



Effects of flow velocity and settlement location on growth rates of early juveniles of the pedunculate barnacle *Pollicipes polymerus* Sowerby, 1833

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ABSTRACT

The intertidal lepadomorph barnacle *Pollicipes polymerus* lives gregariously, preferentially settling on conspecifics. This study asks if and how *P. polymerus* individuals gain in overall fitness from gregarious settlement. The study addresses two questions: 1) Is the growth rate of early juveniles dependent on the velocity of the water in which they feed? and 2) Does settlement on conspecifics benefit early juveniles by increasing growth rate? Two treatment groups (solitary and gregarious) and an experimental velocity gradient were studied in marina and tank environments, with *P. polymerus* individuals ranging in size from 1 to 3 mm (measured by rostro-carinal length). For the trials carried out in a marina environment, growth rates ranged from 0.1 to 1.2 mm per week at any given velocity. For the trials in a tank environment, individual growth never exceeded 0.6 mm per week. Overall results indicate that neither current velocity nor settlement location had consistent effects on early juvenile growth rates. In the tank environment, where food concentrations were lower, velocity had a significant negative effect on the growth rate of gregarious but not solitary juveniles. Meanwhile, settlement on a conspecific had a significant positive effect on average juvenile growth in one of the four trials. The absence of consistent trends within and across trials indicates that velocity and settlement location for early juveniles may not be primary factors in gregarious settlement of this barnacle. The results also have important implications for aquaculture; they suggest that *P. polymerus* juveniles do not require specific flow speeds or adult substrata to cultivate newly-settled barnacles.

1. INTRODUCTION

Anyone who has wandered the rocky intertidal of the Oregon coast surely will have noticed a creature who, along with others of its species, aggregates in irregular- to rosette-shaped clusters on the underlying rock substrata. This unmistakable species, known as the gooseneck barnacle or *Pollicipes polymerus*, has a range along the coast of the Northeastern Pacific from Susk, British Columbia to Baja California Sur (Pilsbry 1907, Cimberg 1981). Their intertidal occurrence overlaps primarily with that of the bivalve *Mytilus californianus*, the upper range of their seastar predator, *Pisaster ochraceus*, and the lower range of acorn barnacles, *Chthamalus* sp. and

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Balanus glandula (Barnes and Reese 1960). European gooseneck barnacles (*P. pollicipes*) are regarded as a culinary delicacy, particularly in Spain, which is commonly referred to as *percebes*. The meat of fresh *Pollicipes* can command as much as 80 USD per kilogram, and the price only continues to climb (López et al. 2010, Gardiner 2015). Due to their high economic value (Bingham et al. 2017, Romersa 2018), gooseneck barnacle populations are subject to overharvesting. This practice poses a significant threat to the population's ability to restore itself for the unique reason that *Pollicipes* cyprids almost exclusively settle on the peduncle of conspecifics, or members of the same species.

Although such scenarios are rare, *P. polymerus* juveniles have also been known to settle in small cracks and crevices that resemble, at the microscopic scale, the interscalar spaces in which they typically settle (Barnes and Reese 1960). Aggregative or gregarious settlement behavior is seen across a plethora of species, though the mechanisms by which such settlements are achieved and the ecological benefits behind them vary by species. For gregarious settlement behavior to evolve, natural selection should provide some benefit that would not otherwise be achieved through a solitary lifestyle, such as to defend against predators (Riipi et al. 2001) or promote cross-fertilization (Wu 1981).

In the case of *P. polymerus* populations, no scientifically-supported benefit is known for early juveniles whose larval cyprid settles on larger conspecifics. The resulting rosette-shaped clumps are an apparent outcome of their gregarious settlement, but the answer as to what these clumps offer an individual or a population remains elusive. Potential benefits notwithstanding, research has shown that the species possesses certain mechanisms which ensure that gregarious settlement perpetuates. Lewis (1975) found lab-reared *P. polymerus* larvae could only be stimulated to settle in the presence of a healthy, adult conspecific. Hoffman (1988) pondered the cirripede's ability to settle on peduncle-like substrate after observing that *P. polymerus* juveniles colonized a settlement plate only after acorn barnacle spat had accumulated on the plate. Helms (2004) studied the precise placement of *P. polymerus* spat around an adult's peduncle and proposed a mechanism of capitular hydrodynamics which traps conspecific larvae in an eddy, directing them toward the adults' capitular-peduncle junction.

Still, questions remain. Do these clusters prevent desiccation, discourage predation, and/or create more favorable micro-environments in which juveniles can thrive? Furthermore, do the potential advantages of gregarious settlement change from one life stage to the next? Finally, can the realized benefits, whatever they may be, even be measured? Ultimately, it is important to know whether the overall fitness of *P. polymerus* individuals improves due to gregarious settlement. *P. polymerus* individuals are highly vulnerable in the early stages of life, and so their need for environmental mediation may be at its highest during this period of development. Answering these questions could support the production of efficient aquaculture systems as an alternative to harvesting natural populations.

This study examines the growth rate of juveniles through mimicry and manipulation of a hypothetical environment within a cluster to determine if any benefit results from gregarious settlement. The study addresses two questions: 1) Is the growth rate of early juveniles dependent

on the velocity of the water in which they feed? and 2) Does settlement on conspecifics benefit early juveniles by increasing juvenile growth rate? The corresponding hypotheses are that 1) The growth rates of early juveniles will be slower at the lowest experimental velocities and 2) The growth rates of early juveniles will be greater for individuals settled on adult conspecifics.

2. MATERIALS AND METHODS

2.1. SPECIMEN COLLECTION

Specimens were collected from wave-exposed rocks in the intertidal zone near the entrance to the Coos Bay estuary (43°21'00.3"N, 124°19'54.2"W). Collection occurred between May and July of 2021. The boulders on which the *P. polymerus* clusters resided, in addition to the *P. polymerus* clusters themselves, were chosen at random. Clusters surrounded by or next to mussel beds (*Mytilus* spp.) were excluded. A crowbar and hammer were used to separate clusters, including some of the rock surface, from the boulders to avoid rupturing or otherwise compromising the peduncles of *P. polymerus* adults. Harvested specimens came from the edge of clusters, and no more than one-third of a cluster was removed per harvest. Collected organisms were placed in a sea table at 11°C with air stones and constant supply of unfiltered seawater for four days to confirm survivorship. Forty-six individuals were subjected to the solitary treatment (explained below) in each trial, while an additional 46 individuals were subjected to the gregarious treatment (explained below) in each trial.

2.2. EXPERIMENTAL VELOCITY GRADIENT

To create a velocity gradient in which to place the barnacles, an apparatus consisting of a 60 cm plexiglass disc connected at its center by an axle and bearings to a variable speed motor was constructed. The apparatus was oriented so that the disc was horizontal and below the surface of the sea water, with the shaft extending up out of the water to connect with the motor (Figure 1a).

Four plexiglass strips (27 cm x 2.5 cm x 0.5 cm) were attached with screws to the underside of the plexiglass disc to create four equidistant spokes (Figure 1b). Two of the strips, located opposite each other, had inverted 1.5 mL microcentrifuge tubes; these tubes were attached by superglue to the strips at 2 cm intervals. Individual *P. polymerus* juveniles were attached by superglue to the widest part of the conical end of the microcentrifuge tube. These individuals were part of Treatment 1 and are referenced throughout the study as solitary juveniles. On the other two strips, *P. polymerus* adults were attached directly to the plexiglass strip with superglue, each placed 2 cm apart from the others. Juveniles living on the peduncle of the fastened adults were part of Treatment 2 and are referred to as gregarious juveniles. All organisms were attached to their substrata in the same orientation, ensuring their extended cirral fans would face oncoming water. Barnes and Reese (1960) found that the species consistently achieved capitular orientation, always facing the rush of water subsequent to a wave breaking. While this suggests that the organisms could have achieved the preferred orientation themselves, the timeline and data necessary for this project required that optimal capitular orientation for feeding be established at the start of the experiment. During a trial, organisms were fully submerged for the entirety of the trial. Trials lasted between two and three weeks.

To calculate the free-stream flow velocity (v) experienced by a *P. polymerus* juvenile at any given distance from the disc center (r), each juvenile's distance along the disc radius was recorded, as was the time elapsed for one complete rotation of the disc (t). Velocity was thus calculated using the following equation:

$$v = \frac{2\pi r}{t}$$

The experimental free-stream velocities ranged from +15 cm/s to +180 cm/s. The upper end of the velocity gradient was limited by the equipment available. The local velocities experienced at the level of the cirral fans were less than the free-stream velocities due to the presence of the boundary layer and the possible entrainment of the water by the rotating disc, but the precise local velocities were not measured.

2.3. FOUR TRIALS EXAMINING GROWTH OF JUVENILES

Trials 1 and 2 were performed in the field at the Charleston Marina in Charleston, OR (43°20'44.0"N, 124°19'41.7"W). The motor and shaft were secured to a floating dock. The plexiglass disc rested horizontally in the water column 20 cm below the surface of the water. At the lowest low tide of the season, the disc was positioned 0.5 m above the ocean floor. A 2-m oil-sorb semicircle attached to the dock on either side of the disc prevented the collection of flotsam drawn in by the vortex from the spinning disc.

To control for the potential of marina pollutants to affect the growth of the study organisms, Trials 3 and 4 were performed in a rectangular tank (1.7 m x 1 m x 0.4 m) at the Oregon Institute of Marine Biology (OIMB) campus. The horizontal disc was situated in the center of the tank, 15 cm below the surface of the water and 15 cm above the tank bottom. Fresh filtered seawater at 10°C was continually pumped into the tank. The contents of a 20-minute plankton tow with a 130 µm net were added to the tank as a food source on a daily basis. The tow was performed at the outer end of F-dock of the Charleston Marina one hour prior to high tide.

2.4. GROWTH RATE

Three days prior to the commencement of a trial, the initial rostro-carinal length (RC_i) of each juvenile was recorded to the nearest 0.1 µm using the calibrated reticle on a dissecting microscope. The size of the experimental individuals ranged from 1-3 mm RC. Treatment 1 juveniles (solitary) were removed from adult peduncles by dissecting forceps. Once measured, juveniles were attached with superglue to the inverted microcentrifuge tubes and floated in a sea table for three days to confirm survivorship. Treatment 2 juveniles (gregarious) were located along the stalk of adult conspecifics. Non-target juveniles were preened from the adult's peduncle so that the number of target juveniles on a stalk never exceeded two. Upon completion of a trial, the barnacles were preserved in 70% EtOH and stored in the dark at room temperature. Mortality was documented and considered as absence of the individual or RC_f lengths that were equal to or less than the individual's initial RC. The final rostro-carinal measurements (RC_f) were recorded within

five days of trial completion. Growth rates (GR) in this study are quantified as millimeters of RC growth per week determined by:

$$GR = \frac{RC_f - RC_i}{\# \text{ of weeks in trial}}$$

2.5. DATA ANALYSIS

For Treatments 1 and 2 (solitary and gregarious), growth rates of *P. polymerus* juveniles from each of the four trials were graphed as a function of flow velocity on separate scatter plots. Correlation coefficients and two-tailed p-values were calculated for each scenario (Zar, 1984). The analysis did not control for differences in RC_i lengths because juveniles on either end of the size spectrum exhibited some of both the highest and lowest observed growth rates.

Because the water velocity only impacted growth of one treatment of only two trials, the growth data for each trial was analyzed with a t-test, comparing treatments (solitary versus gregarious) using JMP statistical software.

3. RESULTS

3.1. EFFECT OF VELOCITY ON GROWTH RATE

Growth (change in RC/week) was highly variable in both treatments and for all four trials. While mortality occurred (36% for solitary treatment; 39% gregarious treatment), it was not disproportionately related to a particular velocity or range of velocities. In addition, because overall mortality was higher for gregarious juveniles, it was assumed that mortality seen in solitary individuals was not a result of the transplant process. For both treatments, there was either no effect of velocity on RC growth or a negative effect at higher velocities for one of the two treatments in a trial. In Trials 1 and 2, growth rates ranged from 0.1 to 1.0 mm/week, while in Trials 3 and 4, growth rates ranged from 0.1 to 0.6 mm/week. In Trials 1 and 2 (Charleston marina), there was no significant effect of velocity on growth for either of the two treatments. Growth rates in Treatment 1 of Trial 2 had the lowest correlation to velocity compared to all other trials (Table 1 and Figure 2).

In Trials 3 and 4 (rectangular tank), growth rate of individuals in Treatment 1 did not vary with flow velocity. However, individuals in Treatment 2 had significantly slower growth rates at higher flow velocities in both trials (Table 1, Figure 2).

In all other models, positive and negative correlations between growth and velocity were nonsignificant (Table 1), a finding which suggests that growth rate in *P. polymerus* juveniles was not impacted by the velocity of the water in which they feed.

3.2. EFFECT OF SETTLEMENT LOCATION ON GROWTH RATE

Because of the limited effect of flow velocity on juvenile growth rate, the data for each treatment were treated as population samples, and the mean growth rates were compared

between treatments within trials. For three of the four trials (Trials 1, 3, and 4), there was no significant difference in growth rate between the two treatments (Table 2). The only statistically significant difference in growth as a function of settlement location occurred in Trial 2 (marina environment), during which juveniles in Treatment 2 demonstrated greater growth rates than those in Treatment 1. *Pollicipes* juveniles grew at a given rate regardless of whether they settled on the primary substrate or the peduncle of a conspecific (Table 2).

4. DISCUSSION

4.1. EFFECT OF FLOW VELOCITY ON EARLY JUVENILE GROWTH RATE

The results of this study show that continuously submerged *P. polymerus* juveniles grew at a rate that was independent of the flow velocity of water in their immediate environment. The temperature and nutritional conditions during the study were similar to those of the natural environment, with water temperatures around 9°C (NERRS 2021) and a range of flow velocities between +15 cm/s and +180 cm/s. The growth rates observed in this analysis (0.1 to 1.2 mm/week) were greater than those reported in other studies of *P. polymerus* juveniles in similar environmental conditions: 0.2 to 1.2 mm RC growth per month (Jacinto et al. 2015, Lewis and Chia 1981, Paine 1974). Hoffman (1988a, 1988b) reported juvenile growth rates between 4 and 9 mm per month in the warmer coastal waters of southern California at approximately 20°C.

Page (1986) found that the average capitulum height growth rate of permanently-submerged *P. polymerus* adults on offshore oil platforms was 3.5 times that of coastal individuals subject to tidal fluctuations. The specimens in this study were fully submerged for the entirety of the trial. Although no literature exists corroborating the relationship of *P. polymerus* capitulum height (length from base of capitulum to top of tergum) growth with RC growth, it stands to reason that there is a positive correlation between the two. Based on this assumption, one could deduce that RC growth rates are slower in cold-water, tide-influenced populations and increase in warm-water, permanently-submerged populations.

It is also possible that water quality in the marina environment in Trials 1 and 2 negatively impacted RC growth in comparison to what could be achieved in a system with a lower level of human influence. Even so, this study's growth rates were higher than intertidal juvenile rates reported by Paine (1974) and Lewis and Chia (1981), supporting the use of the Charleston marina as a viable substitute for in situ water parameters.

In the tank environment, the average growth rate for both treatments was half that for individuals in the marina environment. The slower growth seen in individuals from the tank trials (Trials 3 and 4) was likely a result of insufficient amounts of food. Although supplementary phytoplankton (>130 µm in diameter) was added to the tank on a daily basis, the diets of *P. polymerus* juveniles sized 1 to 6 mm RC consist primarily (92%) of organic particulate matter with diameters less than 10 µm (Lewis 1981). Not only are juvenile feeding appendages in this size class smaller than those of adult conspecifics, but they also employ an entirely different mode of feeding called pumping, which is often also observed in acorn barnacles of all sizes (Lewis 1981). The frequency of pumping in *P. polymerus* juveniles decreases in faster currents, eventually

ceasing altogether and being replaced by continuous extension of the cirral fan as seen in adult conspecifics (Lewis 1981). However, Lewis did not specify what constituted a fast current, so the exact threshold at which pumping ceases remains unknown.

It is possible that Lewis' threshold was surpassed in this particular experiment, since the "fast current" in the Lewis study was described as being faster than the "calm water of laboratory tanks." It is not clear at what velocity the juveniles switch feeding behavior or whether feeding behavior changed along the experimental range of velocities, though Trager et al. (1990) found that the acorn barnacles *Semibalanus balanoides* switched from active pumping to passive cirral extension at water velocities of 3.10 cm/s. Furthermore, it is unclear whether the switch in behavior is a response to greater concentrations of particulates passing the organism in a given amount of time or to faster currents preventing pumping behavior in some way. Interestingly, Barnes and Reese (1960) found that stimulation of cirri by a water jet yielded a prompt capitular reorientation response from *P. polymerus* populations, so it is likely that the juveniles' cirri are receiving some form of input from the faster current and responding to it by means of reorientation. Due to how 1) this study did not record the mode of feeding utilized by juveniles at each experimental velocity, 2) there are no studies comparing the feeding efficiency of the two modes, and 3) there are no studies yet determining the feeding mode of juveniles in clusters in situ, it is difficult to know how the mode of feeding effected the growth rates of experimental individuals, if at all.

Across an experimental velocity gradient of +15 cm/s to +180 cm/s in a tank environment, flow velocity seemingly had no effect on the growth rate of continuously-submerged, solitary *P. polymerus* juveniles (Treatment 1). The growth rate of gregarious juveniles (Treatment 2), however, appeared to have been negatively affected by increased flow velocity. Upon factoring in the dominant particle size of available food (> 130 μm), it appears that growth rates of gregarious juveniles decrease as current velocity increases when appropriately-sized food abundance is low. If the immediate proximity of adult conspecifics, whose diet consists of particulate (< 10 μm , 52%) and large (> 10 μm , 40%) organic matter is taken into consideration, it is possible that, in some way, the adults negatively impact nearby juvenile growth, with the effects increasing in magnitude as current velocity increases.

The hypothesis that growth rates of early juveniles would be slower at lower current velocities was additionally based on previous findings suggesting that *P. polymerus* individuals have specific habitat preferences. The average maximum speed of breaking waves for a wave-exposed, rocky intertidal ranges from 4.26 to 4.41 m/s (Marchinko 2003), so the higher end of the experimental velocity gradient was intended to mimic moderate flow velocities experienced in situ. The lower end of the gradient was meant to simulate flow velocities slower than what would typically be experienced in the natural environment. Eckmann and Duggins (1993) reported no change in growth rate of *P. polymerus* adults over a narrow velocity gradient (2 to 14 cm/s) and interpreted this as unsurprising, given that *P. polymerus* individuals are known to inhabit exclusively high-energy environments.

Additionally, the shelter provided by a conspecific cluster leads one to question the conditions and microenvironment present within a *P. polymerus* cluster, an environment in which current speeds are moderated by eddies, shear, and boundary layers. While my study did not examine the microenvironment surrounding solitary or gregarious juveniles specifically, it was designed to mimic and manipulate a potential circumstance within the cluster. Whether or not a microenvironment with moderated velocity exists remains to be seen. As a hypothetical facet of the microenvironment, however, moderated (i.e., slower) flow alone does not positively affect early juvenile growth rate to the degree that it is a driving force for either evolution or the maintenance of gregarious behavior.

4.2. EFFECT OF SETTLEMENT LOCATION ON EARLY JUVENILE GROWTH RATE

The effect of settlement location on early juvenile growth varied between trials. Only one of the four trials, Trial 2, was significant (Table 2), with faster growth occurring on conspecifics. However, growth rates of solitary or gregarious juveniles were not different in the other three trials. Unlike the relationship between flow velocity and growth rate found in the tank trials (Trials 3 and 4), this result occurred in the marina (Trial 2).

Although the overall analysis did not demonstrate a relationship between growth rate and settlement location — and thus, did not support the hypothesis — the significant results from Trial 2 suggest that further research must still be completed in this area of scholarship. For one, the substantially-larger sample size of Trial 2 not only bolsters the credibility of the probability value, but also calls into question the results of the other trials. In other words, Trials 1, 3, and 4 may have been insufficiently powered to detect a true difference between groups, suggesting a comparison of larger populations may have garnered different results.

Another possible explanation for the observed results is that the duration of the trial was too short to see any significant trends in growth rate. Cirripeds are known for the phenotypic plasticity of their cirral fans and subsequent propensity to alter fans in response to the flow of their environment (Marchinko 2003b). The range in balanomorph plasticity is much greater than that of gooseneck barnacles, as acorn barnacles inhabit a variety of environments subject to different degrees of wave-exposure. Even so, 92% of variation in *P. polymerus* leg length can be explained by water velocity (Marchinko 2003a). This plasticity is achieved by molting, a process that begins to occur in *P. polymerus* adults eight days after perturbation in experimental systems, with subsequent molts occurring in excess of thirty days later (An et al. 1971, Page 1983). Given these temporal relationships between adjustments in cirral dimensions and the resultant increase in feeding efficiency for a given flow environment, trials in this study would have had to last at least 30 days to see if the effects of the various treatments would translate into increased growth rates, assuming that *P. polymerus* juveniles molt at least as often as adult conspecifics. If my trials (two- and three-week durations) had lasted longer, the juveniles may have adjusted their cirral fan dimensions in accordance with the conditions of their settlement location and flow velocity, and greater growth rates may have been observed. Waters with in situ nutritional concentrations would be crucial according to Page's (1983) findings that ration alone can influence molting frequency between 31 and 40 days.

Finally, it is unlikely that the gregarious treatment adequately simulated naturally-occurring conditions in a *P. polymerus* cluster. It would be difficult to recreate the conditions of the inside of a cluster and maintain the experimental design while measuring the original variables (RC growth with respect to flow velocity). The methodology behind this particular study allowed me to achieve a simulation of the conditions at the edge of a cluster. Helms (2004) found that juveniles grew faster when settled on adults at the edge of a cluster than when settled on adults in the center of clusters. Ideally, effects would be more immediately discernible by attempting to simulate edge-like conditions. Because this study did not examine the growth rates of juveniles surrounded by more than one conspecific, it is difficult to say whether the faster growth rates associated with edge-like conditions were present. It also raises the following question: Does having fewer adult conspecifics in the immediate vicinity result in faster growth? Further examination of this hypothesis may help ecologists understand the costs and benefits of gregarious settlement at the early juvenile life stage.

The second hypothesis of this study was that the growth rate of early *P. polymerus* juveniles would be greater for individuals settled on adult conspecifics. It was postulated that gregarious settlement would be preferred to solitary settlement in early life stages because of the benefit of immediate proximity to an adult conspecific; this would increase fitness by increasing a juvenile's growth rate. However, the results of this study suggest that further investigation with modified parameters is necessary to conclusively determine whether attachment or proximity to an adult conspecific improves early juvenile fitness to the effect that it boosts growth beyond what is seen in solitary juveniles.

5. CONCLUSION

A gregarious lifestyle, common among some biota, is thought to increase individuals' overall fitness, and thus, the likelihood that they successfully reproduce. In this study, growth rate was used as a proxy to measure increased or decreased fitness of early *P. polymerus* juveniles. Both flow velocity and settlement location were manipulated to assess the dependence of growth rate on either factor. The experimental velocity gradient, containing both natural and unnatural water speeds, proved inconsequential to the growth rate for juveniles in a marina environment, a finding which did not support the initial hypothesis. In an environment with limited nutritional resources, increased velocity negatively affected gregarious juvenile growth, while growth of solitary juveniles remained independent of flow velocity. Excluding velocity as a contributing factor, a comparison of average growth between solitary and gregarious treatments proved significant in only one of the four trials. Across all trials, analysis suggests that settlement on a conspecific does not improve the growth rate, and therefore fitness, of *P. polymerus* juveniles. Improved growth rate at early *P. polymerus* life stages may not be a direct benefit of gregarious settlement.

5.1. FUTURE DIRECTIONS

The findings of this study reveal there is still much to be uncovered about the evolutionary pressures which selected for gregarious settlement in *P. polymerus* juveniles. Further

investigation into areas such as the conditions and dynamics of the microenvironment in a cluster, the effects of different feeding modes in juveniles, and the effects of the density of conspecifics in a juvenile's immediate vicinity could be very beneficial for ecologists' collective appreciation of the minutia at play. Furthermore, modifications to this particular experimental design could prove incredibly useful. These modifications could take the form of extending the trial duration, increasing the sample size, or creating a treatment where juveniles are at the primary substrate level rather than up on a promontory (which would more closely simulate conditions of the cyprid settling on rock substrata). Ultimately, answering the questions posed in this article will help point the scientific community toward the best parameters for a barnacle aquaculture system, which would in turn eliminate the need to harvest natural *P. polymerus* populations. It would also help educate potential barnacle harvesters on the most sustainable practices to avoid population destabilization and/or extinction.

6. TABLES AND FIGURES

6.1. TABLE 1

Trial	Treatment	R ²	r	n	df	p-value
1	1	0.075	0.274	22	20	<0.50
1	2	0.008	0.0894	20	18	>0.50
2	1	0	0	30	28	>0.50
2	2	0.003	0.0548	35	33	>0.50
3	1	0.015	0.122	21	19	>0.50
3	2	0.262	0.512	32	30	<0.01*
4	1	0.062	0.249	26	24	<0.50
4	2	0.156	0.394	31	29	<0.05*

Linear regression for each trial and associated treatments comparing effect of flow velocity on juvenile rostrum-carinal growth rate. Note: Trial 1 and Trial 2 (marina environment), Trial 3 and Trial 4 (tank environment), Treatment 1 (solitary juvenile), and Treatment 2 (gregarious juvenile).

* represents a significant result.

6.2. TABLE 2

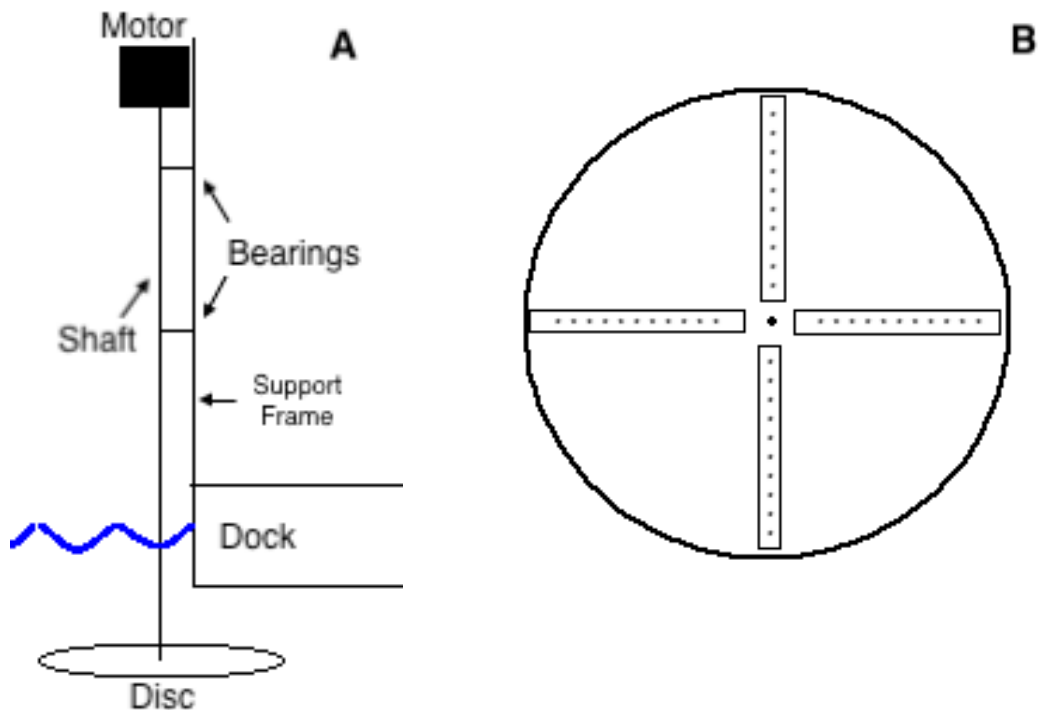
Trial	df	t-ratio	Prob > t
1	40	-0.0005	0.9996
2	65	3.848	*0.0003
3	53	-0.0755	0.9402
4	55	1.534	0.1308

Results from two-tailed t-Tests on RC growth (mm/wk) by treatment for each trial.

Note: Trial 1 and trial 2 (marina environment); Trial 3 and Trial 4 (tank environment).

* represents a significant result.

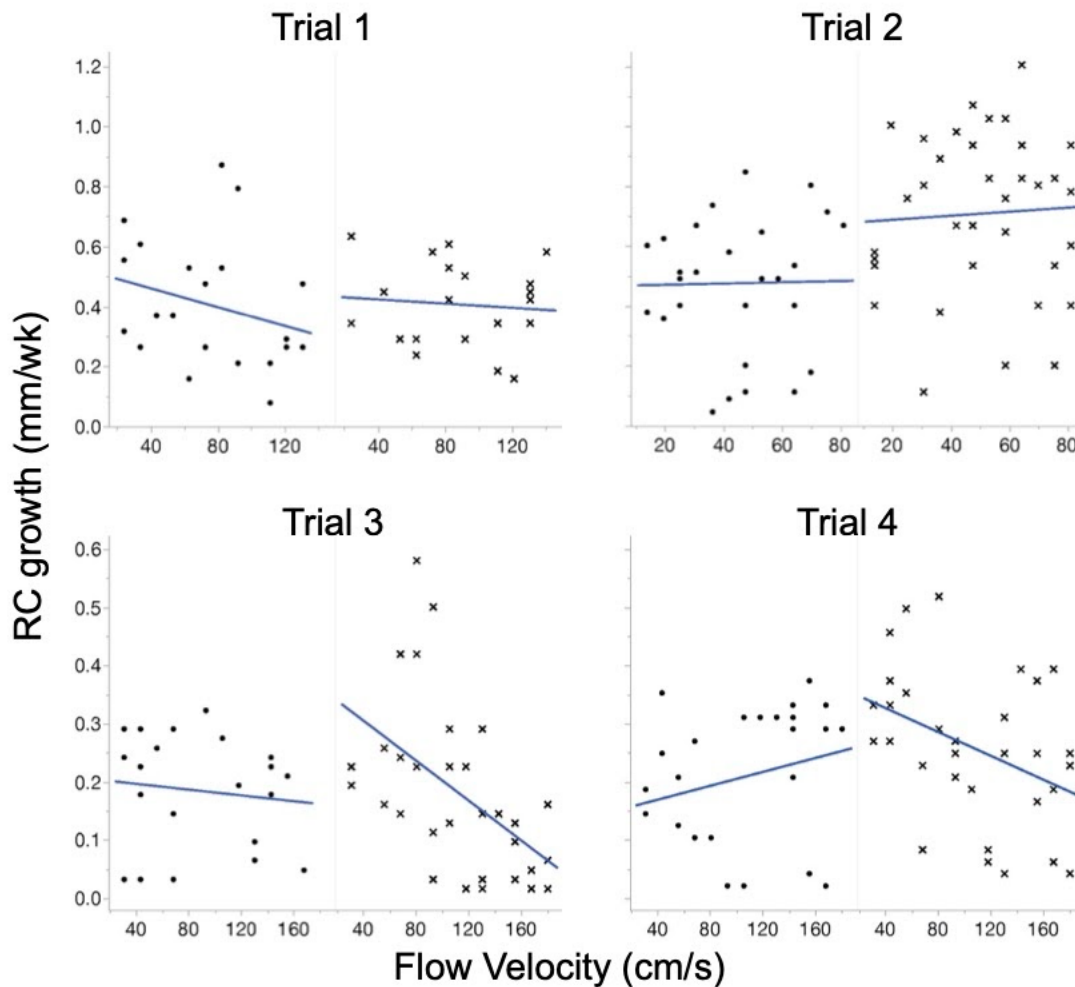
6.3. FIGURE 1



Schematic of the apparatus and plexiglass disc constructed to create the experimental velocity gradient.

Note: (A) Side-view schematic of spinning disc apparatus. Setup is depicted in the Charleston Marina environment. (B) Underside view of plexiglass disc and the four attached plexiglass strips to which the barnacles were adhered.

6.4 FIGURE 2



Note: Scatter plots for all four trials. Note: Blue Line models linear regression. Treatments in like trials are shown on the same graph side-by-side; Treatment 1 left panel (•); Treatment 2 right panel (×).

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REFERENCES

- An, O., Crustacean, I., Fyhn, H. J., Petersenf, J. A., & Johansenj, K. (1971). *Eco-physiological studies of an intertidal crustacean, Pollicipes polymerus (Cirripedia, Lepadomorpha)*.
- Barnes, H., & Reese, E. S. (1960). The Behaviour of the Stalked Intertidal Barnacle *Pollicipes polymerus* J. B. Sowerby, with Special Reference to its Ecology and Distribution. *Journal of Animal Ecology*, 29(1), 169–185. <https://doi.org/10.2307/2276>
- Bingham, J., Thomas, M., & Shanks, A. (n.d.). *Development of a Sustainable Gooseneck Barnacle Fishery; Initial Investigations*.
- Cimberg, R. L. (1981). Variability in brooding activity in the stalked barnacle *Pollicipes polymerus*. *The Biological Bulletin*, 160(1), 31–42. <https://doi.org/10.2307/1540898>
- Eckman, J. E., & Duggins, D. O. (1993). Effects of Flow Speed on Growth of Benthic Suspension Feeders. *The Biological Bulletin*, 185(1), 28–41. <https://doi.org/10.2307/1542128>
- Gardiner, M. (2015). The most expensive seafood on the Rock: Percebes. San Diego Food & Travel. <https://sdfoodtravel.com/the-most-expensive-seafood-on-the-rock/>
- Helms, A. (2004). *Living on the edge: Juvenile recruitment and growth of the gooseneck barnacle Pollicipes polymerus*. <https://scholarsbank.uoregon.edu/xmlui/handle/1794/3716>
- Hoffman, D. (1988) *Settlement and Growth of the Pedunculate Barnacle Pollicipes polymerus Sowerby in an Intake Seawater System at the Scripps Institution of Oceanography, La Jolla, California*. <https://scholarspace.manoa.hawaii.edu/bitstream/10125/1074/1/v42n3n4-154-159.pdf>
- Hoffman, D. (1988). *Settlement and recruitment patterns of the pedunculate barnacle, Pollicipes polymerus Sowerby, off La Jolla, California*. [https://doi.org/10.1016/0022-0981\(89\)90036-1](https://doi.org/10.1016/0022-0981(89)90036-1)
- Jacinto, D., Penteado, N., Pereira, D., Sousa, A., & Cruz, T. (2015). Growth rate variation of the stalked barnacle *Pollicipes pollicipes* (Crustacea: Cirripedia) using calcein as a chemical marker. *Scientia Marina*, 79(1), 117–123. <https://doi.org/10.3989/scimar.04135.08B>
- Lewis, C. A. (1975). Development of the gooseneck barnacle *Pollicipes polymerus* (Cirripedia: Lepadomorpha): Fertilization through settlement. *Marine Biology*, 32(2), 141–153. <https://doi.org/10.1007/BF00388507>

- Lewis, C. A. (1981). Juvenile to Adult Shift in Feeding Strategies in the Pedunculate Barnacle *Pollicipes polymerus* (Sowerby) (Cirripedia, Lepadomorpha). *Crustaceana*, 41(1), 14–20.
- Lewis, C. A., & Chia, F.-S. (1981). Growth, fecundity, and reproductive biology in the pedunculate cirripede *Pollicipes polymerus* at San Juan Island, Washington. *Canadian Journal of Zoology*, 59(6), 893–901. <https://doi.org/10.1139/z81-128>
- López, D. A., López, B. A., Pham, C. K., Isidro, E. J., & De Girolamo, M. (2010). Barnacle culture: Background, potential and challenges. *Aquaculture Research*, 41(10), e367–e375. <https://doi.org/10.1111/j.1365-2109.2010.02508.x>
- Marchinko, K. (2003). *Feeding in flow extremes: Dependence of cirrus form on wave-exposure in four barnacle species*. <https://doi.org/10.1078/0944-2006-00107>
- Marchinko, K. B. (2003). Dramatic Phenotypic Plasticity in Barnacle Legs (*balanus Glandula Darwin*): Magnitude, Age Dependence, and Speed of Response. *Evolution*, 57(6), 1281–1290. <https://doi.org/10.1111/j.0014-3820.2003.tb00336.x>
- National Estuarine Research Reserve System. (2021) <https://coast.noaa.gov/nerrs/reserves/south-slough.html>.
- Page, H. (1986). Differences in population structure and growth rate of the stalked barnacle *Pollicipes polymerus* between a rocky headland and an offshore oil platform. *Marine Ecology Progress Series*, 29, 157–164. <https://doi.org/10.3354/meps029157>
- Page, H. M. (1983). Effect of water temperature and food on energy allocation in the stalked barnacle, *Pollicipes polymerus* Sowerby. *Journal of Experimental Marine Biology and Ecology*, 69(2), 189–202. [https://doi.org/10.1016/0022-0981\(83\)90067-9](https://doi.org/10.1016/0022-0981(83)90067-9)
- Paine, R. T. (1974). Intertidal community structure. *Oecologia*, 15(2), 93–120. <https://doi.org/10.1007/BF00345739>
- Pilsbry, H. A. (1907) The barnacles (Cirripedia) contained in the collections of the U. S. Natinal Museum. The Lepadidae. *U.S. Natl. Mus. Bull*, 60, 1-122.
- Riipi, M., Alatalo, R. V., Lindström, L., & Mappes, J. (2001). Multiple benefits of gregariousness cover detectability costs in aposematic aggregations. *Nature*, 413(6855), 512–514. <https://doi.org/10.1038/35097061>
- Romera, A. (2018). *Growing Goosenecks: A Study on the Growth and Bioenergetics of Pollicipes polymerus in Aquaculture* [M.S., University of Oregon]. <https://www.proquest.com/docview/2139743216/abstract/B5B6807A394F4428PQ/1>
- Trager, G. C., Hwang, J.-S., & Strickler, J. R. (1990). Barnacle suspension-feeding in variable flow. *Marine Biology*, 105(1), 117–127. <https://doi.org/10.1007/BF01344277>

Wu, R. S. S. (1981). The effect of aggregation on breeding in the barnacle *Balanus glandula* Darwin. *Canadian Journal of Zoology*, 59(6), 890–892. <https://doi.org/10.1139/z81-127>

Zar, J. (1984). *Biostatistical Analysis* (2nd ed.). Prentice Hall. <https://alliance-primo.hosted.exlibrisgroup.com>