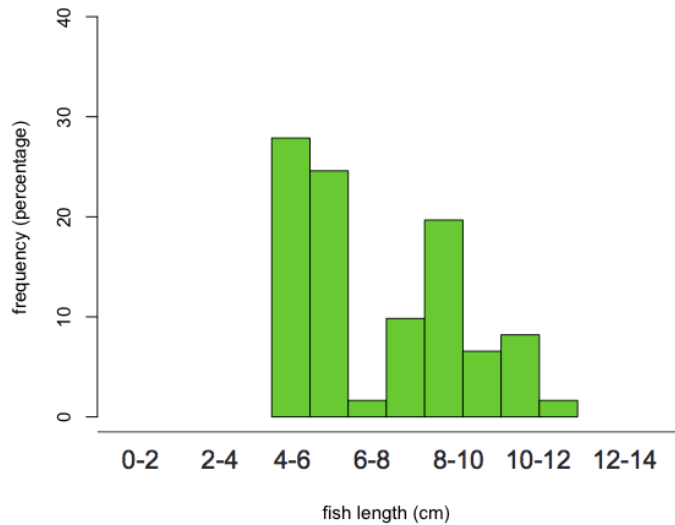


Figure 6: Percentage frequency of fish size distribution (in cm).

There was a slight trend that was visible when comparing fish size and location in the transect. Small fish (4-6 cm) and medium sized fish (> 6-9 cm) travelled closer to the shore than large fish (> 9 cm) did. The highest concentration of small fish occurred in transect A, the highest concentration of medium sized fish occurred in transect E, and the highest concentration of large fish occurred in transect -B (Figure 7).

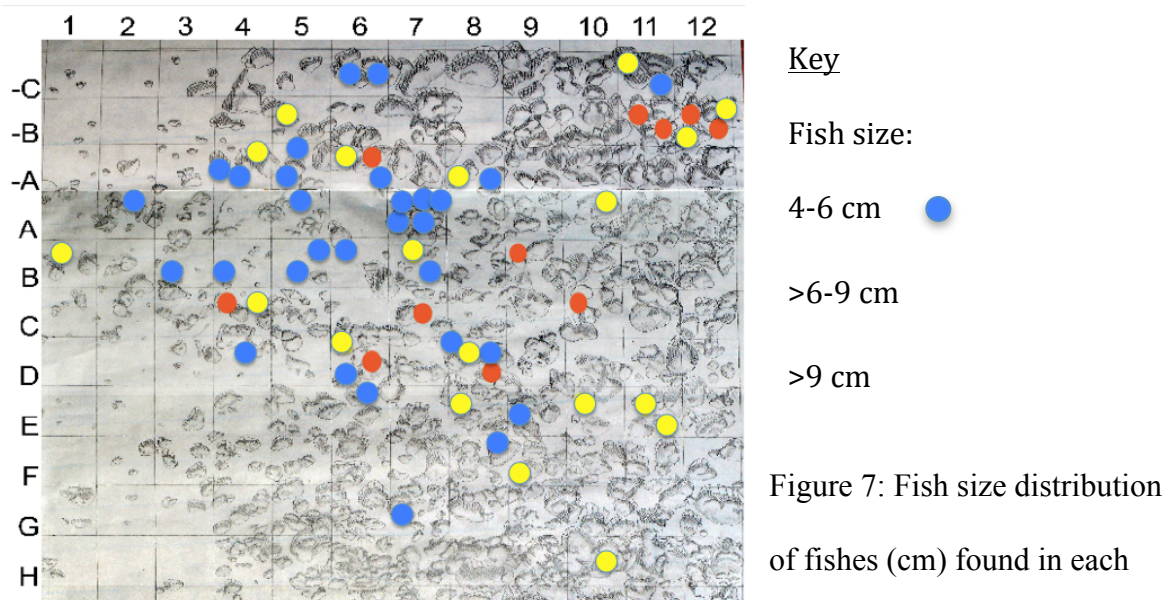


Figure 7: Fish size distribution of fishes (cm) found in each transect square (n=63) for transect columns -C-H, from the waterline to the beach.

Rock Roughness

With the exception of casts with a known grain size of 0-0.269 mm, the method for measuring roughness provided R_{\max} values that lied within the known grain size range (Table 1). The maximum roughness (R_{\max}) found for rocks in the field was 2.5 mm and the lowest was 0.48 mm.

| Known Grain Size | Roughness Correlation (R_{\max}) |
|------------------|--------------------------------------|
| 0-0.269 mm | 0.55 mm |
| 0.5-1 mm | 0.625 mm |
| 1-2 mm | 1.325 mm |
| 2-4 mm | 2.4 mm |

Table 1: Comparison of R_{\max} of known grain size casts and the new method for determining maximum roughness (R_{\max}). R_{\max} was measured using the same method for both known grain sizes and unknown rock casts from the field.

Discussion

Do Northern Clingfish prefer a certain rock size?

As the tide recedes in the rocky intertidal zone, the movement of the Northern Clingfish becomes increasingly restricted. Prior to complete emersion, the fish must select a suitable shelter from the long period of exposure harsh terrestrial environment while it awaits its next chance for submersion. This study shows that shelter selection is not random. Clingfish showed a significant preference for rocks ranging 15-45 cm in circumference, though rocks ranging from 2-60 cm was widely available in their habitat

(Figure 2), which is a preference that is akin to other clingfish species such as *Gobiesox barbatulus* who selects rocks ranging from 5-30 cm, even though rocks between <5 and >50 were available (Pires & Gibran, 2011). A definitive rock size preference may be more advantageous than choosing random rocks because the range that they select may have rocks that are 1) not too small and 2) not too large. Smaller rocks are at a higher risk of crushing their Gobiesocidae inhabitants because of increased movement in the water, and larger rocks are typically situated deeper in the sand, thus provide little to no crevices for clingfish to reside.

Substrate Under the Rocks

Gravel is likely the most important substrate to *G. maeandricus* because of its physical properties that allow for burrowing when the clingfish is disturbed (Eger, 1938). Gravel also may be the substrate with the greatest balance between dampness to prevent desiccation and aeration to allow for land breathing. Clingfish were most commonly found using gravel as the primary substrate under stones, which was a trend that was also seen in Northern Clingfish of California (Eger, 1938). In substrates as fine and compacted as mud and sand, polychaetes and crustaceans were typical inhabitants; and the coarsest substrates (i.e. smaller rocks) were often bare of macro fauna or were inhabited by relatively larger crustaceans or echinoderms. Macpherson (1994) examined the substratum preferences of 11 littoral fish species and found that fish displayed a definitive preference for certain substrates over others but that these preferences are independent of the preferences of intraspecifics so we suspect clingfish to seek protection independently of the presence of different species. Each type of substrate served a

different purpose; for example, large rocks where holes were formed by bivalves were suitable for the blenny *Lipophrys canevai* (Macpherson, 1994).

Aufwuchs and Biofilm Cover of the Rocks

The range of aufwuchs cover on the rocks where we found Northern Clingfish was widely distributed. This was surprising because previous studies have shown that many other Gobiesocidae actually prefer bare to medium covered rocks (Pires & Gibran, 2011), with the exception of *Diplecogaster bimaculata* that preferred more aufwuchs cover at different study sites (Hofrichter & Patzner, 2000).

The water level found under stones also occurred in a wide range (0 cm-6 cm), but it should be noted that even under stones containing no pools of water, the substrate from which the clingfish were found was consistently damp, suggesting that the fish require at least a moist environment. Truong & Ditsche (personal observation) found that the longest period of emersion seen in the Northern Clingfish was around 4 hours, which is probably not a long enough period to allow for complete desiccation of the substrate or rock.

Previous lab studies have shown that clingfish are better able to adhere to unfouled, rough surfaces than to fouled rough surfaces because the presence of biofilm reduces the friction that allows the clingfish suction disc to remain on the substrate, but tenacity on rough, fouled surfaces are still quite high (150 times the fish's body weight) (Ditsche et al., 2014). Nearly all of the clingfish that were found were located in the lower portion of the transect (letters A-D) and these transects maintain a constant layer of biofilm because of its proximity to the water line. The environment offers little relief in

terms of biofilm cover, but the clingfish's well-adapted suction disc allow them to manage the stress of the intertidal zone fairly confidently.

Rock roughness

The maximum roughness (R_{\max}) values found for rocks where clingfish resided was between 2.5 mm and 0.48 mm (Table 1). This is in concurrence with Ditsche *et al.* (2014) who showed that all fish could consistently adhere to surfaces that have a known grain size between 0-0.269 mm, the smallest fish could adhere to a surface with a known grain size of 0.5-1 mm ($R_{\max}=0.625$ mm), and the largest fish could adhere to a surface with a known grain size of 2-4 mm ($R_{\max}=2.4$ mm). Clingfish found in this study inhabited rocks with a range of rock roughness that fell within the minimum and maximum roughness measurements found previously (Ditsche *et al.*, 2014). Our method for measuring rock roughness is reliable because the ranges we find for R_{\max} fall within the known grain sizes (Table 1).

Clingfish size

Rock size selection was not correlated with clingfish size (Figure 5). However, this is intuitive because while larger fish might find larger rocks to be advantageous, smaller fish may not congregate to smaller rocks because, 1. Smaller rocks offer less protection from predators and emersion, and 2. Smaller rocks are likely more susceptible to movement in fluctuating tidal conditions, which could potentially result in harm to the clingfish.

There is an obvious size gap in fish between 6 and 7 cm (figure 3). There are many reasons that can account for size bimodality in a single species such as variability in the location of resources, sexual dimorphisms, or predation events (Huston and DeAngelis, 1987). The most likely explanation for the Northern Clingfish is that there has been a disturbance in reproductive activity during the mating or hatching period that caused a gap in age distribution.

Within the transect, there was no significant correlation between the size classes of fish and their locations in the field (Figure 4). Small fish (4-6 cm) and medium fish (> 6-9 cm) traveled farthest from the water line while large fish (> 9 cm) were not found past transect letter D. One study showed that Northern Clingfish from Californian shores showed a vertical distribution where smaller fish were found higher in the intertidal zone while larger fish were found lower in the intertidal zone (Johnson, 1970). Though trivial, we did see that the smaller clingfish were typically higher in the transect than larger clingfish. A larger sample size might make a vertical distribution more apparent.

Other studies have shown numerous accounts of the spectacular morphological abilities of clingfish, but behavioral and ecological studies are much less common, especially in *G. maeandricus*. The present study has illuminated and described some of the key habitat features of this clingfish and offers *in situ* reasoning that better explains some of the phenomena seen in previous studies that lab experiments have described. There is yet more work that needs to be done to better describe this species and next steps should include underwater and nocturnal observations. Furthermore, we would like to measure the surface roughness of more rocks that clingfish were found under to get a

better understanding of the range that the fish must deal with in comparison to previous lab studies.

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