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FHL – 2014 REU

Title : Northern Clingfish(*Gobiesox maeandricus*): Environmental wave forces and the effect of water levels on their distribution

Abstract:
Diurnal exposure to air during fluctuating tides and forces imposed by rushing waves make the intertidal zone, the habitat of the Northern clingfish, uniquely difficult to survive in. The goals of this study were to answer (1) what are the relevant wave forces acting upon the fish on the San Juan Island and (2) how do changing water levels and thus daily time spent under water percentages (DTUW%) affect their distribution? Dynamometers were built and distributed at 3 locations on the San Juan Island to measure the maximum wave velocities. Results show that over all, wave velocities acting on the island do not exceed 4m/s. Clingfish may have the ability to withstand higher velocities than those measured. A transect was set up at the Reuben Tarte (RT) beach and fish distribution was recorded during the lowest tides between June 30, 2014-July30, 2014. Water heights to reach MLLW were calculated at RT using the law of cosine and these values were later correlated to NOAA's daily water levels to find DTUW%. Clingfish were found exclusively in areas that had at least 80 DTUW% which leads to the conclusion that water levels and thus DTUW% are important determinants in clingfish survival.

Introduction

The rocky shores of the intertidal zone provide a tumultuous environment of harsh extremes. The spontaneous event of water crashing on rocks includes differing wave velocities, accelerations coupled with decelerations, and lift or drag components (Kinsman, 1965). Naturally occurring physical stresses include the vertical gradient, which is dictated by increased stress with increased exposure due to alternating tides, and the horizontal gradient, which results from differences in wave action between exposed and sheltered spaces (Crowe et al. 2000, Jones and Demetropoulo, 1968). Wave forces and time spent under water have been important variants affecting the survival of intertidal organisms. Studies have shown that algae occupy different zones of the intertidal based on their abilities to withstand stress from exposure (Doty 1946). Organisms occupying intertidal zones are exposed to significant and varying hydrodynamic forces.

Although the rough waters of intertidal zones seem inhibitory to life, their mechanically stressful conditions actually promote the biodiversity of life forms across the kingdoms. Intertidal productivity is high due to the robust movement of water; Photosynthetic output and producer metabolism is increased in agitated water as compared to still water (Dennison and Barnes, 1988). The northern Pacific region has an impressive level of biodiversity in the intertidal zones where there are higher hydrodynamic forces (Leigh et al. 1986). This region is also easily assessable and thus serves as an excellent study area for physical disturbances and their biological implications.

Organisms inhabiting the intertidal zone have evolved adaptations to survive the area's dynamically fluid forces of waves and wind as well as the resulting fouling of substrates. Although morphological adjuncts are the most obvious advantages, evidence suggests that it is rarely physiological changes alone that propel a specimen forward through life's complexities (Barnwell, 1968; Hearnkind, 1968). More oft than not, behavioral adaptations combined with morphological ones enable an organism to be truly successful across a wide net of environments (Warburg 1968). Of the various intertidal fishes, this study focuses on the unique systematics of the Gobiesocidae which are known colloquially as the clingfish (Chotkowski, 1999).

Clingfish occupy niches in the intertidal ecosystem that other fish cannot; They have evolved specific adaptations to cope with the irregular surface roughness and fouling rate of rocks (Johnson & Greenfield, 1983). Their morphological modifications of pelvic and pectoral fins into adhesive discs greatly aid in the prevention of being swept away by the crashing waves. Northern clingfish (*Gobiesox maeandricus*) have been found to adhere better to rough than smooth surfaces and to have adhesive forces 150 times their body weight on fouled rough surfaces (Wainwright et al 2013; Ditsche et al 2014). Further morphological adaptations include bodies tapered like droplets, lack of scales, and flat heads. In addition to their physical mechanics, *G. maeandricus* have adopted special behaviors to survive the air exposure in the intertidal zone. During low tides, clingfish will respire aerially but also hide under rocks or algae to prevent desiccation (Graham, 1997). Although physical adaptions are most obvious in helping clingfish survive the intertidal, the contributions of behavioral modifications, such as nocturnal feeding and inactivity during low water levels (Pires and Gibran, 2011), cannot be ignored.

The aim of this paper is to gain knowledge about the actual flow and wave forces acting on the Northern clingfish in their native habitat. Previous work was done by Wainwright et al. (2013) to study attachment forces of clingfish in lab. Our questions involve quantifying the relevant wave force velocities in the field which affect clingfish attachment abilities. The second focus of this research is to quantify the effect of water levels on clingfish distribution. To answer our questions, we collected clingfish at a selected habitat at several low tides, determined the time under water in relation to the sampling point of the fish, and measured wave forces at different clingfish spots of the San Juan Island.

Methods

Site Selection

Three different intertidal zones were sampled on the coasts of San Juan Island in WA, USA before Reuben Tarte was chosen as the primary site because of the high frequency of clingfish found. Both Dead Man's Bay (south) and Cattle Point (southwest) served as comparison sites for wave velocities collected at the main site. Reuben Tarte (northeast) encompasses two pebbled beaches separated by a rock bluff. The eastern pebbled beach was more protected and exposed to calmer waters as opposed to the rougher water of the western beach of Reuben Tarte.

Transect Staging

Data was collected at the Reuben Tarte Country Park located on the San Juan Island, WA, USA from June-July 2014. The transect was formed by outlining a square with measuring tape and rope on the eastern pebbled beach at Reuben Tarte. A tape measure ran from the sea shore to the beach thus forming the right and left perimeters. The right perimeter was labeled with letters –C through S, omitting letter "O" for its resemblance to number "0", which totaled 18 points spaced 1m apart. Letter "A" began at Rock A which was at the right corner of the square closest to the sea. In the north to south direction, each meter was marked with a number 1 through 12. In total, 216 quadrats were formed and each formed a 1m x 1m square and in total. Photographs of the 1m x 1m quadrats were taken and then individually transposed by hand onto vellum to form a field of study map (Figure 1).

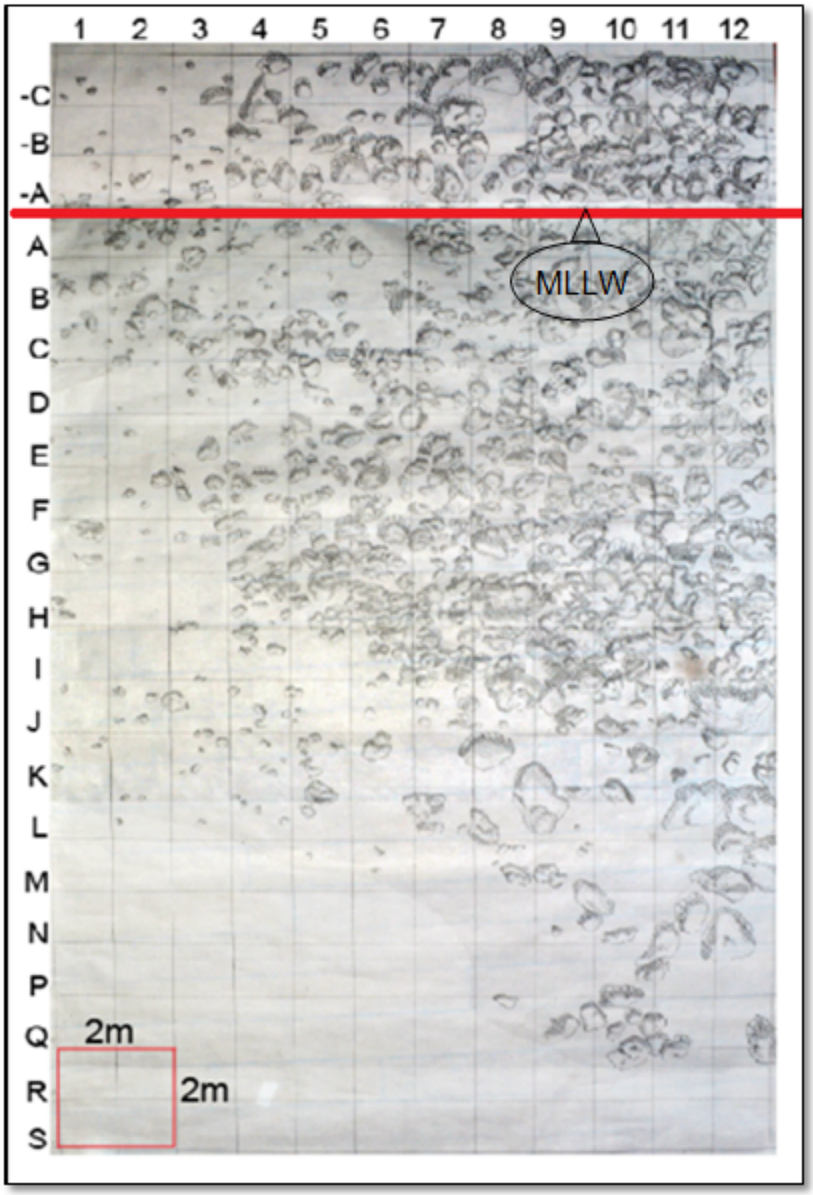

Figure 1: Transect map of Reuben Tarte field site. Each quadrat square measures 1m x 1m. Negative quadrats are closer to the sea while positive quadrats are closer to the shore. Each globular shape represents 1 rock and crosshatching was used to portray three dimensionality. Only rocks with circumferences above 10cm were included. No tide pools were present.

Water Level and Vertical Distribution Determination:

Angles of the outmost perimeter on the right side (20m) of the transect area were measured. A tripod standing vertically 1 meter above the substrate was secured at the uppermost corner of the transect. A 20lb nylon fishing line was strung down 20m towards the corner of quadrat –C12 which marked the bottommost corner of the transect. The angle of the starting point at the uppermost corner to the end point which was the bottommost corner of the transect was then measured via hand protractor. The process was repeated at the start of each new quadrat (-C to S, excluding O), roughly spaced 1m from the previous end point. The presence of large boulders skewed some of the end points so that each quadrat measurement was not a perfect meter apart. Consequently some angle measurements taken were 40-50cm from the start of each new quadrat because we aimed to measure the end points as 1m above the ground exclusive of large boulders.

The setup to measure angles in the field represents a cosine triangle (Figure 1). Line C is the fishing line strung between the uppermost (start point) and bottommost (end point) of the transect. For each quadrat measured, the end point was spaced roughly 1m away from the previous and thus the distance of line C varied for each quadrat. Line A is the protractor arm which is affected by gravity. Line B is the figurative line between

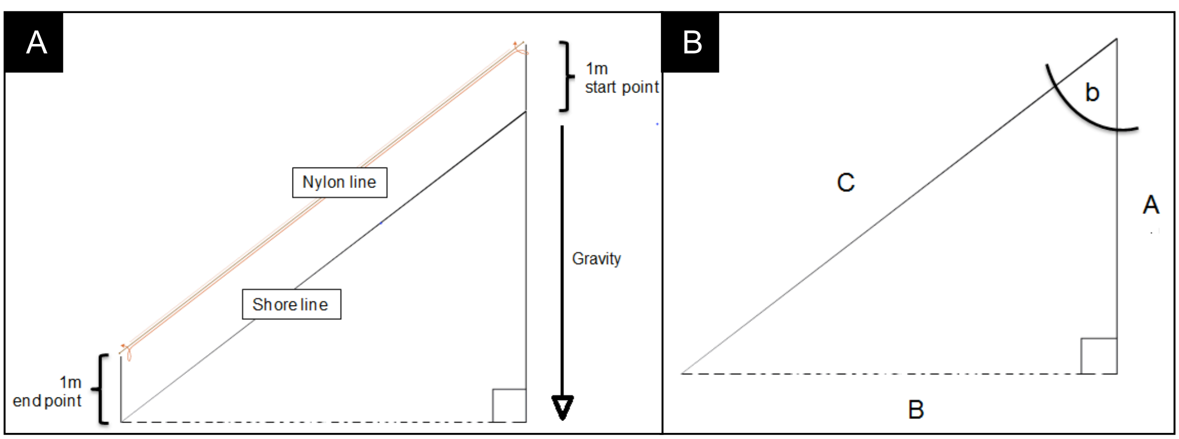

Figure 2: Cosine triangle formed by angle measurement setup. Study site represented by components of a cosine triangle (A). Hypotenuse was created by the nylon line running from the start to the end point which were both 1m above the shore line. The vertical component resulted from the force of gravity. The horizontal component, dotted lines, represents the base of the triangle. The basic cosine triangle free of

study site specifics has been drawn with named lines/angle β. Angle β was measured using a hand protractor.

the end of the protractor arm and the endpoint at the bottom of each quadrat. Angle β was measured between line C and line A.

The law of cosine presents itself in the following equation:

$$\cos\ \beta = \frac{A}{C} \tag{1}$$

A represents the water heights required to reach mean lower low water (MLLW), which is an average height of the lowest tides recorded daily at the tide station of reference, and is the sought after value. In order to derive A, the law of cosine was rearranged into this equation:

$$A = C\ (\cos\ \beta) \tag{2}$$

After finding the measured angles, the corresponding values were inputted into the formula. C is the distance of the line from the start point to the endpoint of each quadrat. Angle β is calculated as the measured angle of the nylon string subtracted from 180.

Daily Time Under Water as Percentages (DTUW%) Calculations

Tidal fluctuations occur daily and are recorded as water level data by NOAA. We recognized our calculated water heights could be related to this data. Our calculations correlate to the height of the water level at MLLW at the study site and NOAA's data correlated the height of water on the San Juan Island to time. Thus by comparing our water heights to NOAA's water height records, we could calculated the time spend under water for each of our quadrats.

In order to calculate the DTUW%, height values of each quadrat were compared to NOAA water level data for each day that fish were found. For example, if quadrat C2 had a measured height of 7m on July 1 then one would find the two points between the low tide of July 1 and low tide of July 2 that the water level reached 7m. The time between these two points is the total time spent under water. The DTUW% is the total time spent under water divided by 24 hours.

Fish Distribution

After the transect was set up, rocks in each quadrat were systematically overturned to find clingfish which are known to adhere to the undersides of rocks during low tide. Found specimens were photographed next to a ruler and body length was later calculated via ImageJ. The specific quadrat that fish were found in was also noted.

Dynamometers: Manufacturing and Placement

We aimed to measure the maximum wave velocity conditions at Reuben Tarte and later compared this data to 2 other field sites. In order to quantify the wave forces, the dynamometer was built according to Carrington Bell and Denny (1994). A practice golf ball was attached to a spring enclosed in a CPVC tubing that was later secured to the intertidal rocks. The motion of water from the waxing and waning of the waves generated drag on the ball. This drag altered the spring's extension which was later calibrated to represent the maximum wave velocity (Carrington and Denny, 1994). Using the spring rates described by Carrington and Denny (1994) at the field site provided insufficient data as the wave forces present were too low. Thus, the following spring rates were used to best measure the maximum wave velocity: 0.75lb/in, 0.5lb/in, and 0.25lb/in.

Dynamometers were placed at Reuben Tarte (15), Cattle Point (2), and Deadman's Bay (2). At Reuben Tarte the dynamometers were secured to rocks at the field site in specific quadrats. The locations of the dynamometers were parceled out over three sub locations: 2 were placed to the right of the main transect where waves were moderately stimulated, 11 were placed within the main transect where clingfish were captured then measured, and 2 were placed on the western pebbled beach where the cove was least protected. The devices were placed in the field on (date) and continually measured whenever the low tide was below the baseline tidal level. The average exposure time between measurements was 36 hours.

Dynamometers: Calibrations and Maximum Velocity Calculations

The maximum flow velocity was calculated in accordance to Carrington Bell and Denny (1994). Therefore, their drag forces (F_d) measured for practice golf balls were used. The forces are described by the power curve that fits the following equation where u is the water's velocity (m/s).

$$F_d = 0.575u^{1.93} \tag{3}$$

Drag coefficient (Cd) is denoted as such in equation 4. P is the density of water which we assumed to be 1000 $kg/m^{3.}$ and S is the cross section of the golf ball.

$$Cd = \frac{2F_d}{pu^2S} \tag{4}$$

Each of the dynamometers was calibrated separately to find if functionality differed due to constructional differences. Calibrations were performed by hanging the device off the ledge so that only gravity acted upon it. Then we attached a series of weights to the golf ball and recorded the distance traveled by the spring. After plotting graphs of the weights and distance traveled, we found the linear regression of each graph (Figure 2). Values from this graph were later used to related spring extension to spring rate and thus velocity.

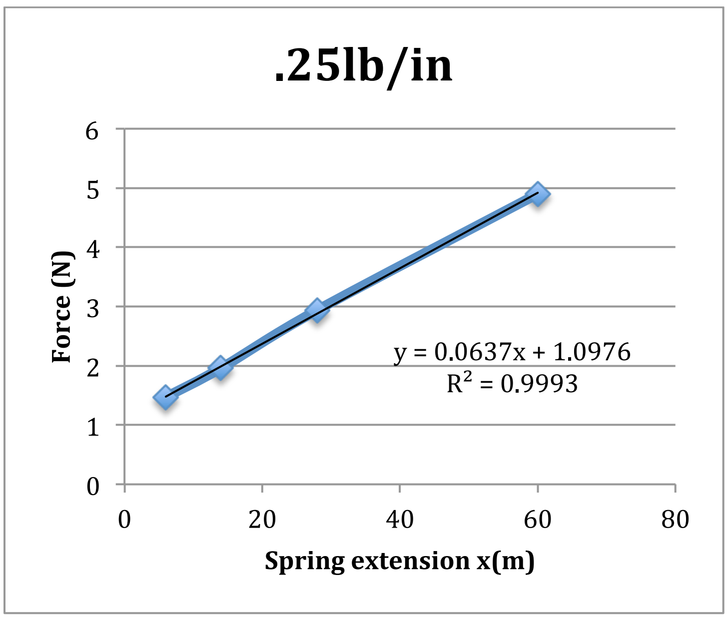

Figure 2: Force and spring extension linear regression of spring (0.25 lb/in).

Velocity (v) was defined using equation (5). The force vs. spring extension graph provided three values for equation 5: k was the slope, c was the start point, and x is the extension. The other variables were used from Carrington Bell and Denny's work (1994). Thus a was known to be 0.575 and b was 1.93.

$$v = \left(\frac{kx+c}{a}\right)^{\frac{1}{b}} \quad (5)$$

Results

The maximum wave velocities at Reuben Tarte never reached more than 3.5 m/s. Velocity measurements of dynamometers placed at the site were taken between June 30, 2014 and July 24, 2014. Dynamometers (1) and (2) were placed to the left of the transect. The maximum wave velocities were 1.6m/s and 1.4m/s respectively. Of the two devices placed in front of the transect only dynamometer (4) recorded values, maximum velocity of 1.29m/s, while dynamometer (5) stayed inactive, which means flow velocities were under values required to activate that dynamometer. Nine devices were placed in the quadrats and of those dynamometers, three did not react, so the wave forces were under the threshold value of 1.10m/s (5,7, and 8). The maximum flow velocities for the rest of the transect devices were as follows: (6) 1.23m/s; (9) 1.23m/s; (10) 1.56m/s; (11) 1.23m/s; (12) 1.50m/s; (13) 1.48 m/s (Figure 1).

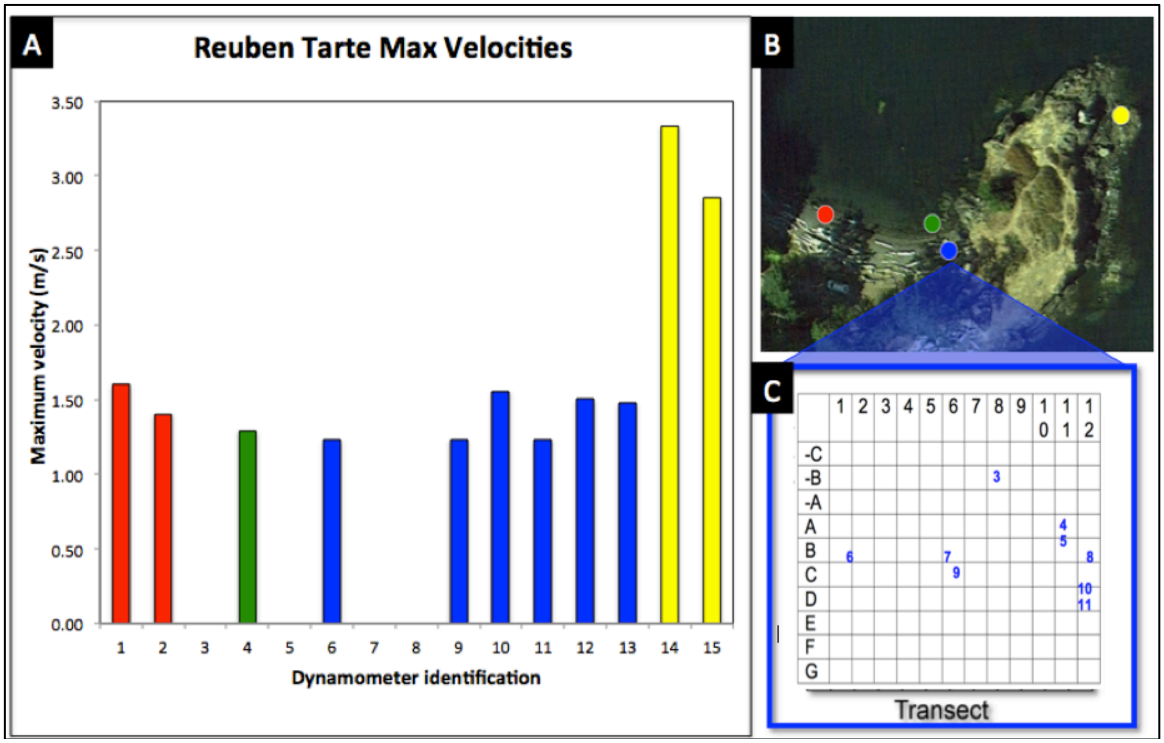

Figure 3: Maximum flow velocities at Reuben Tarte. (A) At Reuben Tarte Beach flow velocities ranged from 0-3.5 m/s. 15 dynamometers were dispersed among the 4 colored dot locations pictured in (B). 9 devices were placed in the quadrats and locations were specified in inset (C) [blue]. 2 were placed to the left of the transect [red]; 2 were placed in front of the transect [green]; 2 were placed to the far left of the transect overlooking the bluff [yellow]. Maximum wave velocities were recorded from each device with the colored bars corresponding to their locations on the map inset [A].

Effect of water levels on clingfish distribution

Water heights at Reuben Tarte depict the study site as a sloped surface. Quadrats –C to –A measured below the MLLW and had negative water heights ranging between (-0.656m) and (-0.225m). Quadrats A through S measured above the MLLW and had positive water heights from (0.074m) to (2.355m). Negative quadrats measure below MLLW while the positive quadrats measure above MLLW (Figure 2).

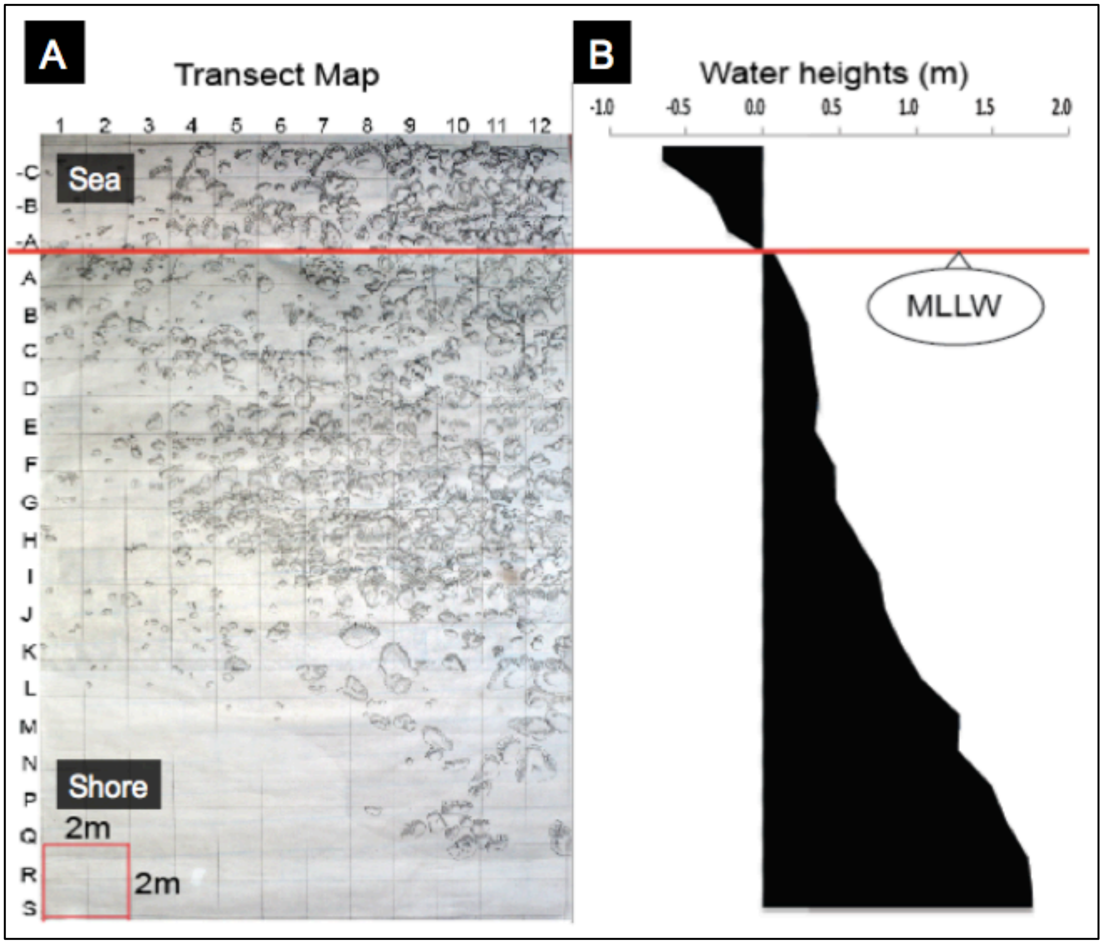

Figure 4: Water heights at Reuben Tarte field site. The left side (A) displays the transect map for comparison to the water height profile on the right (B).

Notably, all of the specimens were located in quadrats closer to the sea and farther from the shore. Only one specimen reached the highest point on the map which was the H quadrat. The majority of the fish were found in quadrats of –A and a particular concentration surround –A6 and A7.

Clingfish were recorded and they were later placed back on the rock they were found under. Thus, although 62 fish locations in the transect have been recorded, it is possible counting of the same fish specimen may have occurred for different days...

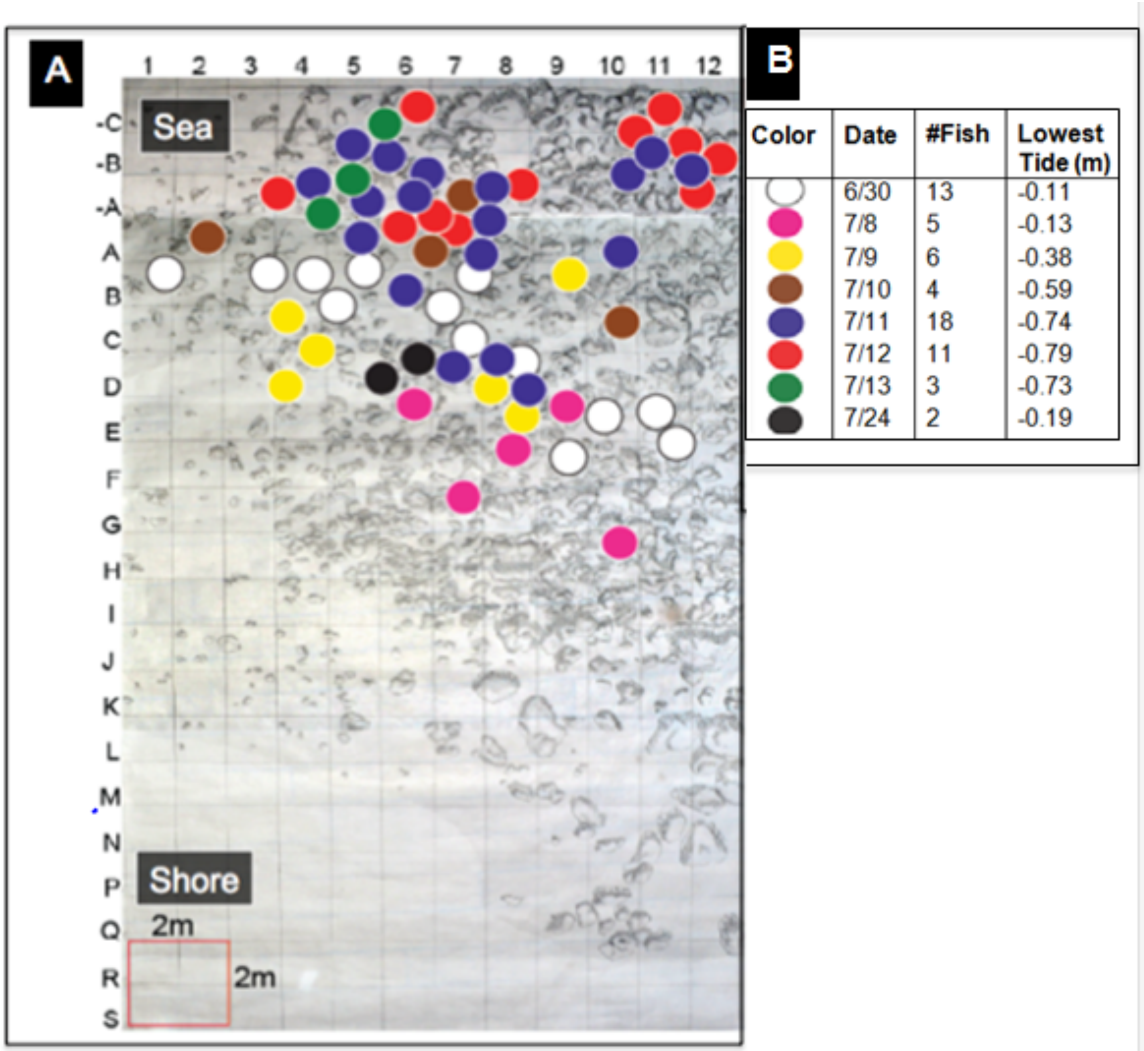

Figure 5: Clingfish distribution in the investigated transect from June 30, 2014 – July 24, 2014. 62 *Gobiesox maeandricus* specimens were found at Reuben Tarte. Each specimen's location was noted within the transect (A). Each colored dot represents a clingfish found on the corresponding day (B). After *G. maeandricus* locations were noted, the specimens were placed back into the habitat.

The daily time under water values measured as a percentages (DTUW%) were calculated for the three days that most fish were found and fish locations were mapped. On June 30, *G. maeandricus* concentrated themselves between quadrats B – F which were submerged between 83 – 86 DTUW% (Figure 4). On July 11, *G. maeandricus* concentrated themselves between quadrats A – D which were submerged between 82 –

90 DTUW% (Figure 5). On July 12, *G. maeandricus* concentrated themselves between quadrats -C and A which were submerged between 85 – 97 DTUW% (Figure 6). No fish was found in quadrats below 80 DTUW% (Figures 6-9).

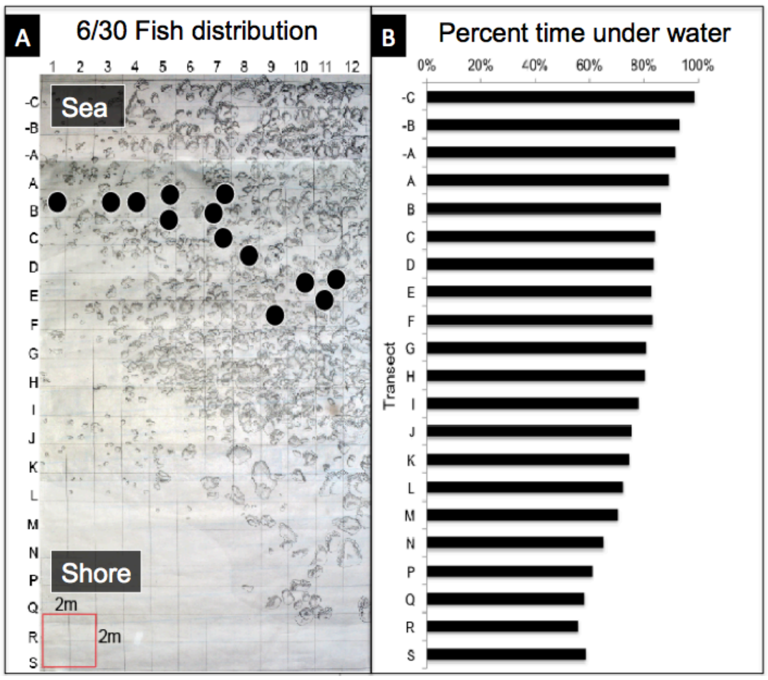

Figure 6: Fish distribution and daily time under water (%) on June 30. Locations of 13 found *Gobiesox maeandricus* were noted in the quadrats (A). DTUW% was calculated for June 30 (B).

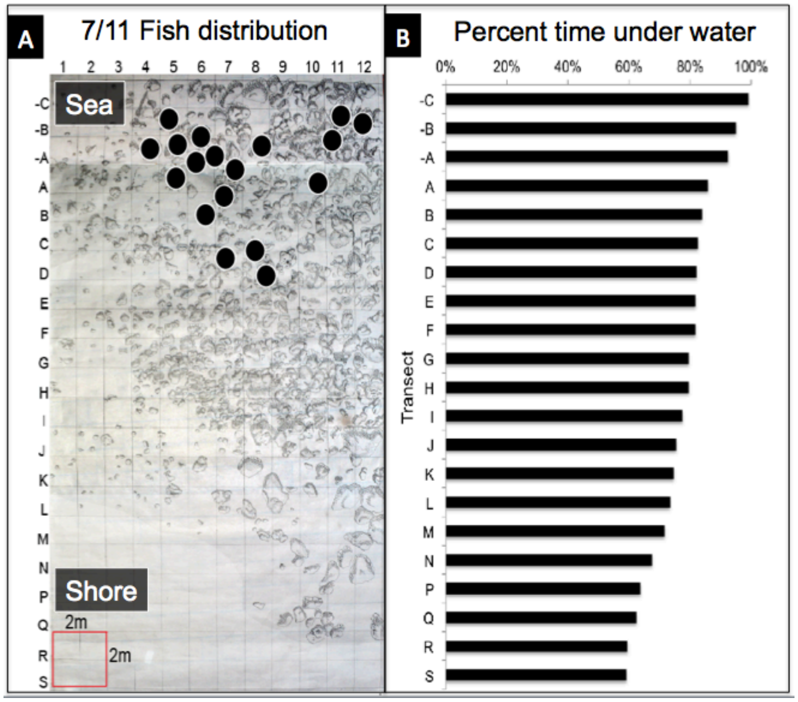

Figure 7: Fish distribution and daily time under water (%) on July 11. *Gobiesox maeandricus* were noted in the quadrats (A). DTUW% was calculated for July 11(B).

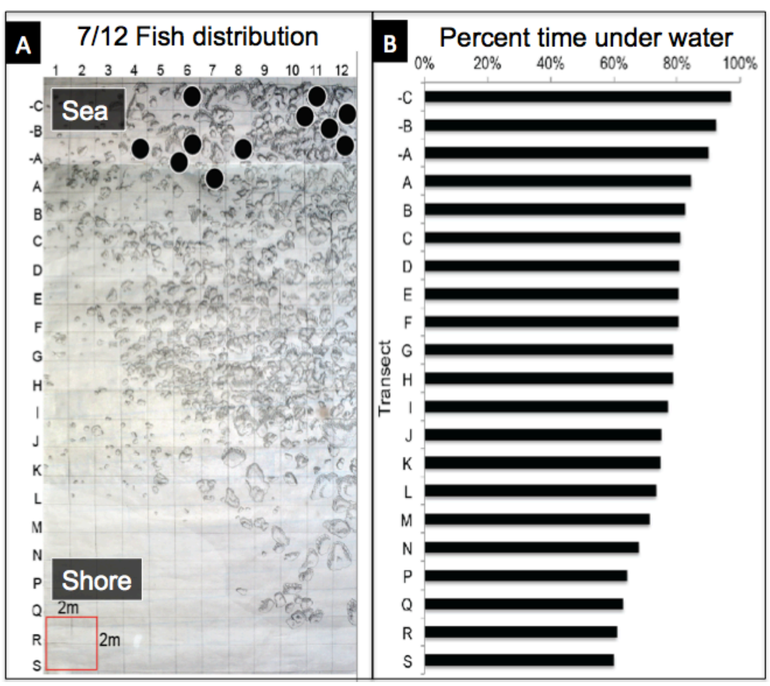

Figure 8: Fish distribution and daily time under water (%) on July 12. *Gobiesox maeandricus* were noted in the quadrats (A).

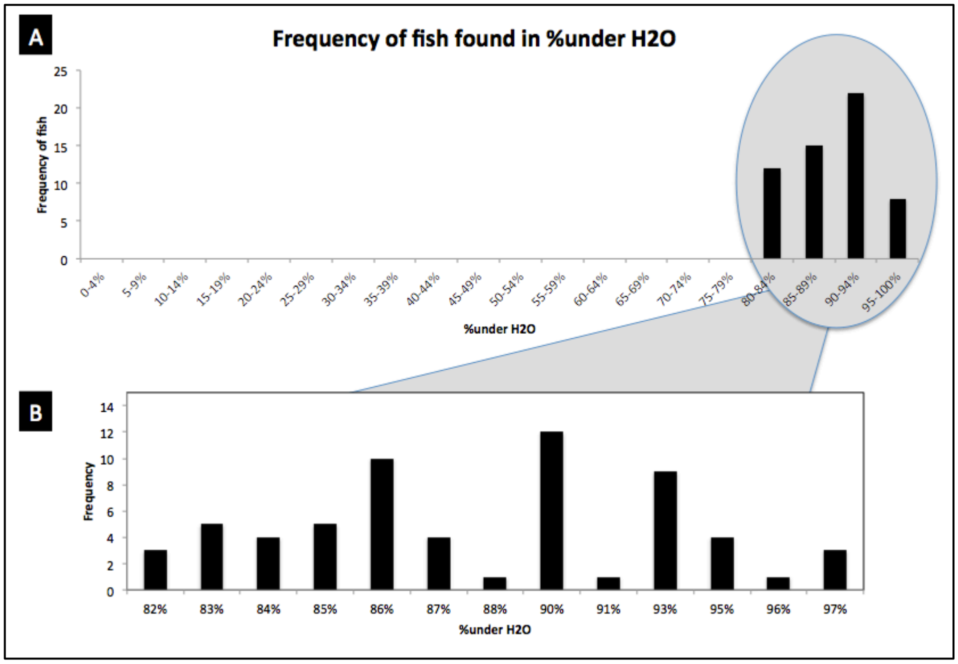

Figure 9: Frequency of fish found in daily time under water (%). The DTUW% for each quadrat that the 62 *Gobiesox maeandricus*, found at Reuben Tarte between June 30 and July 24 was calculated. Clingfish were exclusively found in areas exhibiting DTUW% of at least 80 (A). Further examination of the DTUW% for the 80-100% range (B).

Clingfish distribution was also analyzed in terms of size (Figure 10). Clingfish were divided into 4 size classes with corresponding colors (yellow were between 4-5.9 cm, red measured 6-7.9cm, orange were between 8-9.9cm and black represent those within the 10-11.9 range). As shown in Figure 10, most of the fish found were within the yellow and orange size classes with the most specimens being found in the yellow size class. All size classes appear to disperse widely over the transect area, however, more data is needed to see if there is a noticeable trend in size distribution.

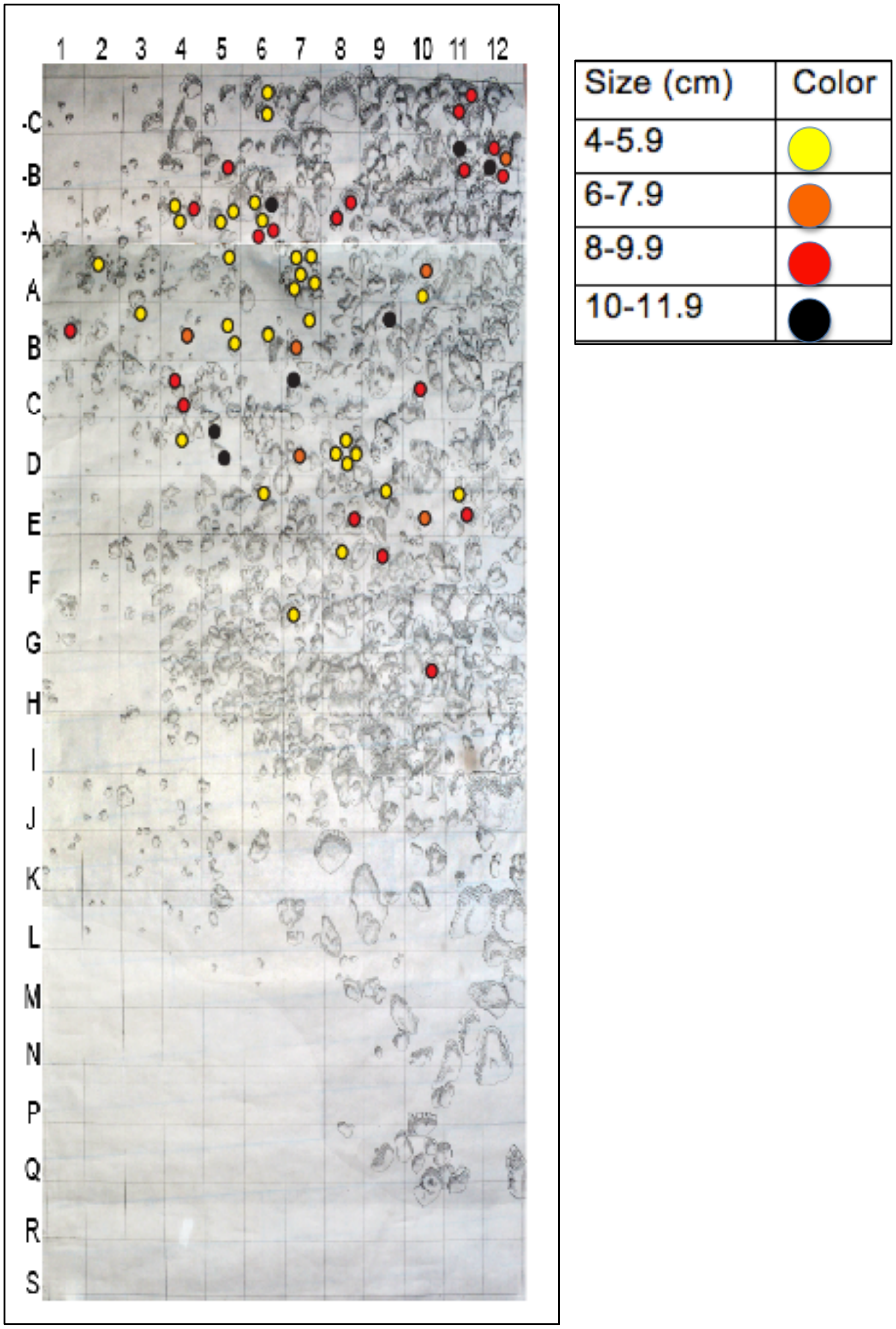

Figure 10: Fish size distribution of clingfish in the investigated transect from June 30, 2014-July 24, 2014. 62 *Gobiesox maeandricus* specimens were found at Reuben Tarte. Each specimen's location was noted within the transect and size was also measured. Each colored dot represents a clingfish of specific size class found on the corresponding day. After *G. maeandricus* locations were noted, the specimens were placed back into the habitat.

Discussion

Flow velocities at observed clingfish spots

Wave energy is not a new phenomenon. Around the world, wave velocity values recorded have reached over 850m/s (Xia et al, 1999). Within a certain area, wave velocities are known to vary as a result of variations in geography. The wave velocities on the San Juan Island are low. On the Tatoosh Island off the Olympic Peninsula, an area neighboring the San Juan Island, wave forces in the intertidal have been measured at 8m/s (Denny, 1985). In comparison, the wave forces measured at San Juan are low. Possible reasons include the topography of the area. Geographically the San Juan Island is but an island within a series of islands. Thus the wave action that reaches the shores has been dissipated. Another reason could be the low seismic activity in the area.

Within our study sites, our experimental data shows differences in wave velocities. At Reuben Tarte, data was measured from 7/11-8/6. Most of the values were below 2m/s and the highest values reached 3.53 m/s which were located over the bluff. The calmest waters were found within the transect closest to the shore. Data at Cattle Point and Deadman's Bay was collected from 7/24-8/6 and thus a fair comparison to Reuben Tarte would be within the same temporal frame. With this in mind, the maximum velocity ranges of Reuben Tarte were between 2m/s and 2.76m/s whereas the velocities at Cattle Point were 1.95-3.12m/s and Deadman's Bay was 1.91m/s.

The two principle reasons for variations could be due to geography and short investigation time. The Reuben Tarte site was a beach that was shielded by stacked rocks. Thus wave action may have dissipated before reaching our shores, where our most of our dynamometers were stationed, but after the bluff. This would explain the unusually high wave velocities at the bluff but not near the transect although the two areas are separated by no less than 100ft. Our data was recorded during the summer of 2014 and thus our data collection period may have coincided with a period of calm water activity. In comparing wave velocities within the transect itself, there appears to be no specific trend. All areas of the transect experience a similar range of wave velocities. Some dynamometers were not activated but this fact is negated by the observation that devices next to them, often in the same transect, were activated. This may have been due to experimental error as devices may have been lodged in between rocks and thus could not measure the wave forces. In conclusion, because wave velocities at San Juan are low, they likely represent the lower threshold of clingfish range and not necessarily the full nor maximum range.

What impact do tides have on clingfish distribution at the shore?

An organism’s distribution is dictated by the availability of a suitable habitat and access to resources. Many of the stresses associated with the intertidal are consequences of emersion such as desiccation, excessive light, salinity changes and temperature (Lewis, 1964). Much work has been done in studying the zonation patterns of relatively sessile organisms such as limpets and chitons. However, it may not be a comparable analysis because fish are more mobile, they can move faster, and can actively select their habitats.

This study shows that clingfish distribution is strongly affected by the time spend under water. Although in daily interaction it appears as if fish distribution differed with the tide, on some days most were found in quadrats A and in other days in the negative quadrats, the main impacts seems to be the time under water. Our evidence shows that a critical threshold of at least 80 DTUW% must be reached in an area for the fish to colonize there. There were no differences in fish size as a result of DTUW. This may be due to breathing and desiccation concerns.

Fish are usually adapted to respire under water but clingfish can breathe air (Ebeling et al 1970). In addition to their morphological adaptations such as specialized respiratory structures, our field experience supports the claim that clingfish breathe air. After flipping rocks during low tide, we did find specimens under rocks that had no water. Behaviorally clingfish assume stationary routines during low tide; They avoid unnecessary movement during air exposure. We hypothesize clingfish are found in high DTUW because it is advantageous to remain in areas where the time they have to wait for high tide is short. Although clingfish can breathe without water, spending time in areas submerged underwater most of the time likely increases their fitness. Because clingfish remain sedentary during low tide, this should affect their predation rates. It would also be advantageous to live in areas of low exposure since clingfish have decreased energy during low tides. Furthermore, the possibility of being caught by predators is higher on land as clingfish have decreased mobility in areas exposed to air. The high energetic costs of breathing air are compounded by the issue of low mobility and therefore clingfish prefer areas of high DTUW.

Another contributing factor to clingfish's distribution being dictated by DTUW percentage is the danger for desiccation. Exposure to air also causes moist membranes to lose water and thus it is beneficial for clingfish to find shade or cover under the rocks. Fauna, a source of cover, grow best in areas submerged under water. Thus clingfish may prefer to congregate in areas of high DTUW because of the fauna that may provide coverage and decrease their rates of desiccation much like a sponge left outside but in the shade retains moisture better than a sponge left in the same conditions but without shade. In addition to protection from desiccation, fauna in the form of aufwuchs or free standing flora may provide ample gathering spaces for breeding as predation is decreased in areas that are covered or protected.

Clingfish occupy a unique niche of intertidal ecosystems. Few animals can balance the precarious position between two extremes as well as they do. This study's relevance lies within the higher depth at which it explores clingfish habitat and in its attempt to classify wave velocities acting upon clingfish habitats. In the future, additional wave force measurements in other seasons would be suggested to get the whole range of wave forces. Moreover, the determination of drag and lift forces which act on Northern Clingfish under the measured flow velocities would give information about the forces acting on the fish under the living conditions.

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