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Development of a Sustainable Gooseneck Barnacle Fishery; Initial Investigations

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Pollicipes, Pollicipes polymerus, gooseneck, percebes, barnacle, mariculture, aquaculture, growth, diet, fishery development, stock assessment, sustainable fishery management, stakeholder collaboration

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ABSTRACT

In Spain, gooseneck barnacles, "percebes," are an overfished delicacy fetching a high market price ($50/lb). Oregon fishing communities show interest in developing a percebes market utilizing *Pollicipes polymerus*. We aim to inform resource managers to avoid over harvesting Oregon goosenecks. In summer 2016, we investigated the current status of *P. polymerus* populations with three primary objectives:

A. Describe Oregon gooseneck populations on coastal jetties to inform harvest management.
B. Explore possible mariculture development for onshore gooseneck production.
C. Establish a collaborative multistakeholder framework for sustainable fishery development.

We surveyed eight southern Oregon jetties using transect sampling and photographic documentation of gooseneck populations, which we characterized by size-frequency distribution and density. We observed spatially explicit trends according to tidal height and large variability in populations between jetties. We estimate there to be roughly one billion adult goosenecks populating the surveyed jetties. Only 2% of these are of harvest-size, providing an Oregon percebes stock of up to 235,000 kg. Our surveys suggest that wild populations of *P. polymerus* are unlikely to sustain long-term commercial harvest should the market significantly expand beyond its current size without implementing adaptive management practices. Affordable mariculture should be established to avoid overharvest in a growing market. We designed a promising prototype for a relatively simple, affordable and effective onshore mariculture design to supplement commercial gooseneck production, with the ability to enhance barnacle growth rates using food supplementation. Throughout the project, we maintained frequent communication with multiple stakeholders to focus our objectives and used public seminars to communicate our findings and their implications to interested harvesters, managers, and the public. Our research expands the knowledge base informing a viable, sustainable fishery. It uniquely joins science, management and fishery expansion in a preemptive approach to combat overfishing and a later need for restorative management while pursuing collaborative and sustainable small-scale fishery development.

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PROJECT OVERVIEW

Species of interest: *Pollicipes polymerus* (Sowerby, 1883)

In Spain, the gooseneck barnacle (*Pollicipes* spp.), "percebes," is an overfished delicacy fetching a high market price ($50/lb) (personal observation, Dec. 2015). The popularity of percebes is no longer exclusive to the Iberian Peninsula; Oregon fishing communities show interest in developing a gooseneck barnacle market utilizing *Pollicipes polymerus*, which is relatively abundant and underutilized species on the Pacific coastline of North America. The Iberian percebes were over fished causing detrimental ecological and socioeconomic consequences before sustainable management practices were established (Molares and Freire 2003; Bald et al. 2006). In starting a new gooseneck barnacle fishery in the Pacific Northwest, it would be wise to learn from the mistakes made in the Iberian fishery to avoid overfishing. Currently, only minimal regulations exist for gooseneck barnacle harvest on both recreational and commercial scales in Oregon (Oregon Department of Fish and Wildlife 2015). These regulations are neither based on any known stock assessment nor on any recent biological research. Overall, *P. polymerus* research literature is severely lacking in the Pacific Northwest. In the summer of 2016, we pursued initial research to fill this information gap with the purpose of informing appropriate fishery management so as to avoid overfishing *P. polymerus* should the fishery expand.

We designed our research to fulfill the following three primary objectives:

A. Describe current gooseneck populations for informed harvest and management and to identify trends to pursue in future research.
B. Explore the possibility of mariculture development for on shore gooseneck production.
C. Establish a collaborative multistakeholder framework for sustainable fishery development.

Objective A

The Oregon Department of Fish and Wildlife (ODFW) currently limits commercial fishing for gooseneck barnacles in Oregon to man-made structures (jetties) yet we have limited information on populations in these habitats. To address this knowledge gap we aimed to answer the following questions:

1. What is the structure of gooseneck barnacle populations on jetties?
2. What is the overall density and the density of adults, new recruits and settlers?
3. Can we summarize jetty populations with an estimated available stock of harvest-sized individuals within the overall population?
4. Are there spatial trends of size, density, distribution, and size frequency between and within jetties?

In summer 2016, we surveyed the gooseneck populations of eight jetties between Winchester Bay and Brookings, Oregon using observational transect-quadrat methods. Using photo documentation of quadrats analyzed with standard ImageJ software techniques (Rasband 1997-215), we collected descriptive data of the overall abundance of goosenecks on southern Oregon jetties and their distribution and density relative to jetty location and tidal height. From each transect we collected representative random samples of clusters of gooseneck barnacles, which we disarticulated to generate size frequency distributions. These data allowed us to describe jetty populations of gooseneck barnacles with both descriptive information of stock availability as well as the identification of potential trends in life history and ecology of the species, providing a foundation of knowledge upon which future projects can be developed.

Objective B

Should harvest increase in an expanding Oregon gooseneck barnacle market, jetty populations alone may not support a viable, sustainable fishery. To avoid overfishing, one option is the development of onshore mariculture: producing goosenecks for commercial sale using a grow-out facility to farm harvest-sized percebes. Previous studies of growth and development have shown that goosenecks can be kept alive within lab-based systems, but only with very high seawater flow rates and food supplementation (Norton 1996; Franco et al. 2015; & Page 1983). However, these designs are generally small scale, high cost and inefficient for expansion to mariculture scale. Using the OIMB seawater system, we designed a simple and cost-efficient prototype mariculture apparatus, which does not require high flow rates to stimulate barnacle feeding behaviors and thus reduces the energy requirement for sustaining such a system. After testing the design's ability to keep transplanted wild goosenecks alive within the system, we subsequently investigated whether we could manipulate growth rates through food supplementation. In wild populations juveniles grow rapidly, but adult barnacle growth rates slow precipitously, taking multiple years to reach harvest size (Lewis & Chia 1981) ; enhancing this growth rate would be substantially beneficial for the efficiency and cost-effectiveness of mariculture expansion.

Objective C
A key aspect of developing a sustainable fishery is having highly involved, dedicated, and communicative stakeholders. Collaboration between researchers, fishers, management groups and the general public enhances efficiency and effectiveness of developing, implementing and enforcing sustainable and productive ecosystem based management (Feldman & Khademian 2007; Hilborn 2007). We intentionally pursued relationship building with other stakeholders throughout our project to establish a collaborative framework and set the precedent for effective integration and application of this and future research in the Oregon gooseneck fishery. We strategized our collaboration around goals in project design, outreach, and application for our research results from Objectives A and B. Collaborative strategies included regular stakeholder meetings, transparency of research progress, fisher interest and manager involvement, public seminars and designing data reports accessible to stakeholders without background training in scientific research. Following the conclusion of our research efforts for Objectives A and B in November 2016, we have since continued to maintain contact with stakeholders and utilize public outreach and engagement through seminars and guest lectures. Stakeholders have engaged enthusiastically throughout the project, fully participating in public outreach and efforts to incorporate our research findings into decision making regarding the pursuit of developing a sustainable Oregon gooseneck fishery. Stakeholders included representatives from the following groups:

- University of Oregon's Oregon Institute for Marine Biology (OIMB)
- The Port Orford Sustainable Seafood (POSS) group
- Oregon State University (OSU) and the Port Orford Field Station
- Oregon Department of Fish and Wildlife (ODFW)
- Oregon Sea Grant

Significance and Broader Impact
Our research will expand the knowledge base to inform a potential fishery that is viable and sustainable. As basic science, sampling populations on jetties allows us to report the status of harvest-targeted gooseneck barnacles in terms of population trends for future biological research and population monitoring while providing an assessment of available stock for interested stakeholders. Because the market for percebes is extremely small, the current needs of the fishery can potentially be met by take from the wild jetty populations. If percebes become popular and the market expands, this may change. Assessing jetty populations will provide ODFW with knowledge essential to successful management.

For a viable fishery there must be a market. The existing Oregon market for gooseneck barnacles is tiny; Americans view barnacles as exotic and strange, much as squid were once viewed. Squid were bait, but by marketing them as calamari consumer perceptions have evolved and calamari is now found on menus of many seafood restaurants. The perception of goosenecks as a seafood delicacy is likewise changing, especially on the west coast of the United States. The fishing community shows interest in developing a market for percebes as a rare wild delicacy from the Oregon coast. Based on the Community Supported Agriculture business model, Port Orford Sustainable Seafood (POSS) runs a Community Supported Fishery (CSF). This is a captive marketplace of seafood consumers who receive a seasonal selection of species landed in Port Orford. By introducing members to novel seafood along with the story behind the product, they are able to change consumer attitude toward exotic, underutilized species. In the case of gooseneck barnacles, they would introduce them as percebes, a luxury seafood in Western Europe, traditionally served as a side dish after boiling in seawater. In this way they can begin to introduce percebes to Oregonians and initiate a market, which could support a fishery. As a local Port Orford seafood label and a local resource for fisheries information, POSS is in an excellent position to develop the market side of the fishery through its CSF while expanding public knowledge of local marine species and research efforts. POSS is interested in the findings of this study to determine if a wild harvest is sustainable under current regulations. If the findings prove otherwise, they hope the data could be used to explore a mariculture program. The ODFW Shellfish Program likewise looks to gain from our research efforts to establish a knowledge base that will help to inform and monitor future gooseneck harvest management decisions. By working concurrently with POSS and ODFW, our project creates an innovative and direct application pathway for research results to inform ecologically and socioeconomically sustainable resource management while empowering local fishers and managers to enhance collaborative relationships.

Research personnel

PI - Dr. Alan Shanks, Prof Marine Biology, Oregon Inst. of Marine Biology, UO. 40 yrs experience in marine biology.
Intern #1 - Julia Bingham, BS in Marine Biology and BA in International Studies at OSU. Honors thesis investigated seasonal and regional variations of Oregon *Pollicipes* life history patterns and explored socio-economic concerns of sustainable harvest of *Pollicipes*.
Intern #2 – Michael Thomas, BS Education with emphasis on Career and Technical Education, Northern Arizona University. Shanks lab research assistant, Oregon Inst. of Marine Biology, UO.

Project Partners

Tom Calvanese, Manager, Port Orford Field Station (OSU), BS Marine Biology, San Francisco State; MS Fisheries Science, OSU; Oregon Commercial Diver, Red Sea Urchin.
Mitch Vance, ODFW Shellfish Project Leader. He manages many recreational and commercial shellfish fisheries.
Mike Baran, CSF Program Manager for POSS. Previously a Fisheries Observer in Port Orford. Four years experience as an ecological tour guide. BS Biology, Armstrong Atlantic State University.
Kean Fleming, Marketing Director, POSS. Connects POSS customers with the Port Orford fishing story. Worked with NFWF to secure fishing rights at Port Orford via a CFA quota bank. Experienced in Natural Resources management and community organizing. BA, Anthropology, Reed College

OBJECTIVE A
Jetty Stock Assessment

Current status of P. polymerus populations on southern Oregon jetties

Julia Bingham, M. Thomas and A. Shanks

INTRODUCTION

Gooseneck barnacles, *Pollicipes* spp., are peduncular cirripeds including three major species: the well studied and heavily exploited *P. pollicipes* in Spain and Portugal, the less extensively studied and generally unexploited *P. polymerus* on northeastern Pacific coastlines, and the locally harvested but essentially unstudied *P. elegans* of the Pacific South American coastline (Molares & Freire 2003). The three species are morphologically similar, but most established knowledge of *Pollicipes* spp. physiology is based on research of Iberian species (Cruz 1993; Borja et al. 2006; Cruz et al. 2010). Most research of *P. polymerus* in the United States was conducted in northern Washington and in southern California over four decades ago (Barnes 1960; Cimberg 1981; Lewis & Chia, 1981; Page 1983, 1986, Hoffman 1989). Research on Oregon-specific populations has only begun within the last two years and is so far limited in scope (Bingham 2016, unpublished data).

Oregon's rocky intertidal habitats are exploited primarily for recreational tide pooling in upper and middle intertidal zones rather than for harvesting of species. Healthy populations of large hummocks of *P. polymerus* are common in Oregon's wave-exposed rocky intertidal zones, and are so far relatively unimpacted by humans. However, in the last two years interest in collection of goosenecks as a food item by both private recreational fishers and commercial harvesters is increasing. We are aware that gooseneck barnacles are particularly susceptible to detrimental effects of overharvest and fishery mismanagement, as demonstrated by the history of *P. pollicipes* fisheries in Spain and Portugal (Molares & Freire 2003; Bald et al. 2006; Rivera et al. 2016). Iberian *P. pollicipes* populations are still recovering more than two decades after *cofradias*, a sustainable fishery cooperative network strategy, were established to try and reverse the previously unsustainable rate of commercial harvest (Rivera et al. 2016). *P. polymerus* show similar life history traits to those of *P. pollicipes*, which make them an easily overfished species. For example, previous research of Oregon *P. polymerus* showed that the species is highly susceptible to long-term consequences of disturbance, requiring a minimum of one year to re-establish densities and a minimum of two years to return to having harvest-sized adults within patches after patch removal (Bingham 2016). Consequently, a newly expanding and uninformed fishery potentially threatens the health and resilience of Oregon *P. polymerus* populations.

The rocky intertidal zones of Oregon are fed by well-circulated and productive cold waters, making them ideal settlement locations for cirripeds, including *Pollicipes polymerus* (Menge 2000; Broitman et al. 2008). *Pollicipes* spp. create hummocks, dense but patchy clusters, on low intertidal zone rocks of coastlines with strong wave action and cold, highly oxygenated and nutrient-rich water (Barnes & Reese 1960, Molares & Freire 2003). They settle gregariously, requiring established patches of individuals for successful settlement, recruitment, and growth (Molares & Freire 2003, Bald et al. 2006; Borja et al. 2006). They cannot easily colonize bare rock, even when the settlement surface is in an ideal habitat zone. Recruits have been observed on the shells of *Mytilus* spp. in mid intertidal mussel beds and in dense clusters of Rhodophyta in mid to low intertidal zones where wave action is not too extreme for macrophytic algaes (Bingham 2016). It remains unclear how interspecies interactions and environmental factors including wave intensity, areal exposure, water and air temperatures and food availability specifically enhance or inhibit the spatially competitive dominance of *P. polymerus*. *Pollicipes* spp. are simultaneously hermaphroditic but reproduce sexually and are dependent on near proximity of other individuals for fertilization (Bald et al. 2006). Individuals brood asynchronously, with some evidence that reproduction in northern populations of *P. polymerus* are seasonally limited by warmer summer water temperatures (Cimberg 1981). They undergo a pelagic larval phase before cyprids settle onto the peduncles of established individuals, preferably large adults (Bald et al. 2006). Survival of recruits to subsequent size classes is low, and only a small percentage of each generation reaches sexual maturity (Paine 1974; Lewis & Chia1981). Further, after reaching an adult size, growth rates fall precipitously (Lewis 1981). A large delay therefore exists between patch establishment and the development of full hummocks containing large individuals. Recent research suggests that these general patterns appear to apply to existing *P. polymerus* populations on rocky shores of protected coastlines in central Oregon (Bingham 2016).

Harvest interest is highest in southern Oregon where, based on current regulations, commercial gooseneck harvest is limited to manmade structures; namely, jetties. No initial stock assessment or population survey has been conducted. We do not yet fully understand the population size, health, seasonal & regional variability of population dynamics or the potential impacts of harvest on local Oregon *P. polymerus* populations. We believe filling these knowledge gaps must be prioritized as commercial interest in gooseneck barnacles increases so that scientifically informed sustainable harvest strategies and effective management can be proactively established. Therefore, in the July - September 2016, we conducted observational surveys of *P. polymerus* populations exclusively on jetties of southern Oregon.

Our overall research objective, therefore, was to expand the available knowledge of Oregon *P. polymerus* populations. Together with local stakeholders, we established a list of questions within our overall objective. We developed these focal points to identify aspects of Oregon *Policipes polymerus* populations and life history traits necessary for informing a sustainable fishery and expanding species-specific biological knowledge of an understudied species:

Questions:

1. What is the current extent of percebes populations on Southern Oregon jetties, and what are their trends in abundance and size?
    a. How are gooseneck barnacle populations spatially distributed along the jetties?
    b. How many are there?
    c. How big are they?
    d. Are there enough large individuals to sustainably support a productive fishery?
2. Are there population trends that correlate with habitat components such as jetty location and tidal height? If so, can we attribute gooseneck barnacle population structure to habitat-specific contexts with enough accuracy to predict gooseneck populations on other potential harvest sites?

In order to answer these questions, we:

1. Described the extent and structure of gooseneck barnacle populations on southern Oregon jetties within the context of:
    a. Total habitat area
    b. Percent coverage of potential habitat
    c. Population density
    d. Size frequency distribution of individuals in a given population
    e. Patchiness (number of patches in a given habitat area)
    f. Gregarious settlement (number of cyprids and recruits settled on the peduncle of established individuals)
    g. Estimated total barnacle population
    h. Estimated total individuals of harvestable size or larger

2. Assess whether the above population metrics correlate with specific geospatial locations including jetty, tidal height and location along jetty relative to shore and jetty terminus. Identify gooseneck population trends to pursue in future research of *P. polymerus* life history research.

Expected Outcomes

We will provide data applicable to pursuing future scientific research of Oregon goosenecks and informing sustainable harvest management should commercial gooseneck harvest expand. We therefore aim to provide a comprehensive description of *P. polymerus* jetty populations. Additionally, we hope to identify questions of interest on trends of gooseneck population dynamics and life history to pursue further in future research. Initial research has shown similarities in population patterns between *P. polymerus* and *P. pollicipes* (Bingham 2016), and we used this knowledge to predict general population trends of Oregon goosenecks on our observed jetties. Longer jetties should have more extensive potential gooseneck habitat and therefore host larger populations of gooseneck barnacles. We expect to see a habitat range determined by similar maximum tidal heights on all jetties. Gooseneck barnacles are not generally observed above mid tide zones or around 1.5 m MLLW in southern Oregon, where duration of aerial exposure lasts for two hours or more. We expected that percent cover and densities of gooseneck populations would increase with decreasing tidal levels, as they generally dominate in lower tidal zones than mussels and prefer zones with more intense wave action and less aerial exposure at low tide (Barnes & Reese 1960; Lewis & Chia 1981). Similarly, we expected percent cover and densities increase closer to the point of the jetties, which extend into and beyond the surf zone and so should receive more wave action. We anticipated a maximum density of patches (patchiness) in the middle tidal range of habitats, with patch density decreasing at higher tidal levels and decreasing as larger patches merge at lower tidal heights. Size-frequency distributions should be dominated by recruits and juveniles at all jetties and across all zones (Bingham 2016). The proportion of adults may vary between and along jetties. We expected more large adults exist in the denser, larger patches and so likely are more abundant in lower zones and nearer to jetty points. Large, harvest size adults are likely a very small proportion of the population. There may actually be too small a stock of large individuals to sustain commercial harvest. Our observational study design will not allow us to conclusively attribute any population trends to specific abiotic conditions but will hopefully identify spatial patterns to investigate further in more targeted, experimental research.

METHODS

Jetty Observations

In July and August 2016, we conducted surveys of *P. polymerus* populations on jetties along the southern Oregon coast. We surveyed eight jetties at Winchester Bay, Coos Bay, Bandon, Port Orford, Gold Beach and Brookings (Fig. 1, Table 1). Due to time constraints and the inaccessible nature of the north jetties at several locations, we elected to focus our studies on the southern jetties at each bay. We conducted transect surveys during morning low spring tides in order to safely access as much of the low intertidal zone gooseneck habitat as possible. Figure 2 provides a visual representation of the jetties surveyed.

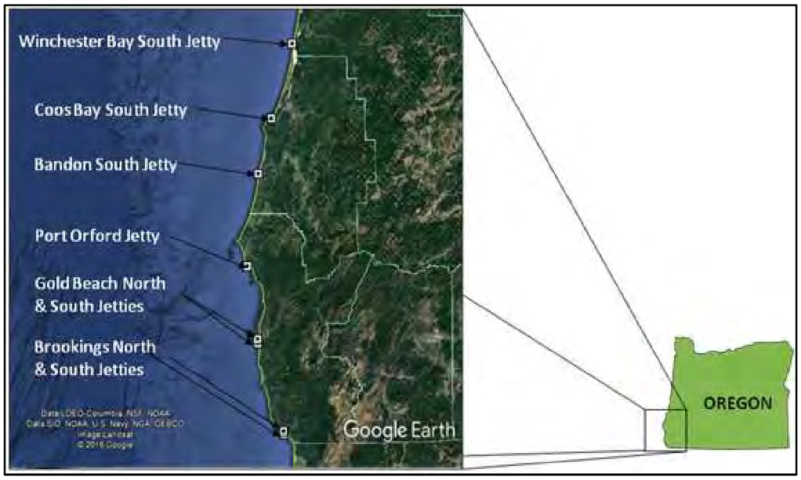

Figure 1: Map of surveyed jetty locations in Southern Oregon.

Table 1: Surveyed jetties, their headings (orientation), geospatial position and lengths (jetty point to shore). South jetties at Gold Beach and Brookings had no gooseneck populations and so were excluded from analysis.

Jetty	Heading (°magnetic)	Latitude, Longitude	Length (m)
Winchester Bay, South	277	43.66, 124.21	800
Coos Bay, South	276	43.35, 124.35	550
Bandon, South	273	43.12, 124.42	200
Port Orford	105	42.74, 124.50	150
Gold Beach, North	209	42.42,124.43	350
Brookings, North	196	42.04, 124.27	310

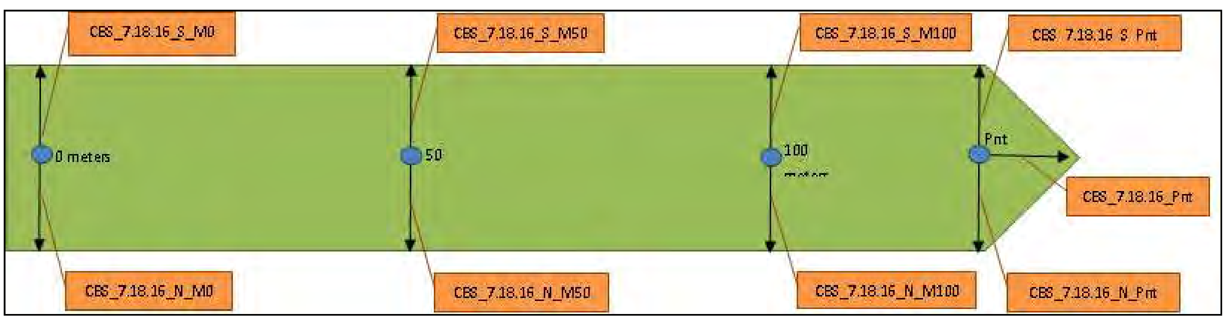

Figure 2: A visual representation of transect survey organization along a jetty: regular intervals of two transects ran down opposing jetty sides (black arrows), perpendicular to the length of the jetty, between the jetty point and the 0 m survey starting mark (mean high water level). Transects started at the highest observed tidal level of the gooseneck population and ended at the lowest observed extent of the population, or at the water's edge if the gooseneck habitat range extended beyond the water level at the time of surveying. Transect labels provide organization for photos and samples according to jetty (ex: CBS for Coos Bay South), survey date, transect orientation on jetty slope (N or S), and meter mark (M) of transect along the jetty length.

We marked the survey start point as "0 m" along the length of each jetty at the GPS location of mean high water, identified using USGS and NOAA Marine Chart map data available through CalTopo, and recorded the range limit of goosenecks along the length of the jetty relative to this "0 m" mark. We stratified our survey sampling by using transects conducted at even intervals along the length of each jetty, which ranged in length from 150 m (Port Orford) to 800 m (Winchester Bay South Jetty). During each survey, we first ran a transect off the point of the jetty (the farthest transect from the high water level mark), parallel to its length, and then two transects perpendicular to the length of the jetty on the north and south side of the jetty point. We repeated transects at regular intervals of 50 m on either side of the jetty between the point and 0 m mark or habitat range limit. In order to collect gooseneck population data across the entire jetty under tidal time constraints, we ran transects at intervals of 150 m on the Coos Bay South Jetty and the Winchester Bay jetty, which are both over 500 m in length.

We began transects at the highest tidal height at which we found living gooseneck barnacles and extended them to the water level or the end of the gooseneck habitat range, if the tidal range ended above the water line. We recorded the upper and, if accessible, lower extent of the transect using a clinometers and telescoping survey pole to determine the height of the transect ends relative to water level. We then used 1-minute Water Level Data publically available online by NOAA for each respective transect time and location to convert our measurements to height relative to Mean Lower Low Water (MLLW), allowing us to estimate range of tidal elevation of gooseneck barnacle habitat.

We took photos at 2.5 m intervals along each transect using an Olympus Stylus TG-4 shockproof and waterproof camera. Due to the highly rugose and complex nature of jetty slopes consisting primarily of large boulders, much of the intertidal habitat is irregularly sloped, angled or even nested within caverns making the use of standardized quadrats impractical. Instead, we used a scale reference such as a ruler or tape measure placed within each photo, which we later used to standardize photo areas for analysis. When necessary, we attached the camera to a pole to extend the camera to otherwise inaccessible regions of transects (e.g., within small caves) and used Wifi communication with an iPhone 5 to control the camera. In some cases, wave action made the lower limits of transects too dangerous to access even with the camera stick. We were unable to photograph the lower extent of these transects. Additionally, we sampled goosenecks from each transect by physically removing clumps of individuals. At the transect midpoint, we sampled the nearest representative group of at least 50 individuals. Clump removal required a flathead screwdriver to dig under the base of barnacle hummocks without extensively damaging individual barnacles or neighboring clumps. We placed samples on ice in a cooler to bring back to the laboratory, where we then froze the samples for later size-frequency analysis.

Photo Analysis

We used standardized ImageJ techniques (Rasband 1997-215) to process photos from jetty surveys. Each photo area was standardized to 0.25 m^2 using the in-photo scale reference. We then identified and measured the area of each patch of goosenecks in the photo. We classified a "patch" as any bunch of four or more barnacles immediately adjacent to each other on the substrate surface. We marked each identifiable individual in the photo to enumerate the number of individuals per patch and per photo to quantify densities as a metric of abundance. Most if not all recruits and all cyprids were too small to be identified and enumerated in this technique, so abundance estimates from photos include adults and juveniles but exclude recruits and cyprids. Photo analyses additionally provided an estimate of within-habitat percent cover, number of patches or clumps per given area, and densities of gooseneck barnacles across jetty habitats. Populated jetty habitats at the lowest tidal heights, however, were not always sampled due to the inaccessible nature of some of the lowest extending transects, where the last several meters of barnacle habitat were either underwater or too wave-beaten to safely survey. We estimated the tidal height (MLLW) of each photo using following equation:

$$TH_p = TH_t - \frac{P_i(TH_t - TH_w)}{P_t}$$

Where TH_p = tidal height of photo, TH_t = tidal height of top of habitat range for that transect, TH_w = tidal height of end of transect (the tidal height of seawater at time of measurement or tidal height of bottom of barnacle habitat range, whichever was higher), P_i = Photo number-1, and P_t = Total number of photos taken. All tidal height measurements were in meters relative to the Mean Lower Low Water level recorded for a given site by publically available NOAA data.

Sample Analysis
Collected samples were frozen and later processed by hand in the lab. After thawing, we disarticulated the sampled clumps, removing individuals attached at the base, enumerating and separating individuals based on size class. We used the rostro-carinal (RC) length (see Fig. 3) of the carapace as a reference measurement to separate juveniles (<13mm RC length) from adult individuals (≥13mm RC length). We did not remove barnacles attached to the peduncle of others regardless of size. 30 juveniles were randomly selected from each sample. We used digital calipers to measure the RC length of selected juveniles and of all adults (there were usually fewer than 30 adults per sampled clump). Additionally, we measured the RC of any other goosenecks attached to the peduncle of measured individuals. Using a stereo microscope, we tallied the number of cyprids and recruits attached to the peduncle of each measured individual. From these data, we were able to establish the average number of cyprids, recruits and juveniles attached to the peduncle of an individual juvenile or adult barnacle. These numbers were then used in conjunction with the density data from photo analyses to extrapolate complete population estimates for each jetty. Additionally, we used measurements of RC lengths for size-frequency analysis of jetty populations and to determine the proportion of goosenecks of adult size and of harvestable size (≥14mm RC). These data provide a detailed initial description of southern Oregon gooseneck populations on jetties as well as providing harvesters, managers, and future researchers with data for stock assessments and a reference for tracking any changes in the population resulting from beginning and expanding commercial harvest of adult barnacles.

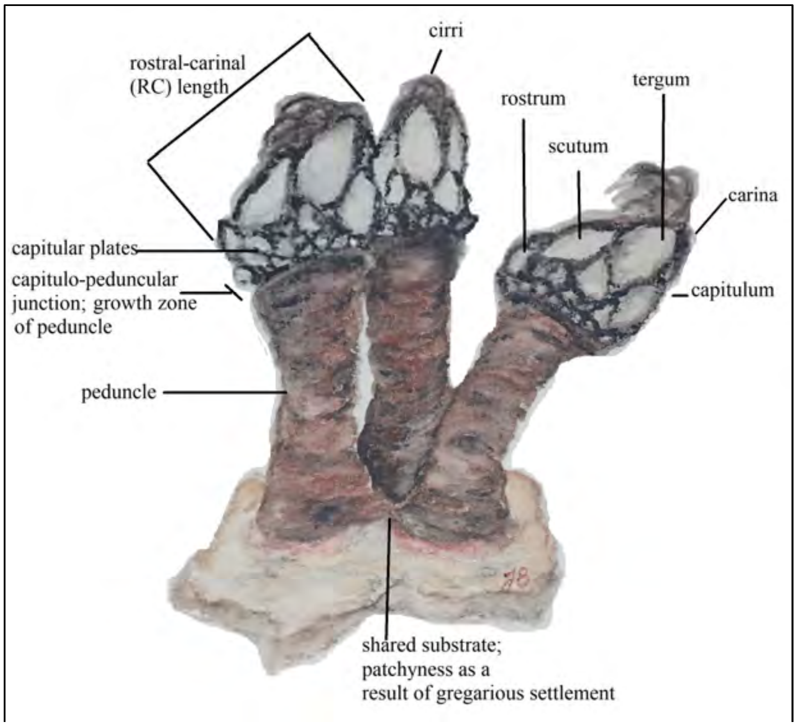

Figure 3: External anatomy of *Pollicipes polymerus*. Illustration courtesy of Julia Bingham.

Determining "Adult" and "Harvestable" size
In order to determine the proportion of *P. polymerus* populations of adult size required identifying a specific minimal rostro-carinal [RC] length at which a barnacle could be considered an adult. Before our survey, no established method existed to qualify an individual *P. polymerus* as an adult based solely on rosto-carinal [RC] length. Sestello and Roca-Pardinas (2011) established an allometric model of weight – length relationship for *P. pollicipes* in Spain and determined the minimum size of an adult P. pollicipes to be 15.7 mm RC, confirmed by dissection for proof of reproductive maturity. We used their allometric

model and a subsample of *P. polymerus* collected from the Coos Bay South Jetty to estimate a minimum adult size for Oregon *P. polymerus* to be 12 – 14 mm RC. Indeed, when dissecting this subsample we did not find clear evidence of reproductive maturity in any barnacle smaller than 11.8 mm RC. Since Sestello and Roca-Pardinas' model was established for the Iberian species of gooseneck which likely varies from the pacific species in growth rates, we also tested the allometric model on a larger data set of individual dry biomass measurements of *P. polymerus* samples collected from natural rock formations along the central Oregon coast and dissected to confirm reproductive maturity as a qualifier of adulthood during a previous survey (Bingham 2016, unpublished data). For this data set, the allometric model confirmed adult *P. polymerus* barnacles measure 13 – 14.4 mm RC. We felt that these combined tests allowed sufficient confidence in using 13 mm RC as an estimated minimum adult size for all samples collected during our surveys. We qualified barnacles smaller than 13 mm RC but otherwise morphologically resembling adult barnacles as juveniles. We qualified barnacles larger than cyprid stage but not yet morphologically resembling an adult as recruits, which were generally < 3 mm RC.

Qualifying an adult barnacle as large enough to be considered of harvestable size required more subjective input from harvesters. Discussions with local fishers interested in expanding gooseneck harvest revealed that commercially ideal individuals have long (≥ 7 cm) peduncles that are at least 1 cm wide when fully extended. We used the above mentioned allometric model and our subsampled barnacles to convert this to a carapace measurement of at least 14 mm RC. Peduncular measurements are far more variable than carapace measurements at a given age as it depends on food availability, tidal height, and wave exposure (Lewis & Chia 1981, Sestelo & Roca-Pardiñas 2011). This harvester preference therefore likely provides a less accurate estimated minimal RC length for harvestable size than our estimated minimal adult size, however, we elected to use it in our population assessment in order to make our data more accessible and relevant to interpretation by stakeholders including gooseneck fishers and managers. "Harvestable" barnacles (≥14 mm RC) were assumed based on our subsample to individually weigh 2 – 10 g, allowing us to estimate stock in terms of biomass and, therefore, market value.

Jetty Data Summary, Analysis, and Modeling

To summarize data collected through jetty surveys, we organized data within Excel using *Data Tables*, *Pivot Tables*, and *Slicers* functions and then used SigmaPlot 12.5 to generate relative frequency histograms of the jetty size-frequency data. Results from sample and photo analyses were statistically analyzed using R. We used Rhinoceros 4.0 CAD software to build a 3D model of each jetty's surface using our tidal height and geospatial data gathered for each transect during jetty surveys. We used the models of the jetty surface and the software's area calculation algorithm to estimate the total area of gooseneck habitat. These 3D models are quite conservative and assume planar surfaces between sampling locations and thus do not account for the rugosity of the jetty surface, likely underestimating the total surface area of jetty habitat. This area in conjunction with our data describing percent cover, density, and size frequency were used to create numerical estimates of each jetty population as a whole and estimates of relative numbers of cyprids, recruits, juveniles, adults, and "harvestable" individuals which we reported as an initial stock estimate to stakeholders.

RESULTS

Tables and Figures

Table 2: General summary of jetty observation results; habitat estimates express the approximate jetty area within the tidal ranges observed through transect surveys to host populations of gooseneck barnacles. Average % cover refers to the percent of this barnacle habitat observed through photo studies to actually have patches of barnacles covering the substrate. Average established density refers to the density of barnacles/m^2 as observed through jetty photo studies and includes only adults and juveniles, as barnacles smaller than 3 mm RC length cannot be accurately tallied through photo analysis. Size-frequency distributions collected through sampling provided ratios of barnacles including recruits (<3 mm RC) and cyprids (<1 mm RC) in a patch, settled on to the peduncles of substrate – settled adults and juveniles. Estimated full populations were calculated using observed densities, estimated habitat, and observed ratios of attached individuals to substrate settled adults and juveniles. Cyprids are assumed to be under 14 days old (Cruz, Castro & Hawkins 2010) and so are too inconsistent a number to include in a full population estimate. Estimated established population includes only adults and juveniles that were connected to the substrate, excluding recruits, cyprids, and juveniles not attached to habitat substrate.

Jetty	Estimated Total Habitat (m^2)	Average % Cover (+/- SE)	Average Established Density (#/m^2) (+/- SE)	Ratio: Attached Adults and Juveniles to Settled	Ratio: Attached Recruits to Settled	Ratio: Attached Cyprids to Settled	Estimated Full Population (excludes cyprids)	Estimated Established Population
Winchester Bay South	7,128	42 (+/- 4.6)	7,221 (+/-4,867)	0.14	8.48	0.58	4,260,607,042	494,728,689
Coos Bay South	10,993	37 (+/- 4.6)	6,809 (+/-7,866)	0.26	2.07	1.04	583,624,005	249,756,841
Bandon South	1,576	37 (+/- 6.3)	6,638 (+/-5,718)	0.09	12.35	6.76	175,052,8750	140,652,550
Port Orford	1,954	16 (+/- 4.1)	3,044 (3,037)	0.38	8.42	2.53	512,850,027	58,289,043
Gold Beach North	2,101	34 (+/- 5.8)	7,729 (5,343)	0.01	2.22	0.03	116,536,809	52,373,922
Gold Beach South	0	0	0	NA	NA	NA	0	0
Brookings North	521	21 (+/- 5.5)	5,393 (4,818)	0.01	2.76	0.02	29,299,176	10,586,087
Brookings South	0	0	0	NA	NA	NA	0	0
All Jetties	24,273	32 (+/-26)	6,139 (5,274)	0.15	6.05	1.8	6,239,600,223	1,006,387,133

Table 3: Estimated stock of large, harvest – size adult gooseneck barnacles (RC length ≥14mm) on surveyed jetties.

Jetty	Estimate Established Population (millions)	% Harvestable (≥14 mm RC)	Harvestable Population (millions)	Estimated Available Biomass (kg), 2 - 10g/each
Winchester Bay South	495	17.62	9.07	18,135 -90,676
Coos Bay South	250	13.75	10.24	20,588 - 102,941
Bandon South	141	15.55	1.62	3,253 - 16,267
Port Orford	59	18.67	1.11	2,222 - 11,108
Gold Beach South	52	8.30	1.35	2,697 - 13,483
Brookings North	11	3.68	0.10	207 -1,033
All	1,006	2.34	23.6	47,102 – 235,509

Table 4: Significant ANOVA results for pooled jetty data. Full ANOVA results are in Appendix A.

All Jetties					
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Significance**
Jetty	**Patches per m^2**	5	2.88	0.01661	*
	RC length (mm)		20.14	$2.20e^{-16}$	***
	Recruits per Peduncle		33.42	$2.20e^{-16}$	***
Meters along Jetty	**RC length (mm)**	16	8.64	$2.20e^{-16}$	***
	Recruits per Peduncle		8.54	$2.20e^{-16}$	***
Meters along Transect	**Density (barnacles / cm^2)**	6	26.65	$7.95e^{-07}$	***
	Patches per m^2		8.52	$4.07e^{-3}$	**
Tidal Height (MLLW)	**Total Barnacles**	1	7.04	$8.88e^{-3}$	**
Density (barnacles / cm^2)	**Total Barnacles**	1	241.6	$2.20e^{-16}$	***

Table 5: Significant ANOVA results for each jetty survey. A P(>F) value ≤0.05 is considered statistically significant. For significant ANOVA results, relative significance is denoted as follows: *P(>F) ≤ 0.05, **P(>F) ≤ 0.01, ***P(>F) ≤ 0.001. Full ANOVA results are in Appendix A.

		BANDON SOUTH JETTY				**BROOKINGS SOUTH JETTY**				**COOS BAY SOUTH JETTY**			
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Sig.**	**Df**	**F value**	**P(>F)**	**Sig.**	**Df**	**F value**	**P(>F)**	**Sig.**
Meters Along Jetty	**% Cover**	5	1.72	0.20		1	2.1	0.18		4	1.03	0.41	
	RC length (mm)		7.07	$1.79e^{-05}$	***		1.4	0.24			0.21	0.81	
	Recruits per Peduncle		10.17	$1.37e^{-07}$	***		22.6	$4.58e^{-04}$	***		21.53	$9.83e^{-09}$	***
Meters along Transect	**Total Barnacles**	5	21.71	1.87e-07	***	3	1.6	0.27		6	3.55	0.01	*
	Density (barnacles / cm^2)		4.90	$4.35e^{-03}$	**		1.2	0.38			2.66	0.04	*
	% Cover		11.89	1.97e-05	***		1.1	0.41			2.26	0.07	
	Patches per m^2		0.68	0.65			0.7	0.60			0.38	0.88	
Tidal Height	**Total Barnacles**	1	14.63	8.17e-04	***	1	8.2	0.02	*	1	2.57	0.12	
	Density (barnacles / cm^2)		6.21	0.02	*		7.1	0.03	*		2.10	0.16	
	Patches per m^2		0.88	0.36			0.9	0.38			0.59	0.45	
% Cover	**Total Barnacles**	1	28.59	$1.73e^{-05}$	***	1	97.7	$3.94e^{-06}$	***	1	19.19	$1.33e^{-04}$	***
	Density (barnacles / cm^2)		23.32	$6.42e^{-05}$	***		26.6	$5.99e^{-04}$	***		21.44	$6.61e^{-05}$	***
	Patches per m^2		0.43	0.52			0.0	0.95			2.38	0.13	
Total Barnacles	**Density (barnacles / cm^2)**	1	55.45	$1.10e^{-07}$	***	1	57.8	$3.32e^{-05}$	***	1	61.33	$9.72e^{-09}$	***

		GOLD BEACH NORTH JETTY				**PORT ORFORD JETTY**				**WINCHESTER BAY SOUTH JETTY**			
		Df	**F value**	**P(>F)**	**Sig.**	**Df**	**F value**	**P(>F)**	**Sig.**	**Df**	**F value**	**P(>F)**	**Sig.**
Meters Along Jetty	**% Cover**	5	1.21	0.35		3	5.12	0.01	*	8	1.21	0.34	
	RC length (mm)		3.96	$1.68e^{-03}$	**		10.86	$3.31e^{-08}$	***		1.96	0.05	*
	Recruits per Peduncle		8.02	$3.82e^{-07}$	***		14.99	$8.13e^{-11}$	***		6.95	0.00	***
Meters along Transect	**Total Barnacles**	3	1.94	0.16		5	0.55	0.74		4	2.45	0.07	**
	Density (barnacles / cm^2)		0.18	0.91			0.03	1.00			2.06	0.12	
	% Cover		3.00	0.06			0.58	0.72			0.54	0.71	
	Patches per m^2		2.93	0.06			3.51	0.03	*		3.80	0.01	*
Tidal Height	**Total Barnacles**	1	1.69	0.21		1	0.56	0.46		1	10.78	$2.68e^{-03}$	**
	Density (barnacles / cm^2)		3.33	0.08			0.01	0.92			6.61	0.02	*
	Patches per m^2		2.14	0.16			3.14	0.09			18.89	$1.55e^{-04}$	***
% Cover	**Total Barnacles**	1	0.85	0.37		1	31.97	$1.88e^{-05}$	***	1	0.28	0.60	
	Density (barnacles / cm^2)		1.48	0.24			12.17	$2.46e^{-03}$	**		0.03	0.86	
	Patches per m^2		8.65	$8.08e^{-03}$	**		0.07	0.80			0.02	0.88	
Total Barnacles	**Density (barnacles / cm^2)**	1	32.30	$1.46e^{-05}$	***	1	11.60	$2.97e^{-03}$	**	1	155.3	$3.61e^{-13}$	***

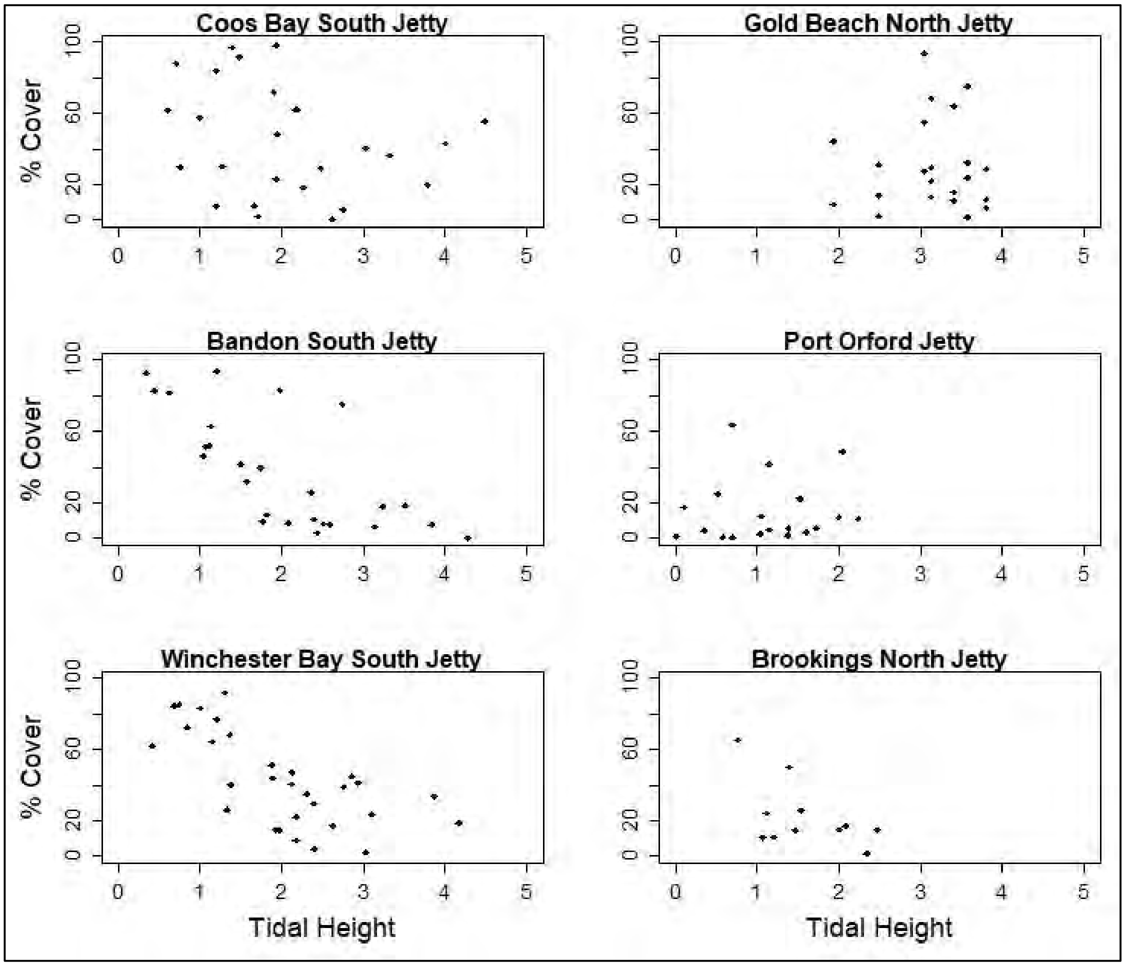

Figure 4: Percent cover of habitat populated by gooseneck barnacles at a given tidal height (m) on each surveyed jetty.

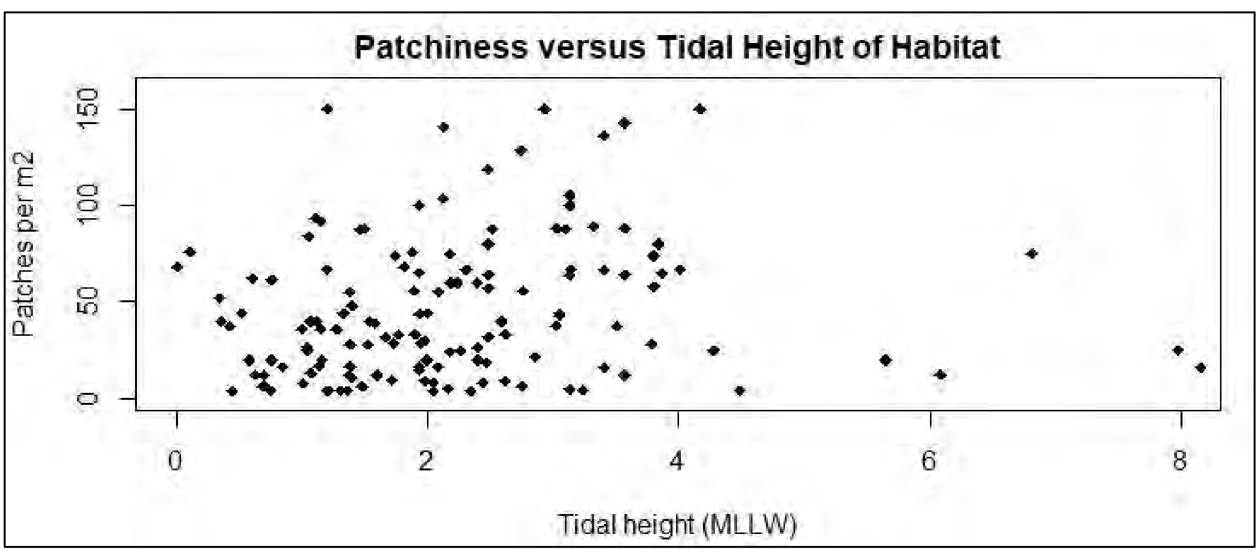

Figure 5: Patchiness (patches/m^2) of gooseneck barnacle distribution for a population at a given tidal height (MLLW), data combined for all jetties. Jetty-specific scatterplots included in Appendix C.

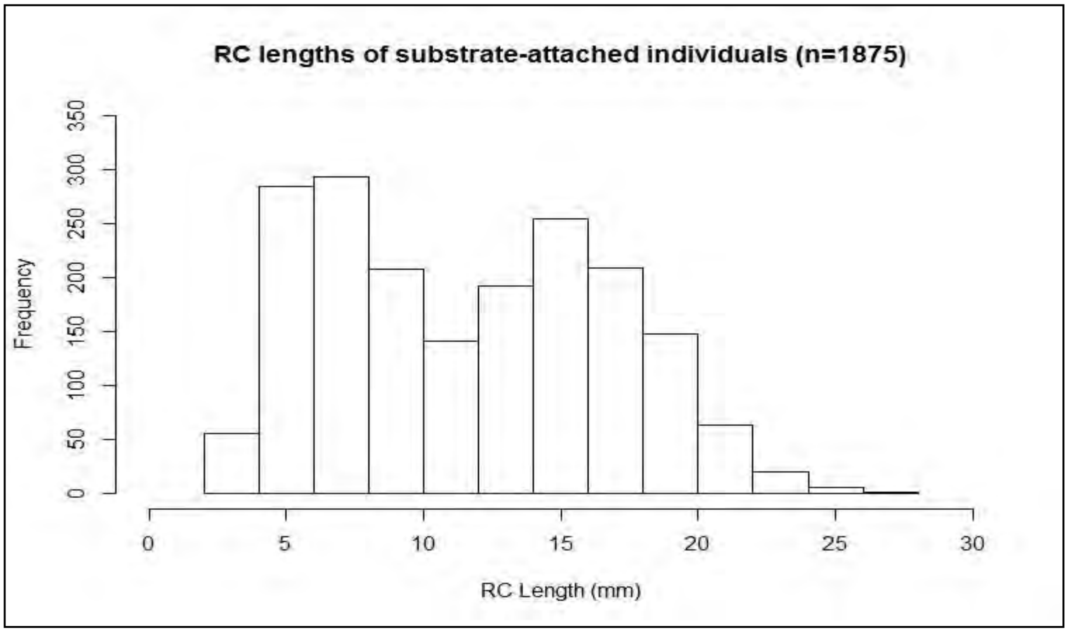

Figure 6: Size frequency of barnacle rostro - carinal (RC) lengths of substrate-settled individuals from all collected samples on all jetties, all of which were juveniles (3 – 13 mm RC) or adults (≥13mm RC).

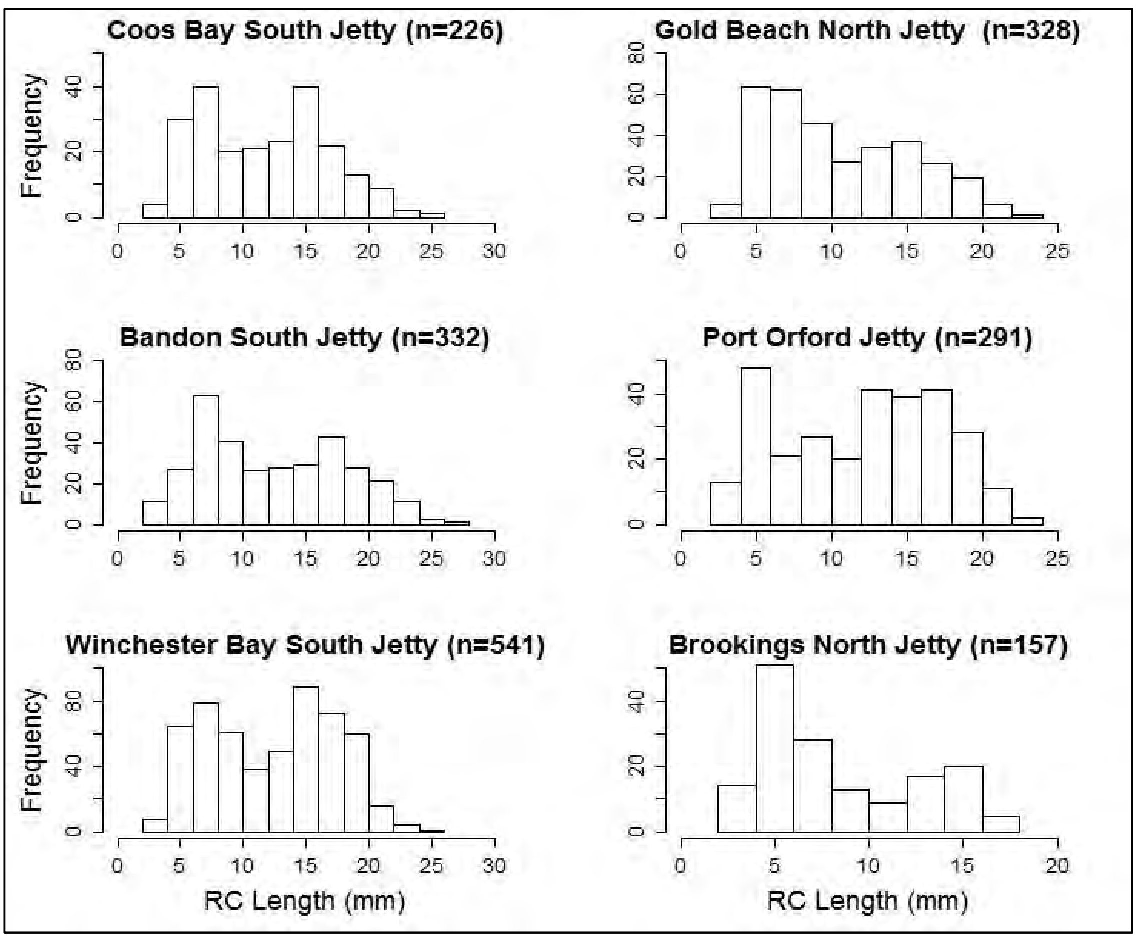

Figure 7: Size frequency of barnacle rostro-corinal (RC) lengths of substrate-settled individuals from all collected samples on all jetties, all of which were juveniles (3 – 13 mm RC) or adults (≥13 mm RC).

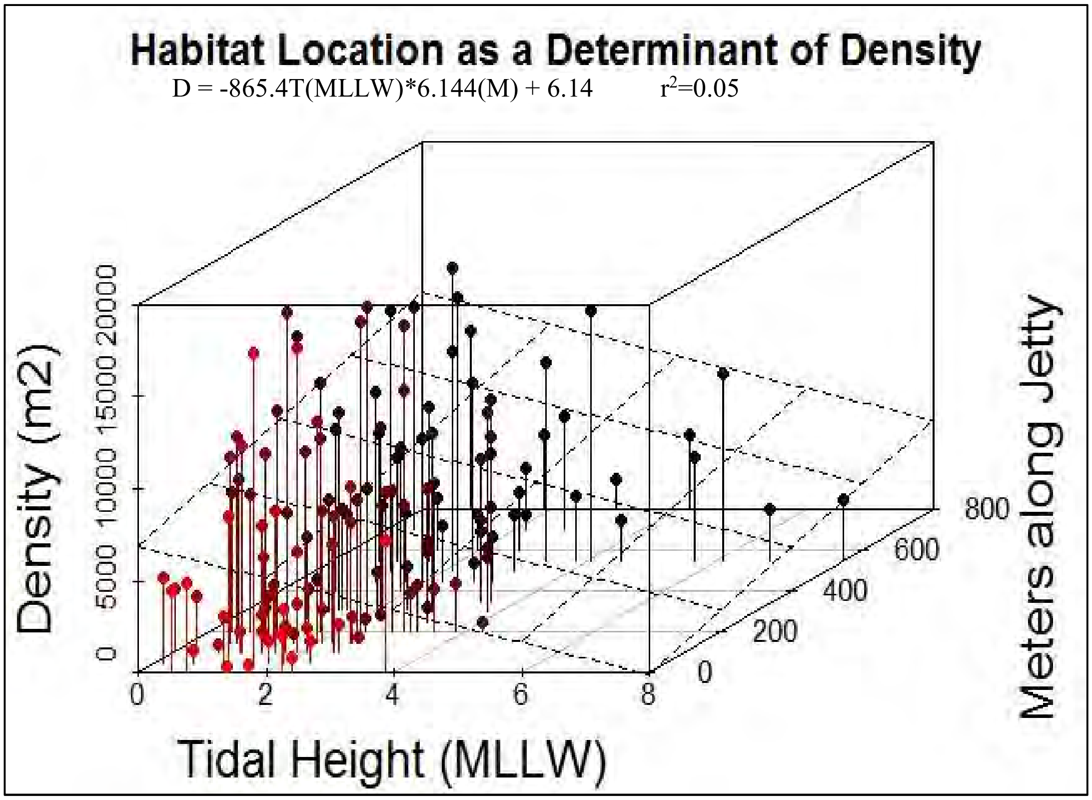

Figure 8: Regression model predicting density of substrate-settled goosenecks/m^2 (D) given a habitat location's vertical position in tidal height (m) relative to MLLW and lateral position along a jetty in meters from the shoreline high water level (M) using data pooled from all jetty surveys. Df=140, F-stat = 4.76, P(>F)= 0.01. t and p(>|t|) values for predicted coefficients are listed in Table C.1 of Appendix C.

Distribution

We did not observe any gooseneck populations on the entirety of the south jetties of Gold Beach and Brookings, and so for these locations we conducted surveys only on the north jetties. *P. polymerus* populations within the bay outlet channels on the north facing slope of Coos Bay south jetty and the south facing slope of Winchester Bay north jetty extended shoreward, beyond the 0 m starting mark of our surveys. The rocks of the Brookings and Gold Beach north jetties (southfacing slope) and the Winchester Bay and Bandon south jetties (northfacing slope), which in both cases were adjacent to the bay outlet channel, contained none or nearly no populated barnacle habitat. We therefore cannot compare jetty slopes in our data.

We estimate that across all jetties there exists a total of 24,273 m^2 gooseneck habitat. Lower limits of gooseneck barnacle habitat often extended underwater, beyond our reach, and so we likely underestimated the total area of gooseneck habitat. All observed barnacle habitat was within a specific range of tidal heights. We found substrate-settled goosenecks on jetty rock surfaces ranging between -0.4 m MLLW (Winchester Bay) to 10.4 m MLLW (Coos Bay). Tidal height ranges of populated barnacle habitat were widest at Coos Bay (average range = 3.9 m, max = 10.2 m, min = -0.2m) and most narrow at Gold Beach (av range = 2 m, max = 3.8 m, min = -0.4 m MLLW). Extremely high zone ranges (above 3.5 m MLLW) exist exclusively on the seaward end of the longest jetties (Winchester Bay, Coos Bay, and Gold Beach). Analysis of percent cover showed that large, dense patches were far more constrained in tidal height and location relative to shore within the otherwise wide range of potential habitat. Generally, on all jetties goosenecks covered at least 50% of jetty habitat between 0.3 and 5.7 m MLLW on transects at least 150 m and usually more than 200 m from the 0 m shoreline transect mark. Goosenecks were the spatially dominant species in an even more contained area, maintaining at least 80% habitat coverage on only specific transects: between 0.7 and 2.2 m MLLW at the point of Bandon South Jetty (200 m from shore), between 0.7 and 4.2 m MLLW on Coos Bay transects at least 450 m from shore and between 0.4 and 1.4 m MLLW on south facing Winchester Bay transects at least 400 m from shore. With the exception of the Gold Beach jetty, distributions show a trend of increasing percent cover at decreasing tidal height on each jetty regardless of jetty length, though an ANOVA and post hoc show this trend to be statistically significant only on select jetties (Fig. 4, Table 5).

The gregarious nature of *Pollicipes* spp. settlement creates a patchy distribution within a given habitat. However, the number of patches/m^2 – "patchiness" – did not correlate well with patterns of percent cover, and even less so with abundance metrics including density. Each jetty displays a unique pattern of patchiness relative to specific tidal height (Appendix C). Generally, patchiness was not highest at the low tidal height levels where percent cover and established densities peaked but rather at lower mid-tidal levels, around 3 m MLLW (Fig. 5). Patchiness is generally lower and less variable at lower tidal levels and especially at the points of each jetty where populations are so extensive that patches overlap and are no longer individually distinguishable.

Abundances

The Coos Bay and Winchester Bay south jetties have the most extensive populations of gooseneck barnacles (Table 2). These are the longest jetties and the most potential habitat. Barnacle populations on these jetties were comparable in percent cover and density to the smaller jetties of Bandon (south jetty) and Gold Beach (north jetty) (Table 2). Populations on the Port Orford jetty and Brookings north jetty are more limited in estimated densities, percent cover, and total barnacles counted per quadrat. These abundance metrics were highly variable across locations on every jetty. Further analysis showed that abundances correlate more consistently with specific variables of sampling location including tidal height than with the overall jetty (Tables 4,5).

In all surveys, density correlated significantly ($p<0.01$) with total barnacles counted in quadrat photo analyses. Percent cover and patches per square meter were less consistent in this comparison, and so we maintained density as the choice metric for standardized abundance assessments and applications in estimating overall population size and stock availability. Densities ranged from near 0 up to 20,000/m^2. On all jetties, we generally observed densities increasing at lower tidal heights and with increasing distance along the jetty from the shoreline. Figure 8 depicts a regression model of densities at a given tidal height and distance from the high water survey start, with a similar pattern (r^2=0.06, p= 0.01). Variance is such that this regression is not very powerful for predicting densities of goosenecks on a given habitat space using spatially specific variables, despite ANOVAS generally confirming a correlation between the two. Regression models for densities and percent covers do not improve in accuracy when separating individual jetty data.

We estimate there to be over one billion gooseneck barnacles populating the southern Oregon jetties we surveyed (Table 3). Samples from our surveys show that the majority of the population consists of recruits (≤3 mm RC) and cyprids (<1 mm RC), and that even small juveniles (3-13 mm RC) outnumber adult barnacles (≥13 mm RC) (Table 2, Fig. 6). When including recruits and cyprids, we estimate the overall population was over 6.2 billion at the time of the survey. This number potentially fluctuates as reproduction, settlement and recruitment of goosenecks are seasonally variable. We therefore elected to pursue analyses of abundances and distribution using the more conservative population estimates of exclusively adults and juveniles.

Estimated stock
Only about 2.3% of established, substrate-settled individuals across all jetties are adult percebes of a size large enough to be of commercial interest to fishers (i.e., ≥14 mm, Table 3). Port Orford and Winchester Bay population boasted the highest percentage of large barnacles, however, no jetty population consisted of more than 18.7% harvestable adult goosenecks (Table 3). Assuming a wet mass of up to 10 g/barnacle for harvest - sized individuals, we estimate the combined jetties to host an initial stock of around 130 million individual barnacles or up to 235,500 kg (260 tons). This stock is not spread evenly across the jetties. Based on jetty-specific estimates of habitat extent, overall abundance, and percent harvestable size, our conservative stock estimates per jetty range from 207 kg (0.2 tons) on the Brookings north jetty to 20,588 kg (23 tons) on the Coos Bay south jetty.

Size – Frequency Distribution
All jetty – specific populations display size-frequency trends similar to that which we observed across the overall gooseneck population: a dominance of small, immature barnacles and a generally tiny fraction of large adults (Fig 4). At each jetty, size-frequency distributions of barnacles larger than 3 mm RC show two distinct peaks in frequency, generally around 7 mm and 15 mm RC (Fig.5). Overall, we found very few barnacles above 20 mm RC and only observed barnacles longer than 25 mm RC at the south jetties of Winchester Bay, Coos Bay and Bandon. On most jetties, an ANOVA suggests RC length correlates with habitat location along the length of a jetty (Tables 4, 5). However, a Tukey post-hoc analysis shows no consistent trend in this correlation (Appendix C). Instead, patterns of RC length distributions along the length of a jetty were jetty-specific. Our survey methods did not allow us to compare RC lengths of patches at varying tidal heights.

Recruitment
Ratios of recruits per peduncle of substrate settled barnacles varied widely and were highly spatially-specific along each jetty. Bandon, Port Orford, and Winchester Bay populations had the highest average ratios of juveniles, recruits, and cyprids attached to the peduncle of substrate-settled barnacles. At these jetties, we frequently observed barnacles with over 50 and as many as 150 recruits attached to their peduncles. At the other jetties, adult peduncles rarely hosted more than 40 recruits/peduncle. Recruits/peduncle correlated significantly ($p \leq 0.001$) to location along the length of a jetty in all surveys (Table 5). As with measurements of RC length, a Tukey post-hoc analysis shows no consistent trend in this correlation (Appendix C). Instead, patterns of recruitment levels to individual peduncles of substrate-settled adults and juveniles along the length of a jetty were jetty-specific. Our survey methods did not allow us to compare recruitment patterns at varying tidal heights.

DISCUSSION

Our surveys provided sufficient data to summarize the general structure of *P. polymerus* populations on each jetty. From our surveys, we were able to estimate the area of potential habitat. Our photo analyses provided an estimate of percent cover, clumps per given area and densities of adults and juveniles. Our size-frequency analyses provided a descriptive assessment of relative frequencies of large, harvestable sized adults, smaller adults, juveniles, recruits and cyprids as well as the proportion of individuals of each size class settled on the peduncle of larger individuals rather than the substrate.

Distribution and Abundances
Patterns do exist in *P. polymerus* abundances, densities, percent cover, size frequency and recruitment on each jetty. Most of these demographics correlate with habitat tidal heights. Generally, abundances increase with decreasing tidal height and with increasing distance from shore. The lowest tidal ranges of gooseneck habitat were difficult to access. As a result, we do not have enough data to determine whether observed patterns in abundance continue all the way to the lowest tidal levels of gooseneck habitat. High

variance in our results prevents tidal height and distance from shore along the length of a jetty from being reliable predictors for densities and percent cover. Patchiness (patches/m^2), also highly variable across all surveys, peaked at higher tidal levels than what we observed for density and percent cover assessments. Patchiness decreased at lower tidal heights, areas of high abundance, where patches were so large that they converged and covered a majority of the habitat. An improved understanding of the biotic and abiotic factors determining abundances and distributions of goosenecks in a given habitat could provide a more reliable model predicting densities based on tidal height and distance from shore at a jetty or offshore rock. Such a model would be useful in expediting stock estimates and for future comparative analyses of harvested populations with expected abundances of unexploited barnacle populations. Future research on the specific biotic and abiotic factors determining the range limits of gooseneck barnacle populations is necessary.

The upper range of *P. polymerus* was higher than expected, extending into the maximum upper intertidal zone. The highest tidal reaches we observed were generally in locations along jetties where wave splash regularly delivers water far beyond the tidal water level, namely jetty points and transects beyond 300m from shore. Abundances were extremely sparse in these areas, however it does appear that the upper limit of gooseneck barnacle settlement may be less limited by tidal height than previously described. This could be due in part to additional wave action which may serve a multitude of purposes from delivering water and food to preventing desiccation during tidal exposure (Lewis & Chia 1981). Extended ranges on jetties might also be related to a lack of *Mytilus* spp. and other species on jetty rocks relative to natural rocky intertidal habitats. Mussels are known competitors for space and usually dominate the intertidal zone above substantial clusters of gooseneck barnacle patches (Paine 1974; Menge et al. 2015). We noted that on most jetty habitat, *Mytilus* populations are far less substantial than those we typically observe on nearby non-jetty rocky intertidal habitats. Additional research is needed to confirm this trend and identify its cause, and it would be interesting to further investigate whether a different distribution and dominance of species on jetties versus natural rocks impacts the population demographics of *P. polymerus*.

Jetties without barnacles

South jetties at Gold Beach and Brookings were both bare of gooseneck barnacles. These sites are the southernmost of our surveyed locations and their jetties have a more south facing heading relative to the others surveyed. That is, they do not extend at an angle so near perpendicular to nearshore waves and currents. Additionally, their orientations are such that the more northern jetty at each location breaks the majority of waves. This creates a relatively calm, protected area surrounding the southern jetties lacking in direct impact of large waves. Gooseneck barnacles have been shown repeatedly to prefer habitats with high wave action (Barnes & Reese 1960; Lewis & Chia 1981; Molares & Freire 2003; Hoffman 1988). It is possible that the protected nature of these jetties make the habitat unsuitable for goosenecks. Freshwater influence may also play a role in limiting gooseneck populations. The south facing slopes of the Brookings and Gold Beach north jetties and the north facing slope of the Winchester Bay and Bandon south jetties face the channel. The freshwater river influence is fairly direct in these smaller bays. Gooseneck barnacles require a saline habitat (Barnes & Reese 1960; Lewis & Chia 1981; Hoffman 1988). It is likely that the freshwater influence on this face of these jetties unsuitable for goosenecks. Coos Bay is a more estuarine system with a far less fresh water input. On this jetty, gooseneck populations extended all along the side of the jetty facing the channel, further suggesting the relationship between freshwater influence and range limitation for *P. polymerus*.

Size frequency distribution and recruitment

Gooseneck patches that develop full hummocks on natural rock habitats are a complex arrangement of sizes and ages which takes multiple years to fully develop due to the gregarious patterns of settlement and recruitment (Lewis & Chia 1981; Bingham 2016). The patches we observed on jetties reflect the same complexity. Size frequency data from every jetty consistently shows two peaks in the distribution of RC lengths. Substrate-settled gooseneck barnacle populations therefore include a minimum of two distinct age classes, suggesting two recruitment events. In the size-frequency distribution, we can identify the two classes as juveniles and adults. Assuming that growth rates for Oregon *P. polymerus* are similar to those observed in Mukkaw Bay and in San Juan Island, Washington, areas with comparable rocky intertidal habitat to Oregon, juveniles are under six months old while smaller adults are up to one year in age (Paine 1974; Lewis & Chia 1981). Larger adults (RC >15 mm) are estimated to be between two and five years old and up to seven years or more when RC lengths reach above 25 mm RC. We therefore can assume that the distribution of adult barnacles has accumulated with multiple recruitment events over several years while the distribution of juveniles is the result of a single, more recent recruitment event. Additionally, we observed an abundance of cyprids and recruits on the peduncles of substrate-settled individuals. Recruits likely settled within a month before our sampling and cyprids within the previous week or two (Lewis & Chia 1981). It appears that Oregon gooseneck populations experience regular settlement events given the presence of these three different size classes less than a few months old in each patch. Their dominance in numbers relative to the entire adult population suggests a precipitous drop in survival early in life; out of every settlement pulse, very few of those that successfully recruit survive into adulthood and grow to a substantial size. Based on this information, it is most useful to only include substrate-settled adults and juveniles when estimating gooseneck abundances. Estimates are thus not inflated by temporal variability of settlement pulses nor by the ephemeral nature of high populations of recruits which may not survive beyond the first month of life.

Stock Estimate

A tiny fraction (2.3%) of jetty populations are large enough to be of commercial interest to fishers, providing an initial stock of 47,000 - 235,500 kg of harvest-sized percebes, given a range of 2 – 10 g/barnacle. Current commercial market rates in Spain and Portugal are up to $90/kg, and market rates in BC range from $100 /kg to $200/kg depending on distributor (personal observation Dec. 2015; Mikuni Wild Harvest 2017; La Tienda 2017). At these prices, a midrange estimate of available Oregon stock (141,000 kg) provides market value of $12.7 - $28.2 million. The exact market value of barnacle populations on southern Oregon jetties will be determined by local consumer interest and stakeholder efforts for commercial expansion of a new fishery. Initial market prices will likely be a fraction of those in already established fisheries elsewhere, since the Oregon community is generally unfamiliar with percebes as a food item. Nonetheless, this is a substantial projected commercial value, and it is likely that interested fishers will pursue commercial harvest of goosenecks from Oregon jetty given the estimated population size and value.

Potential Harvest Impacts

Though we estimate a generally large existing and unexploited barnacle stock across all jetties, extensive harvesting could pose a threat to these gooseneck populations. Fishers will likely target areas within each jetty boasting the largest barnacles and the densest populations in order to maximize the quality of their catch, unevenly distributing harvest pressure. Gooseneck populations are not homogenous in abundance or size patterns across jetties and harvest accessibility is limited at very low tidal heights on habitat farther from shore due to the inherent danger of wave action, especially in stormy winter months. Additionally, other than Coos Bay and Winchester Bay, individual jetties have such limited populations of large barnacles that even very small scale harvest rate (~500 lb/yr) could eliminate the available stock of harvest sized goosenecks within five years under our most conservative stock estimates. A harvested area requires a minimum of three years to recover in densities, and longer to develop established patches of multiple size classes (Bingham 2016). Based on observed adult growth rates, this recovery time could extend as long as seven years to reestablish a significant proportion of large individuals. Therefore, at population - limited jetties, overharvest is an imminent threat. A harvest management plan intentionally distributed to not overload a single jetty at a time might avoid causing within jetty population collapse, allowing harvest expansion without overfishing risks.

Most substrate-settled individuals had several small juveniles, recruits, and cyprids attached to the peduncle. Almost all recruits and all cyprids we observed were settled on other goosenecks. This presents a potential within-species bycatch risk for harvest. Collection of barnacles would additionally remove any attached individuals of a smaller size class in addition to removing settlement surfaces for future cyprids. This means that a single harvest event impacts at least three different age classes of barnacles, increasing the amount of time for population recovery. Management restrictions for an expanding fishery should consider this risk when describing harvest methods and setting catch limits.

Other Limitations

Our survey was designed as an observation of existing and well established jetty intertidal communities and so we could not control for a number of both biotic and abiotic factors. Each jetty was unique in length and orientation, influencing the specific wave dynamics at individual surveys, especially at jetty points. Intertidal ecosystems on jetty rocks were intact, so confounding biological factors include space competitors like algae and mussels. It is likely that wave impact, nearshore currents and food availability, and various species interactions influence the abundance, distribution, and size of barnacles on the individual jetties as those are primary ecological factors recognized in studies of other *Pollicipes* species life history patterns (Lewis & Chia 1981; Page 1986; Leslie et al. 2005). From our data alone, we cannot determine the specific drivers of observed patterns. Further, our surveys were temporally limited. Preliminary research suggests that population dynamics fluctuate throughout the year, given nonconstant patterns of reproduction, settlement, and recruitment and the influence of seasonal storms and upwelling systems (Bingham 2016; Cimberg 1981). Through only sampling for one summer, we did not account for seasonal fluctuations.

Study Applications:

Our survey illuminates gaps in biological understanding of gooseneck population trends. Future research should identify which factors drive the patterns we have observed, including but not limited to wave impact, nearshore currents, food availability, predation, competition, exposure and disturbance frequency. If significant habitat-specific population trends exist that can be directly linked to environmental factors, they can provide a tool to estimate populations on unexploited jetties without need for extensive stock assessments thereby saving time, manpower, money and reducing safety hazards. Further, such research will be necessary for understanding harvest effects and for expanding the species - specific and ecological knowledge of this understudied species.

Our data function as a baseline stock assessment for the emerging fishery, allowing stakeholders to determine if commercial harvest of *P. polymerus* is at all feasible. From this data we can reasonably extrapolate potential harvest effects based on our current knowledge of *Pollicipes* spp. life history and response to disturbance. Additionally, our results inform fishermen, managers and other stakeholders of the extent or limitation of existing jetty populations. We used descriptive data from our study to generate fact sheets describing population metrics for each jetty (Appendix A). These can be used as communication tools when conducting outreach to discuss harvest practice and management with stakeholders. They can also be used as references for fishers planning where to collect barnacles and for managers in developing strategic harvest protocol and monitoring gooseneck populations. This study will be useful for future comparative analyses to analyze fishery impacts on jetty populations. Such analyses will help determine potential impacts should harvest extend to populations on natural rock formations. Ideally, applications of this survey will include a contribution to both the biological knowledge of an understudied species and to a local community's ability to take ownership of small business opportunity while enhancing the economic and ecological stability of fisheries on the Oregon coast. Ultimately, this study should enable the development of a well-informed and proactive sustainable management plan to allow a new market to develop on the Oregon coast while minimizing detrimental overfishing effects.

CONCLUSION

We have presented a comprehensive description of the status of gooseneck barnacle populations on the jetties of southern Oregon. Through descriptions of abundance, distributions and size frequency analyses we have with reasonable confidence provided estimates of the total population and its demographics on each jetty. Our study has illuminated the inherent variability of these metrics between and within jetty habitats. We identified several basic patterns in abundance, gregarious settlement and size frequency distributions correlated with habitat location on the jetties, e.g., distance from shore and tidal height. However, we could not from our data create a reliable model of these patterns, nor attribute patterns to specific environmental drivers. Instead, our observations provide interesting areas for further study. Future experimental research may explore these trends to identify the key abiotic and biotic conditions that determine the patterns we observed and influence life history patterns in the so far understudied Oregon *P. polymerus*.

Additionally, our study serves as a preliminary stock assessment. In addition to traditional reporting methods, we have transformed our findings into summary sheets for the use of harvesters, managers, and scientists in assessing gooseneck populations on southern Oregon jetties. Our data suggests that a restricted but viable stock of large, harvest-sized barnacles exist exists on the jetties and could likely support initial small scale commercial harvest efforts. Our analyses illuminate some overfishing risks, emphasize the need for a conservative approach to gooseneck barnacle harvest expansion with a focus on consistent population monitoring and proactive sustainable management strategies. This requires stakeholder participation and accountability in pursuing responsible harvest techniques. We hope our data will contribute to making such efforts possible.

OBJECTIVE B:
Trial Mariculture Development

Growth and survival of the gooseneck barnacle (Pollicipes polymerus, Sowerby) in a low flow mariculture system under different diets

Michael Thomas, J. Bingham and A. Shanks

Introduction

Pollicipes polymerus (Sowerby) is a stalked Thoracican crustacean, which inhabits the exposed rocky shores of the Eastern Pacific from Alaska to Baja California (Rickets & Calvin, 1968). It is found in the shallow sub-tidal to mid-intertidal and is frequently found in association with *Mytilus californianus* and *Pisaster ochraceus;* so much so that Rickets and Calvin (1968) referred to them as "horizon-markers in marine ecology". *P. polymerus* tends to form dense aggregations in the form of clumps on the rock's surface (Rickets & Calvin, 1968) and larvae are known to settle gregariously on the peduncles of adult conspecifics (Hoffman, 1989). *P. polymerus* belongs to a genus of stalked barnacles, known as "gooseneck barnacles" found throughout the world. One of which is *P. pollicipes*, the Atlantic species, which is a highly-prized delicacy on the Iberian Peninsula (Bernard, 1988). High demand, inflated prices, and challenges brought on by the genus' life-history led to over-harvest of this species and reactive management practices had to be put into place to control harvest pressure (Bernard, 1988). The larval gooseneck's preference for settling on adult barnacles means settlement substrate is removed during harvest. Larvae will settle on bare rock surfaces, but recruitment success is lower (Bernard, 1988), probably a result of abiotic stressors and predation. Replenishment of natural populations is also affected by the planktonic nature of gooseneck larvae, which rely on regional oceanographic conditions for their distribution and delivery. Fluctuations brought on by varied physical oceanographic conditions mean larval subsidies may not be consistent and reestablishment of harvested barnacles spatially and temporally variable (Shanks, 2006). There is a small North American market for *P. polymerus*, but it is relatively restricted to tribal members of British Columbia (Gagne, Picco, Rutherford, & Rogers, 2016) and North American populations are presently not in danger of overharvest. Currently there is growing interest in Oregon for the establishment of a new fishery for *P. polymerus* (pers. obs.). Since a fishery for this species faces the same life-history challenges presented by the Atlantic species, it is prudent to begin investigating the feasibility of supplementing wild-harvested barnacles with maricultured stock.

Mariculture is often the only long-term solution to a successful fishery of an easily over-harvested, but highly desirable food item. Currently, no successful mariculture operation exists for the gooseneck barnacle, despite the high demand from the European market and growing interest in North America. This is because gooseneck barnacles have been notoriously difficult to culture due to their affinity for areas of high water flow, barriers to larval culture, and a lack of knowledge of their dietary needs (Barnes & Reese, 1960; Franco S. C., 2014; Bernard, 1988; & Howard & Scott, 1959). Some work has been done to address these difficulties, particularly with the Atlantic species (*P. pollicipes*) (Norton, 1996; Franco et al., 2015), however, no solutions currently exist which offer the potential for mariculture to be a profitable business venture. One particularly challenging aspect has been the previously held belief that goosenecks require high water flows to feed (Barnes & Reese, 1960; Franco S. C., 2014; Bernard, 1988; & Howard & Scott, 1959). A mariculture system that incorporates high water flow requires the use of a great deal of energy and expensive pumps to maintain this flow. The development of a technique to sustain gooseneck barnacles using low flow would decrease operating costs and simplify the process of culturing this organism.

One of the authors (Shanks) observed gooseneck barnacles in a fish aquarium at the University of Oregon's public marine life center. These barnacles were part of a bio-fouling community that had entered the aquarium through the seawater pumped in from adjacent Coos Bay. The gooseneck barnacles in this tank were only seen attached to the wall of the aquarium where they were in the path of air bubbles created by an air source near the bottom. There was no source of significant water flow in this area of the tank and it appeared the barnacles were responding to the air bubbles. This observation led to the design of the low-flow, aerated mariculture apparatus used in this experiment.

Here we attempt to find a method of culturing gooseneck barnacles with as little water flow as possible and hope to develop a promising design for a mariculture apparatus. Barnacle growth rates have been shown to vary with food quantity/quality and gooseneck barnacles show a high protein digestive efficiency (Norton, 1996). We attempt to modify growth rates by diet modification within the mariculture system using only small amounts of zooplankton and micro-algal food subsidies and expect to see accelerated growth in barnacles fed more zooplankton-based diets. Additionally, we wanted to know if we could encourage clump formation using juvenile barnacles as seed-stock for settlement and subsequent grow-out of gregarious *P. polymerus* larvae. By transplanting solitary juvenile barnacles into a mariculture system fed by unfiltered seawater, we hope to see the settlement and subsequent recruitment of any gooseneck barnacle larvae which may enter the system. Larval recruitment onto transplanted barnacles would demonstrate the feasibility of inducing clump formation in culture and greatly increase the output per unit of effort of a mariculture program.

Materials and Methods

To test whether gooseneck barnacles will settle, survive, and thrive in a mariculture setting, we constructed a mariculture apparatus (Figure 1) designed to mimic the conditions of the bio-fouling community in the fish aquarium. Additional design considerations included ease of maintenance, modular construction, widely available/inexpensive parts, and low flow rates, as water pumps are expensive and require large quantities of energy. Acrylic plates were seeded with barnacles and suspended in vertically oriented tubes. The easily removable plates suspended in each tube simplified the processes of maintenance, cleaning, and monitoring of barnacles. They also provided a settlement

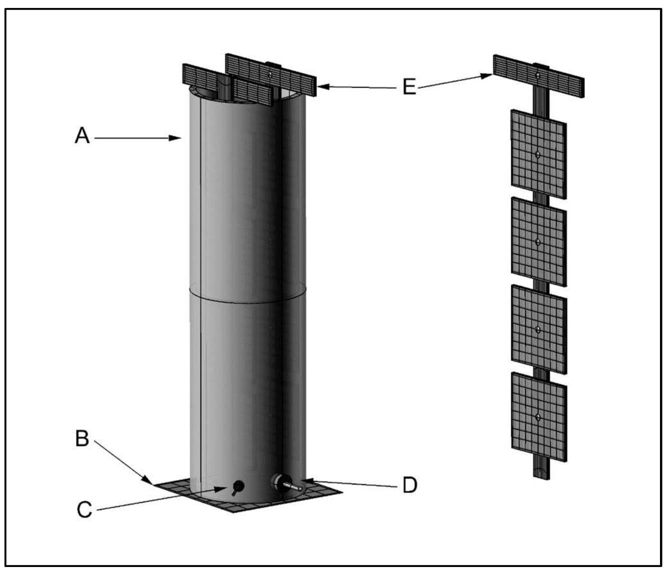

Figure 1 - Perspective view of a "barnacle nursery" with main ABS plastic housing (A), acrylic base (B), air hose with airstone (C), PVC hose barb (D), and plate hanger with plates (E)

surface for larvae, which entered via the seawater system. Unfiltered sea-water was pumped in through the base of each tube and allowed to overflow. An air stone was installed at the bottom to create a vertical cascade of small bubbles within the tubes. The ability to temporarily stop the inflow of seawater to each tube using a ball valve allowed for food subsidies to be added without being immediately expelled. Continuing to aerate the seawater remaining in the tubes during feeding kept food subsidies suspended and distributed throughout the water column.

The vertical tubes that housed the acrylic plates were constructed of 40.6 cm lengths of black acrylonitrile butadiene styrene (ABS) tubing with an internal diameter (ID) of 10 cm. A section of tubing formed the main housing of each mariculture apparatus, that we affectionately dubbed a “barnacle nursery”. One end of each barnacle nursery was glued to an oversized square piece of 3 mm thick acrylic sheeting using cyanoacrylate glue and the interface was sealed using silicone caulking. The acrylic sheets were cut large enough to cover the entire internal diameter of each nursery and to extend far enough on each side to provide sufficient support for the nursery to remain upright when full of water. Two holes were drilled near the base of each nursery to support the attachment of water and air supply tubes. A 3/8” poly-vinyl chloride (PVC) hose barb fitting was threaded into each water supply opening to allow for quick attachment/detachment of water supply hoses. Each air supply hole was drilled just large enough to allow a ¼” air supply tube to pass through the wall of the nursery. A small aquarium-style air stone was fitted to the end of the air supply lines and centered within the lumen of each nursery. The air supply tubes were cut to leave approximately 10 cm of tubing on the exterior and PVC couplers were placed on the ends for quick removal of air supply lines. The area where the air supply tubing was inserted through the wall of each nursery was sealed with silicone caulking.

The suspended plates were seeded with gooseneck barnacles, *Pollicipes polymerus* (Sowerby), disarticulated from clumps collected off the University of Oregon Institute of Marine Biology (OIMB) boathouse breakwater (43.3497° N, 124.3305° W) on 17 August 2017. Disarticulated barnacles in the 6 -12 mm rostro-carinal (RC) length range were separated and barnacles used in the experiment were then selected haphazardly from these individuals. *P. pollicipes* below 12-13 mm RC are considered juveniles (Bingham, 2016; unpublished data) and juveniles have been shown to grow more rapidly than adult barnacles (Barnes, 1996). The 6-12 mm RC length size class was selected because they were large enough to accurately measure, but small enough to expect significant growth within the timeframe of the experiment. Any conspecifics attached to the peduncles of selected individuals and visible to the naked eye were removed. Plates were cut from 3 mm thick acrylic sheet into 76 mm square pieces. One side of each plate was covered with 3M “Safety-walk” textured tape to create a more preferential surface for settlement of rugophilic *Pollicipes sp.* larvae. Four plates were attached to each “T” shaped, acrylic hanger using stainless steel machine bolts threaded through holes drilled in the center of each plate. Barnacles were attached to the same side of every plate on a hanger and on only one side of each plate. Two hangers were suspended in each tube with the side containing barnacles facing the center of each nursery. Suspending barnacles within the nurseries this way situates them centrally within the lumen of each tube where water flow is expected to be greatest. Barnacles were attached to plates using cyanoacrylate glue and a loop of monofilament line threaded through two small holes drilled in the plate and looped over the most distal part of the peduncle. Two barnacles were attached to each plate in opposing corners to provide adequate separation. Barnacles were attached to only 3 of the 4 plates on each hanger, leaving the fourth empty to provide unimpeded settlement substrata. The location of this fourth plate was randomized throughout the nurseries using a random number generator.

The seawater used in this experiment came directly from the seawater pumping system, supplying the sea tables at OIMB. This system pumps water at each high tide from the end of the OIMB Boathouse dock into three large storage tanks located in the hills above the campus. These storage tanks provide a constant supply of unmodified seawater. The guard on the pump end of the system, which prevents large objects and megafauna from entering the system, has a relatively large network of holes. It is well documented that larvae, detritus, and zooplankters frequently enter the system and are observed in the institution's sea tables.

In an effort to standardize the delivery of air and water between treatments, the internal diameter and length of seawater and air supply lines connected to each nursery were identical. Despite this effort, there was a wide variation in seawater flow rate and intensity of aeration when all ball valves were completely open. This was likely caused by uneven fouling of supply lines and ball valves by detritus and further confounded by additional fluid dynamics phenomena affecting the flow of seawater. Several times during this experiment, the authors had to remove and clean seawater system ball valves and hose barbs to remove the occasional fouling *Diodora sp.* or *Mytilus spp.* test. Due to this fouling and temporal changes in water pressure, maintaining a constant flow rate in each nursery was difficult. Instead, steps were taken to ensure the flow rate was always approximately equal between all treatments and replicates even if it was not held constant. Using a specially constructed cap to collect and funnel the seawater overflowing the top of each nursery, we could approximate the rate of seawater flow and equalize all nurseries. We found that a visual estimation of the flow rate by looking at the height of the bolus of water above the top of the nursery tubes and the amount flowing down the sides was sufficient to equalize the flow rate to within $\pm$ 0.2 L $\cdot$ min^{-1}. The effect of gravity resisting vertical flow through the tubes was expected to decrease the volume of water supply lines could deliver, but we expected vertical forces delivered by the bubbles would counter some of this resistance to flow. The flow rate during this experiment was maintained as close to ~1.5 L $\cdot$ min^{-1} as possible. Given the diameter of the nurseries, this equated to a vertical water velocity of 0.3 cm $\cdot$ sec^{-1}.

A total of 12 barnacle nurseries were constructed, three replicates for each of four diet treatments (1. No barnacles on plates and no food subsidy, 2. Barnacles on plates and no food subsidy, 3. Barnacles on plates and micro-algae subsidy, 4. Barnacles on plates and decapsulated *Artemia sp.* cyst subsidy). Treatment 1 was used to provide unimpeded settlement substrata to any larvae, which may have entered the seawater system. The three nurseries in this treatment were the first ones constructed after designing the apparatus. As a result, they were used during operational testing of the apparatus and prior to the transplantation of any barnacles into the other nurseries. This meant they were operational for approximately 2 weeks prior to any of the other nurseries. Treatment 2 was used as a control to demonstrate the growth rate of barnacles given only the food available in the OIMB seawater system. Treatment 3 introduced 1 mL of Shellfish Diet 1800™ (Reed Mariculture) during each feeding. Shellfish Diet 1800 is a blend of micro-algae reported to contain 40% *Isochrysis*, 15% *Pavlova*, 25% *Tetraselmis*, 20% *Thalassiosira pseudonana* by dry weight and is reported to contain ~2 billion cells $\cdot$ ml^{-1} and 8% biomass by dry weight. Treatment 4 introduced decapsulated cysts of *Artemia sp.* (Brine Shrimp Direct, Inc.) at a concentration of 5 cysts $\cdot$ ml^{-1}. These food subsidies were selected because they are easily obtained and already widely used in aquaculture. To approximate the twice daily delivery of food by the semidiurnal tides which exist in this region, barnacles were fed two times per day, separated by 12 hours. To prevent food subsidies from immediately being diluted and removed from the nurseries, seawater inflow for all treatments was stopped before the addition of food. The inflow of water remained off for 20 minutes and the food was allowed to circulate in the remaining water by action of the continued aeration. Halfway through the feeding period, a short pulse of seawater was pumped into each nursery to suspend any food which may have settled to the bottom of each tube. This step was taken as a precaution, however, water flow was such that no sedimentation of food or other particulate was observed in any of the nurseries.

After being removed from the breakwater and attached to plates, the barnacles were given one week to acclimate to the mariculture system and feeding regime before the experiment began on 25 August 2017. The RC length of each barnacle was measured weekly for 8 weeks using digital Vernier calipers (reading error ± 0.05 mm). Taking growth measurements was time consuming. All hangers containing barnacles were therefore removed from the nurseries before measurements began so barnacles not actively being measured did not have additional feeding time. At the completion of measuring, hangers were replaced into the same position in each nursery in the reverse order in which they were removed.

The flexible nature of gooseneck capitula confounds accurate RC measurements and occasionally measured individual barnacle RC length would appear to decrease in size from a previous week. To minimize this effect and obtain univariate data, growth rates ($mm \cdot wk^{-1}$) were calculated by dividing the total growth (final length – initial length) by the 8-week duration. While logarithmic models are widely used to assess organismal growth, we applied a linear model here due to the short duration of the experiment and similar initial size classes of barnacles used. Barnacles were deemed to have not survived if they were obviously deceased or if they failed to grow more than the reading error of the measuring device (0.05 mm) during the 8-week experiment.

Results were analyzed using SPSS Version 20 (IBM Corporation) at a significance level of $\alpha=0.05$. Data were assessed for normality (Shapiro-Wilk's test) and natural logarithm transformed to achieve homogeneity of variance (Levene's test). Although there were three nurseries for each diet modification, they were treated as separate experimental units in the analysis and labeled with the name of their diet followed by the letter A, B, or C to identify which nursery was being examined (ex: AlgaeA, AlgaeB, AlgaeC, ArtemiaA, ArtemiaB, ArtemiaC). Average initial RC lengths were compared by analysis of variance (ANOVA). Since linear measurements of growth rate in many animals have been shown to decline with size, differences in growth rates were compared by one-way univariate analysis of covariance (ANCOVA) using initial RC length as a covariate. Data used in ANCOVA were assessed for homogeneity of regression slopes and did not satisfy this assumption of ANCOVA. Thus, they were also analyzed by one-way ANOVA.

Results

At the beginning of the experiment, average initial RC lengths (8.7mm ± SE 0.16) were significantly different between nurseries [$F(8, 86) = 2.732$, $p = 0.01$], but a post-hoc test (Bonferroni) revealed no significant differences in initial sizes (Figure 2). Two of the nurseries fed *Artemia* cysts (ArtemiaB & ArtemiaC) were the closest to being significantly different ($p = 0.08$). ArtemiaB and ArtemiaC had the highest (9.7 mm) and lowest (7.7 mm), respectively, average initial starting size of all nurseries (Table 1). All other pairwise comparisons between nurseries were statistically similar ($p > 0.201$). Barnacle survival during the experiment was high (88%, n=95/108) with the highest survival in the no-subsidy treatment (34 out of 36) and the lowest in the micro-algae treatment (29 out of 36) (Table 1). Five barnacles grew less than the reading error of the Vernier calipers and were assumed deceased and not considered in the analysis. The other eight losses occurred early in the experiment and no additional barnacles died after the 2nd week.

Treatment		No subsidy	Micro-algae	*Artemia* cysts
Replicate A	growth ± CI (mm · wk^{-1})	0.14 ± 0.03	0.15 ± 0.06	0.29 ± 0.07
	initial RC size ± CI (mm)	9.36 ± 1.02	8.23 ± 1.00	9.20 ± 0.89
	Initial *n*	12	12	12
	Surviving *n*	12	8	11
Replicate B	growth ± CI (mm · wk^{-1})	0.19 ± 0.06	0.16 ± 0.05	0.28 ± 0.09
	initial RC size ± CI (mm)	9.33 ± 1.22	8.10 ± 1.23	9.71 ± 1.30
	Initial *n*	12	12	12
	Surviving *n*	11	10	10
Replicate C	growth ± CI (mm · wk^{-1})	0.20 ± 0.04	0.14 ± 0.03	0.36 ± 0.06
	initial RC size ± CI (mm)	8.59 ± 0.93	7.84 ± 0.65	7.69 ± 0.79
	Initial *n*	12	12	12
	Surviving *n*	11	11	11
Treatment Averages/Totals	**growth ± CI (mm · wk^{-1})**	**0.17 ± 0.08**	**0.15 ± 0.02**	**0.31 ± 0.11**
	initial RC size ± CI (mm)	**9.09 ± 1.08**	**8.05 ± 0.49**	**8.87 ± 2.61**
	Total Initial *n*	**36**	**36**	**36**
	Total Surviving *n*	**34**	**29**	**32**

Table 1 – Summary table of barnacle nursery descriptive statistics.

After eight weeks, average total RC growth for nurseries given no food subsidy was between 1.1 mm (No_subsidyA) and 1.6 mm (No_subsidyC), for nurseries given micro-algae between 1.2 mm (AlgaeA & AlgaeC) and 1.3 mm (AlgaeB), and for nurseries given *Artemia* cysts between 2.3 mm (ArtemiaA & ArtemiaB) and 2.9 mm (ArtemiaC). Although significant differences in estimated marginal mean growth rates were detected between nurseries when initial size was considered as a covariate [$F(1, 85) = 9.950$, $p = 0.002$], a significant interaction between initial size and nursery was detected ($p < 0.001$) when data were tested for homogeneity of regression slopes. The lack of homogeneity of regression slopes violates one of the assumptions of analysis of covariance (ANCOVA) and calls for elimination of the covariate from the analysis. We find this an acceptable approach as groups in this experiment started at very similar size classes. Due to this, we ran a one-way analysis of variance and detected a significant difference in average growth rates between nurseries [$F(8, 86) = 9.915$, $p < 0.001$] (Figure 2). A post-hoc test (Bonferroni) indicated that barnacles in nurseries subsidized with *Artemia spp.* cysts grew significantly faster than those given micro-algae ($p < 0.022$). The post-hoc test did not detect a difference in growth rates between barnacles receiving no subsidy and those fed micro-algae ($p = 1.000$). The pairwise comparisons between the three nurseries given no food subsidy and the three given *Artemia* cysts revealed significant differences between some nurseries and no differences between others. Since a comparison of initial RC sizes indicated a significant difference between barnacle nurseries *Artemia*B and *Artemia*C, the analysis was conducted two more times by leaving one of them out of each analysis. The significant differences remained as observed in the first analysis that considered all nurseries (without *Artemia*B: [$F(7, 77) = 9.854$, $p < 0.001$], without *Artemia*C: [$F(7,76) = 6.221$, $p < 0.001$]).

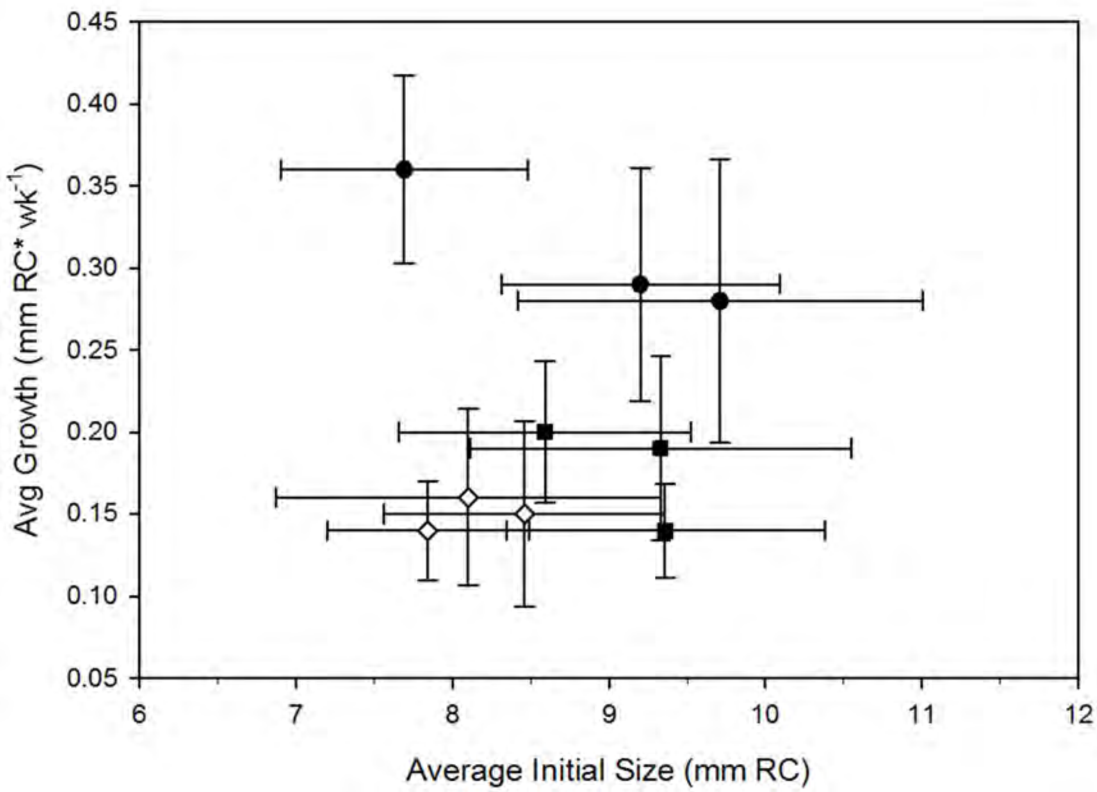

Figure 2 - Comparison of average initial RC length to average growth rates across treatments for *Pollicipes polymerus*. Solid squares are nurseries given no food subsidy. Unfilled diamonds are nurseries fed micro-algae. Solid circles are nurseries fed *Artemia* cysts. Error bars are 95% confidence intervals. Note the similar initial RC size for all nurseries except between the ArtemiaB and ArtemiaC, the nurseries with the highest and lowest, respectively, initial RC size.

Larval settlement

During the two weeks that three nurseries were operational before any barnacles were transplanted into the system, a definitive pulse of various acorn barnacle larvae entered the seawater system and were observed settling on the inside of each nursery. Another worker monitoring acorn barnacle settlement and growth in the field near the school reported observing new spat settling in the intertidal during this same time frame. No *P. polymerus* larvae were seen amongst those settled within the nurseries. Survival and growth of the acorn barnacles were not monitored quantitatively, but of the thousands settled, many recruited and grew 1-3 mm in basal diameter by the end of the experiment.

During weekly measurements, very small *P. polymerus* juveniles were seen attached to the peduncles of transplanted barnacles (Figure 3, plates A, B, & C). Many of these new recruits grew to 4-5 mm RC length by the end of the experimental period (Figure 3, plate C). Since only new recruits and juveniles visible to the unaided eye were removed from the peduncles of experimental barnacles, it is unknown which of these new recruits were already attached when the barnacles were collected. Some of the populations of new recruits on transplanted barnacles were of distinctly different size classes. The population attached to one barnacle exhibited a distinct tri-modality in size (Figure 4).

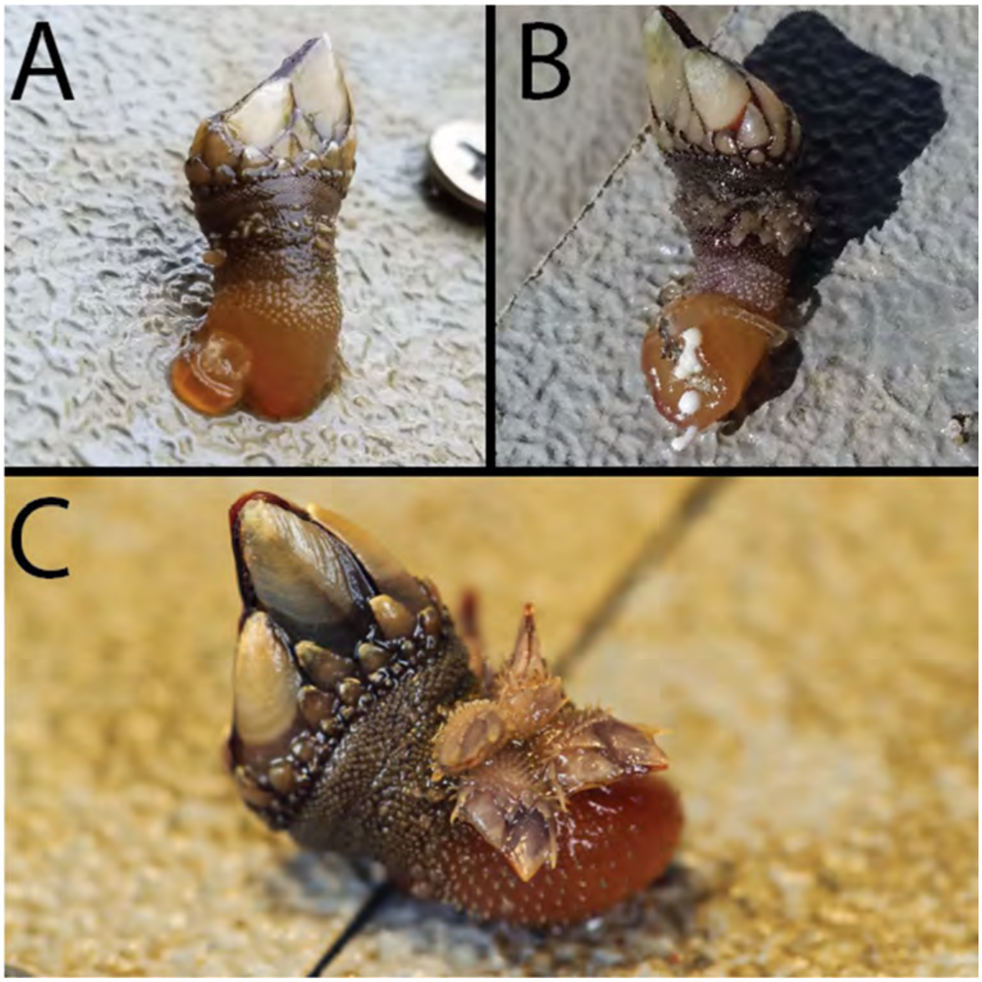

Figure 3 – Photographs of experimental barnacles. Panel A shows basal peduncular projection and subsequent attachment to textured plate. Panel B shows the white colored cement secreted by a barnacle which was not attached to the plate in the proper orientation for the barnacle to attach itself. Panel C shows juveniles attached to the peduncle of an experimental barnacle. The photograph was taken at the end of the experiment. Juveniles are approximately 4.8mm in RC length. These photographs were taken at different times during the experiment; note the various stages of growth of attached recruits and juvenile conspecifics.

Barnacle reattachment / feeding behavior

Barnacles readily began secreting biological cement from the most distal part of their peduncles after the first week in culture. If this part of the peduncle was in contact with the acrylic plates they were secured to, the barnacles became firmly attached to the plates just as they would be to rocks in the wild (Figure 3, plate A). Occasionally, the most distal portion of a barnacle's peduncle was not in contact with a plate, due simply to the way it had been secured at the beginning of the experiment. When this occurred, barnacles would still secrete cement, but it would form white, projecting accumulations that appeared to emanate from multiple glandular pores (Figure 3, plate B).

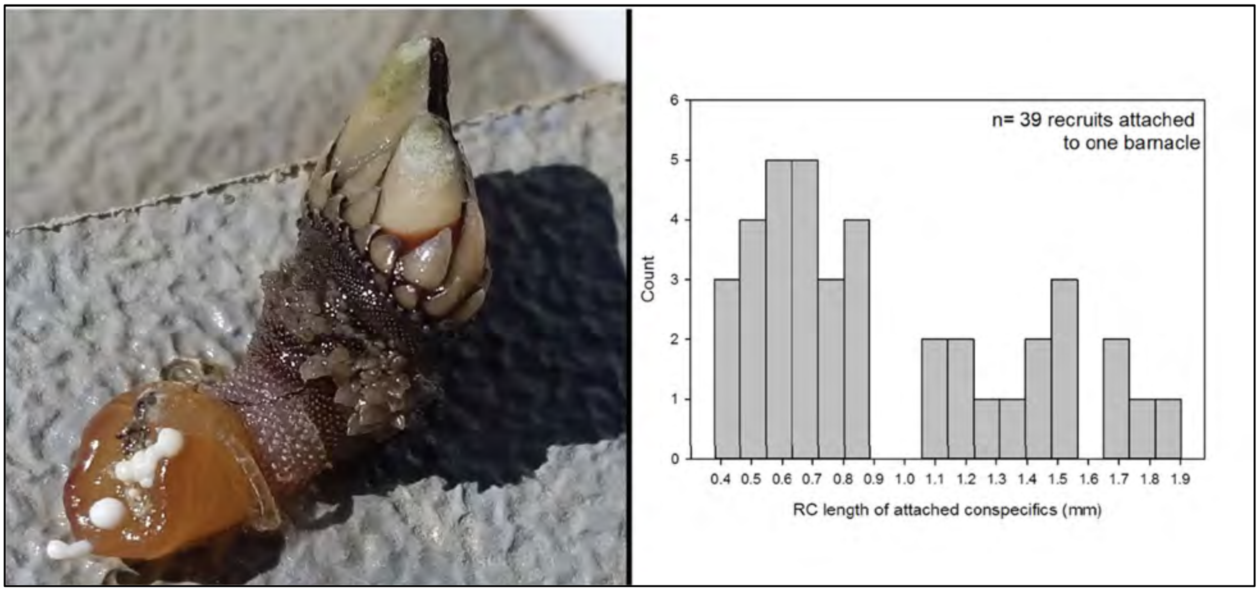

Figure 4 – Photograph is of a barnacle two weeks into the experiment (the same barnacle in Figure 3, plate B). Note the distinct size classes of attached recruits. The histogram shows the tri-modal size frequency distribution of n=39 of these recruits. The histogram is not meant to represent absolute sizes, as measurements were approximated from the photograph, but is intended to represent the relative size distribution amongst the recruits.

During feeding periods, limited observation of feeding behavior was possible by looking down into the top of the opaque nursery tubes. Barnacles in all treatments were observed fully extending their cirral fan into the water column. Due to the size of the decapsulated *Artemia* cysts (~250 µm), it was possible to see cysts being captured by the barnacles and brought into the mantle cavity by curling of the cirral rami. Several of the barnacles with longer peduncles were observed bending 90-180° to orient their capitula behind the plate to which they were attached. In these cases, either by choice or by limitations in their flexibility, their rostral plates were oriented towards the top of the tube (opposite of the way they had been attached). Given that water inflow was stopped during feeding while aeration continued, it is possible the vertical flow created by the bubbles in the center of the tube created a downwelling condition along the walls of the tubes that barnacles were using to feed.

Discussion

Despite the low water velocity used in this experiment (~0.3 cm · sec^{-1}), we found that juvenile *P. polymerus* survived and grew in mariculture at rates comparable to or greater than what has been observed for wild populations. Early observations of the growth of *Pollicipes spp.*

indicated they were a slow-growing genus taking about 5 years to mature and 15-20 years to reach full size (Batham, 1945; Barnes & Reese, 1960), but more recent work has shown that growth is quite variable and dependent on local conditions and that sexual maturity can be reached in as little as 1 year (Cruz, Castro, & Hawkins, 2010; Bernard, 1988; Lewis & Chia, 1981; Paine, 1974, Page, 1986; Hoffman, 1988; & Hoffman, 1989). Barnes (1996) provides a thorough review of the genus including a table summarizing observed growth rates of *P. polymerus* and *P. pollicipes* documented within the literature. Most juvenile growth rates in the wild range from a minimum of 0.01 mm $\cdot$ wk^{-1} (Cruz, 1993) to a maximum of 0.86 mm $\cdot$ wk^{-1} (Page, 1986); the latter occurred on an offshore oil rig. In an isolated case, Hoffman (1989) observed a dramatically higher juvenile growth rate of 2.3 mm $\cdot$ wk^{-1} where barnacles were attached to the overhanging surface of a rock that remained submerged continuosuly. In the wild, *Pollicpes spp.* are restricted to exposed rocky substrata battered by waves (Borja, Liria, Muxika, & Bald, 2006; Ricketts and Calvin, 1939; Barnes M. , 1996; Paine, 1974) and many workers believe gooseneck feeding is stimulated by the higher flow regimes of these locations (Barnes & Reese, 1960;; Franco S. C., 2014; Bernard, 1988; & Howard & Scott, 1959). Franco (2014) found that juvenile *P. pollicipes* unconditioned to the laboratory environment required water velocities of >23 cm $\cdot$ sec^{-1} to feed and those conditioned in culture conditions for several months required > 6 cm $\cdot$ sec^{-1}. The results of this experiment have demonstrated that feeding behavior of *P. polymerus* is not dependent on high water velocities and barnacles can be stimulated to feed using aeration and will survive and grow readily in mariculture.

A major contributor to the success of cultured animals is the efficacy of their diet in meeting biological needs. Gut content analyses of gooseneck barnacles show them to be omnivorous (Lewis, 1981) while energy utilization experiments have shown the consumption of algae is not required for barnacles to obtain sufficient energy or nutrients (Norton, 1996). Norton (1996) observed that *P. pollicipes* fed only *Skeletonema sp.* gained significantly less weight than those fed *Artemia* nauplii and those given mixed diets. Norton (1996) reported that while ingestions rates of algae were high, the overall energy consumed was small compared to those fed animal diets. Additionally, she found no difference in weight gain between those fed *Artemia* and those given mixed diets. We concur that a protenaceous diet is prefereable for mariculture given the higher growth rates seen in barnacles fed *Artemia* cycsts over micro-algal diets. While it is not surprising diet plays an important role in the growth of *P. polymerus*, it is interesting the addition of only a small amount of food to their diet can accelerate growth rate. Barnacles in this experiment were given only 40 min $\cdot$ day^{-1} to feed on food subsidies, yet those fed *Artemia spp.* nauplii were still able to ingest enough additional biomass to show significantly faster growth rates. Additionally, this experiment has demosntrated that gooseneck barnacles can be maintained in culture while being fed passive particles as long as particulate food is sufficiently stirred to allow barnacles ample opportunity for food capture.

While mature gooseneck barnacles have been succussfully conditioned as broodstock in culture by controlling ambient temperature (Franco et al., 2015), there is currently no known method in which to reliably induce settlement in the *Pollicipes spp.* larvae. Using transplanted juvenile and adult barnacles as settlement substrate and seed stock may be a solution. At the end of 8 weeks, we saw new recruits (upwards of 4-5 mm RC) on the peduncles of transplanted barnacles. The tri-modal size frequency distribution observed in the population of newly recruited conspecifics on one barnacle suggests the attached recruits seen in this experiment were from separate cohorts and were not all brought into the system when juvenile barnacles were first collected. The median size of the smallest cohort (~0.6 mm RC) was not much larger than the size of a *P. pollicipes* cyprid and the median size of the largest cohort was ~1.8 mm RC. Even if the recruits from the largest cohort had been newly settled immediately prior to collection of experimental barnacles, this would equate to a minimum average growth rate in mariculture of 0.6 mm RC $\cdot$ wk^{-1}. Relying on the use of oceanic waters to bring larvae into a mariculture system, however, increases the risk of introducing bio-fouling organisms and pathogens into the system as Norton (1996) experienced when much of her gooseneck stock (*P. pollicipes*) was destroyed by an unknown peduncular fungus. Locating and transplanting into mariculture adult barnacles covered by newly settled cyprids may also be a way to induce clump formation without having to care for larval stages. Hoffman (1989) found 150-300 new spat per adult barnacle in the early spring and found settlement to occur year-round off the coast of La Jolla, California. Transplanting similarly colonized barnacles into mariculture where the settlers are free from dessication stress, predation, and removal by wave action may result in higher than normal recruitment and establishment of greater stock per unit of effort when compared to rearing larval stages through to settlement.

Conclusion

This experiment has offered a novel mariculture system design that provides an alternative to costly high-flow systems. The current work has also provided evidence that even small dietary subsidies can have significant impacts on gooseneck barnacle growth rates and has demonstrated possible methods for inducing the formation of clumps of barnacles from small numbers of seed-stock. Future work should focus on dietary enhancement, increasing barnacle capacity, and long-term monitoring of clump formation by selective transplantation of adult barnacles settled by new spat. Additional research should be conducted in Oregon to determine if the quantity and temporal variation of larval settlement is comparable to what Hoffman (1989) observed in southern California.

OBJECTIVE C:
Multistakeholder Collaboration, Application and Outreach

Fostering Sustainability through Collaboration

Julia Bingham, M. Thomas and A. Shanks

Introduction

A key aspect of developing a sustainable fishery is having highly involved, dedicated, and communicative stakeholders. Communication between researchers and stakeholder groups encourages resource users to understand the impacts of their actions while building partnerships and expanding a practice of transparency. Transparency and clear communication between resource managers and users builds trust and improves collaboration (Feldman & Khademian 2007; Hilborn 2007; Shindler et al. 2010). Collaboration between researchers, fishers, management groups and the general public enhances efficiency and effectiveness of developing, implementing and enforcing sustainable and productive ecosystem based management (Shindler et al. 2010). Networking between all groups encourages further outreach including citizen science education and public involvement in decision making processes. As such, we pursued stakeholder involvement throughout our project to establish a collaborative framework and set the precedent for effective integration and application of this and future research in the Oregon gooseneck fishery. Stakeholders included representatives from the following groups:

- University of Oregon's Oregon Institute for Marine Biology (OIMB)
- Port Orford Sustainable Seafood (POSS)
- Oregon State University (OSU) and the Port Orford Field Station
- Oregon Department of Fish and Wildlife (ODFW)
- Oregon Sea Grant

We strategized our collaboration around goals in project design, outreach, and application for our research results from our jetty surveys and mariculture investigation. Collaborative strategies included regular stakeholder meetings, transparency of research progress, fisher interest and manager involvement, public seminars and designing data reports accessible to stakeholders without background training in scientific research.

Project Design

In building relationships with stakeholders, we modified our research objectives so that our work could specifically answer harvest-relevant questions within the larger scope of our investigation. To do so required communicating with stakeholders and asking about their motivations and questions in approaching a new fishery. Through preliminary meetings with stakeholders, we explored the goals and resources of stakeholders to establish roles within the project, described below.

We were motivated by a desire to develop a better knowledge of an understudied species and the promising potential for impactful application of our findings. We utilized the proximity of OIMB to access the southern Oregon jetties for our surveys. We also utilized the OIMB seawater system to support our mariculture experiments.

POSS is a primary stakeholder interested in commercial harvest and distribution of gooseneck barnacles to their shareholders. Based on the Community Supported Agriculture business model, POSS runs a Community Supported Fishery (CSF). Members receive a monthly share of seafood caught by Port Orford fishers. They currently serve 300+ members in 17 communities throughout Western Oregon. This is a captive marketplace of seafood consumers who receive a seasonal selection of species landed in Port Orford. By introducing members to novel seafood along with the story behind the product, they are able to change consumer attitude toward exotic, underutilized species. For example, they introduced their membership to Longnose Skate, an underutilized bycatch species from the Sablefish fishery that is a popular dish in France. In the case of gooseneck barnacles, they would introduce them as percebes, a luxury seafood in Western Europe, traditionally served as a side dish after boiling in seawater. In this way they can begin to introduce percebes to Oregonians and initiate a market. POSS has already received positive feedback from their members in a survey about potential additions to their seafood menu, including percebes, and so feels confident that they could establish a consumer market for *P. polymerus*. POSS is interested in using researched-based information to make sustainable commercial harvest decisions. POSS was therefore especially interested in seeing a stock assessment of available barnacles and an analysis of potential harvest impacts produced within our research. They wish to determine if a wild harvest is sustainable under current ODFW regulations. Additionally, POSS has expressed interest in efforts to develop onshore mariculture of goosenecks.

The OSU Port Orford Field Station is a research and education facility aiming to support research, learning, community outreach and economic priorities while fostering coastal stewardship and sustainability (Port Orford 2017). Station faculty were therefore enthusiastic about serving as a liaison between our research and their local fishers and community members. The station shares a building with the POSS office and served as a primary meeting location for all stakeholders.

ODFW is the primary management group responsible for establishing and enforcing harvest management of recreational and commercial coastal fisheries. They did not express immediate interest in modifying management of gooseneck harvest due to the small size of the existing Oregon market. However, given the growing stakeholder interest in harvest and our ability to provide preliminary research of the status of current underutilized stock, the ODFW shellfish program is interested in potential future application of our research results for monitoring of gooseneck populations and, if necessary, modifying harvest restrictions.

Oregon Sea Grant is an OSU supported program within the National Oceanic and Atmospheric Administration's Sea Grant College Program supporting research, outreach and engagement, and ocean and coastal education to address strategic issues of Oregon’s marine resources through federal and state funding and project-specific contributions from industry and local government (Oregon Sea Grant 2017). Oregon Sea Grant provided the funding for this project and expressed interest in our ability to incorporate stakeholder collaboration and public outreach to enhance the broader impact of our work.

We intentionally allowed our research questions to be shaped by the interests of an expanding fishery. We prioritized goals in areas of knowledge severely understudied but potentially relevant to informing ecologically sustainable harvest practices for Oregon *Policipes polymerus*. Together with POSS and ODFW, we established a list of goals we aimed to fill within our overall objectives in our jetty surveys and experimental mariculture development. We developed these focal points based on overlapping points of interests in the shared goals of stakeholders. We aimed to provide the research necessary for developing a viable fishery and expanding species-specific biological knowledge of an understudied species. Our goals included:

1. An estimation of total barnacle population on jetties open to commercial harvest
    a. A stock assessment of harvest sized barnacles within the overall jetty populations
    b. Identification of population trends potentially attributed to physical conditions of jetty structure habitats (tidal height, exposure, etc).
2. A preliminary investigation into potential harvest impacts on barnacle populations given their known gregarious settlement patterns and slow growth.

3. An investigation into the feasibility of onshore mariculture development
    a. If successful at building a prototype, an experimental test of growth rate manipulation through food supplementation
4. A strategy for communicating our findings to stakeholders and the public in such a way that individuals without a scientific research background can access and easily understand our findings and their implications.
5. Public outreach that simultaneously expands the potential gooseneck consumer market for POSS and other harvesters while educating fishers and the public on a local species and ecosystem and the potential effects of harvest expansion

Throughout the project, we maintained correspondence with stakeholders to gauge any shift in their questions and interest in the fishery and to maintain transparency of progress. We were in general successful in fulfilling our outlined goals. We were able to estimate jetty populations, provide an initial stock assessment and identify potential trends in gooseneck distribution and size relative to tidal height. We created a promising mariculture prototype and experimentally demonstrated the ability to enhance growth rates. We developed a visual summary of our findings for each jetty to transform our data into an accessible stock summary in a series of fact sheets useful for stakeholders in making harvest and management decisions (Appendix A). Additionally, we hosted several outreach functions to include the general public and additional stakeholders in the application of our research and connect POSS and ODFW to others interested in the expanding gooseneck market. Finally, our barnacle population surveys introduced a new set of potential research paths motivated by biological and ecological questions we were unable to answer within the scope of our study.

Application of Results

Our research is intended to expand the knowledge base for the newly emerging fishery on the Oregon coast in such a way that harvest, management, and commercial growth of the gooseneck fishery proceed in a way that is both ecologically sustainable and economically viable. Our jetty survey results provide a baseline description of the scope and variation of current jetty populations of goosenecks with a specific estimate of available stock. This allows fishers like POSS to realistically assess their ability to pursue commercial gooseneck harvest. It allows managers including ODFW to set restrictions on harvest to prevent overfishing of existing stock. Furthermore, our assessment provides a baseline reference against which to compare future populations of goosenecks after harvest, allowing us to better understand the impact of the expanding fishery and allowing managers to adjust policy if necessary. Our jetty survey data also suggest population trends of gooseneck size, settlement, distribution and density potentially attributable to specific habitat conditions. These possible trends point to a series of additional questions for continued biological research, continuing to fill the knowledge gaps surrounding *P. polymerus* in Oregon,

Our mariculture prototype can easily be expanded and enhanced for more effective and efficient onshore barnacle growth for harvesters. This will allow commercial expansion of the gooseneck market without direct disruption of natural jetty populations. The mariculture design also provides an easily replicable layout for in-lab experiments and investigations of barnacle growth, reproduction, feeding habits and other traits to expand the species-specific knowledge of Oregon *P. polymerus* behavior and life history.

Outreach

At the conclusion of the field research efforts for the project, POSS hosted a percebes outreach seminar at the OSU Port Orford Field Station in late October. The seminar connected the major stakeholders: Fisheries Managers (ODFW), Scientists (OSU/OIMB), Seafood Consumers (CSF membership, Port Orford residents), Seafood Producers (Port Orford fishing families, POSS), and research funders (Oregon Sea Grant). The seminar included a short presentation by each stakeholder partner that had been a continuous part of the project followed by a discussion open to questions by those attending – namely, local residents and fishers. POSS hosted a percebes tasting for everyone in attendance featuring freshly harvested goosenecks. Additionally, we presented our jetty survey and mariculture research efforts at the annual Western Society for Naturalists meeting in November 2017. We repeated the percebes outreach seminar and tasting session during a "Pub Science" public event hosted at the 7 Devils Brewery in Coos Bay in December, which engaged a wide variety of community members curious about ongoing coastal research. We engaged with marine science students at Pacific University by giving a guest lecture for an undergraduate class in January 2017. Finally, we hope to publish our findings as two papers in peer reviewed research journals in the upcoming months. We have in this way engaged beyond our initial stakeholder collaborative group to include additional fishers, the general public and students in our outreach efforts to create a more connected community. We hope that these efforts have helped to strengthen relationships between POSS, ODFW and additional stakeholders while expanding the potential gooseneck market. Ultimately, we hope that our role in this network expansion and outreach have helped to foster a sense of stewardship and goals for sustainability within a more informed and involved coastal community while providing biologically relevant research for ecologically sound fishery management.

Continued Collaboration

Following the conclusion of our population survey and mariculture design research efforts in November 2016, we have since continued to maintain contact with stakeholders and utilize public outreach and engagement through seminars and guest lectures. Stakeholders engaged enthusiastically throughout the project, fully participating in public outreach and efforts to incorporate our research findings into harvest and management decision making. ODFW and POSS are open to ongoing communication with each other and with future research personnel to integrate stakeholder goals and developing research into management decisions as the Oregon gooseneck fishery develops. Through this project, we have helped to build a multistakholder collaborative network and strengthen relationships between researchers, fishers, and resource managers. This allows the pursuit of future research with the knowledge that it will continue to be directly applied to informing ecologically sustainable fishery development. In fact, work on the viability of mariculture and establishing a test fishery is already being investigated further in Dr. Shanks' laboratory thanks to continued support by Oregon Sea Grant in the form of a SEED grant**.** Applied research aiming to fill the gaps in understanding gooseneck barnacle life history and ecological roles, harvest impact and mariculture development will have a direct pathway to application in this collaborative, multistakeholder network.

CONCLUDING REMARKS

In summer 2016, we established three primary objectives for a multifaceted approach to broadening established knowledge of Oregon *Pollicipes polymerus* populations, known generally as gooseneck barnacles or percebes. We intended to fill basic knowledge gaps of the species while providing relevant data to inform interested stakeholders in their ongoing efforts to establish a new and ecologically sustainable fishery for percebes. Additionally we launched initial investigations into the feasibility of developing affordable and efficient onshore mariculture of the species. Throughout the project, we utilized multistakeholder collaboration to ensure the immediate and responsible application of or research results. Our outcomes from the project included:

- A full description of the distribution, abundances, size frequency, recruitment, and spatial patterns of gooseneck populations on southern Oregon jetties
- A stock assessment of harvest-sized barnacles within the jetty populations, accompanied by a statement of relevant factors to consider when developing responsible harvest management based on our data
- A collection of summary fact sheets stating the key gooseneck population and harvestable stock information for each jetty, designed with stakeholder accessibility in mind
- A simple, affordable and effective prototype mariculture system
- Evidence that mariculture populations may be manipulated by, for example, enhancing growth rates through feeding supplementation
- A strong and transparent collaborative networking relationship between stakeholders
- A series of presentations including local public seminars, scientific conference presentations, and a guest lecture in order to utilize outreach to a variety of public audiences and enhance community engagement in relevant coastal ecological challenges to sustainability
- Leads to further field research projects and an already ongoing continuation of laboratory investigations into related questions of gooseneck life history patterns and mariculture prospects

We proudly present our outcomes with the hope that our project encourages continued efforts in pursuing scientific investigation of Oregon's gooseneck barnacle population, application of data towards sustainable fisheries management, and the pursuit of stakeholder collaboration and community involvement in enhancing the health and resilience of Oregon's coastal communities and ecosystems.

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Appendices

A: Jetty Fact Sheets

The following are jetty – specific fact sheets we designed for the purpose of presenting our findings to stakeholders interested in harvesting, managing or researching *P. polymerus* populations in harvest-targeted jetties of Southern Oregon. We designed a summary for each of the six jetties we surveyed and found gooseneck populations. Each jetty summary consists of two pages of information: first, a page describing the jetty location, physical features and gooseneck population statistics and general trends followed by the second page, an infographic displaying the transect-specific variations in size-frequency results along the jetty. We designed the summaries to be visually engaging, consistent in format and generally easy to read and interpret with only the most relevant information on abundance, density, distribution, percent cover¸ size-frequency and stock availability of gooseneck barnacles. Each summary can function as an individual jetty-specific document. We intentionally focused on technical simplicity, visual accessibility, and descriptive but concise data summary so that readers without a background in biological sciences but with a relevant interest in gooseneck populations can more easily understand and apply our findings.

The jetty summaries do not account for seasonal variations that may exist in *P. polymerus* populations including recruitment and rates of growth and reproduction. Neither do they provide any background information on gooseneck barnacle physiology or life history including the gregarious nature of gooseneck settlement. These summaries therefore do not explicitly suggest that gooseneck harvest provides a within-species bycatch risk or requires long-term recovery of a patch after disturbance by destructive harvest. Such interpretations should be discussed, however, whenever stakeholders interact in planning gooseneck management policy or harvest regulation and considering risks of human impact

I. Summary sheet 1: Winchester Bay South Jetty

Winchester Bay South Jetty

Length of survey: 800 m
Heading of jetty: 277° magnetic
Lat/Long: 43.664861, -124.214552

The Winchester Bay South Jetty is actually composed of two long jetties that meet at an offshore point, forming a triangle containing a small lagoon. Drainage pipes embedded in the jetty allow tidal flows to enter and exit the lagoon. The lagoon supports an oyster farm but does not support any gooseneck barnacle populations. The most southern side of the Winchester Bay South Jetty is adjacent to Ziolkouski Beach. Due to time constraints, our survey did not include the northern / bay side arm of the Winchester Bay South Jetty.

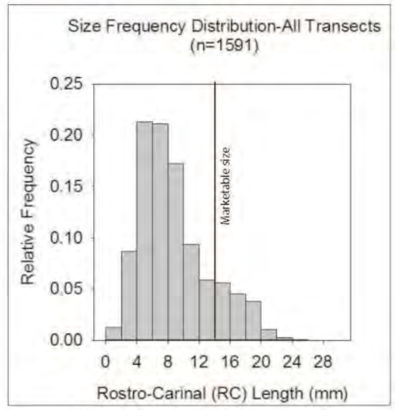


Figure 1. Does not include new recruits.

Gooseneck Barnacle (*Pollicipes polymerus*) Population Status Within Survey

Estimated total harvestable habitat: 7,128 m²
Average percent cover within habitat: 42% ± SE 4.6%
Avg. adult/juv. pop. density :7,220.8 ± SE 860.3
Est. total pop. density (includes new recruits): 69,475 ± SE 8,277 indv./m²
% of total population which are of marketable size (>14mm RC): 1.8%
Est. of available biomass of marketable-sized individuals (2-10 g ea.): 18,135-90,676 kg

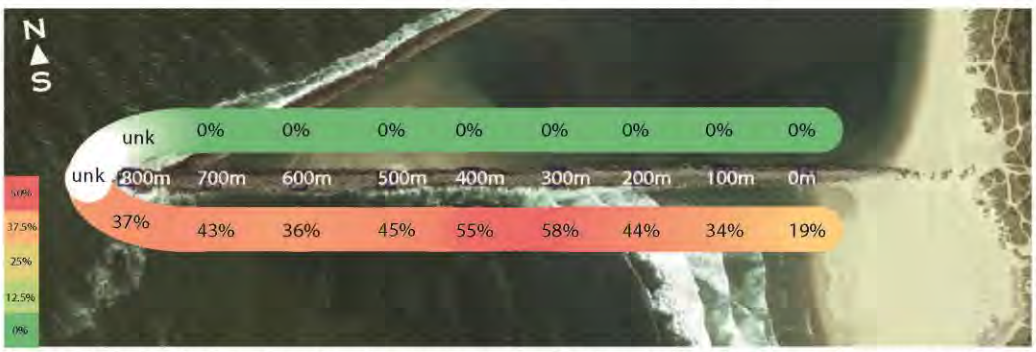


Figure 2. Distribution of % Cover - Figure shows the average percentage of *P. polymerus* habitat which is covered by goosenecks within each transect surveyed. Locations of surveys are marked in white and denote meters from high water line on adjacent shore. Surveys took place on both North and South sides of jetty at marked locations. Color gradient is reflective of percent cover and assumes a linear percentage gradient in areas between transects.

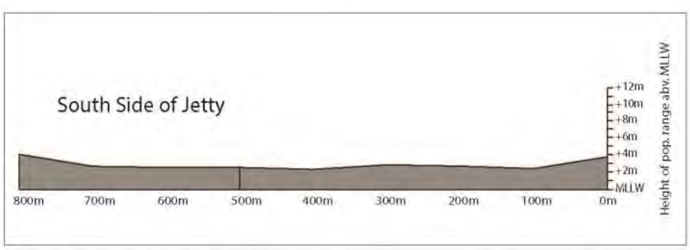


Figure 3. Range of Habitat - Shaded area represents range of *P. polymerus* relative to Mean Lower Low Water (MLLW). Horizontal axis represents locations of transects along jetty and are in meters from high water line on adjacent shore. Vertical axis represents height in meters above MLLW. Note that the entire range of habitat may not be represented if the lower bound was below MLLW. The elevation of the top of the jetty varied along its length, however, it was consistently higher than the extent of *P. polymerus* habitat.

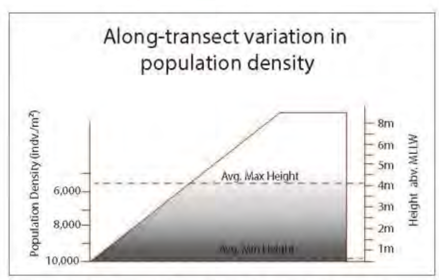


Figure 4. Variation in Population Density - Figure shows cross-section of a transect. Left axis represents population density. Right axis represents height above MLLW. Dashed lines show average max/min height of surveys conducted from all transects. Darker color in gradient represents higher population densities with decreasing tidal height.

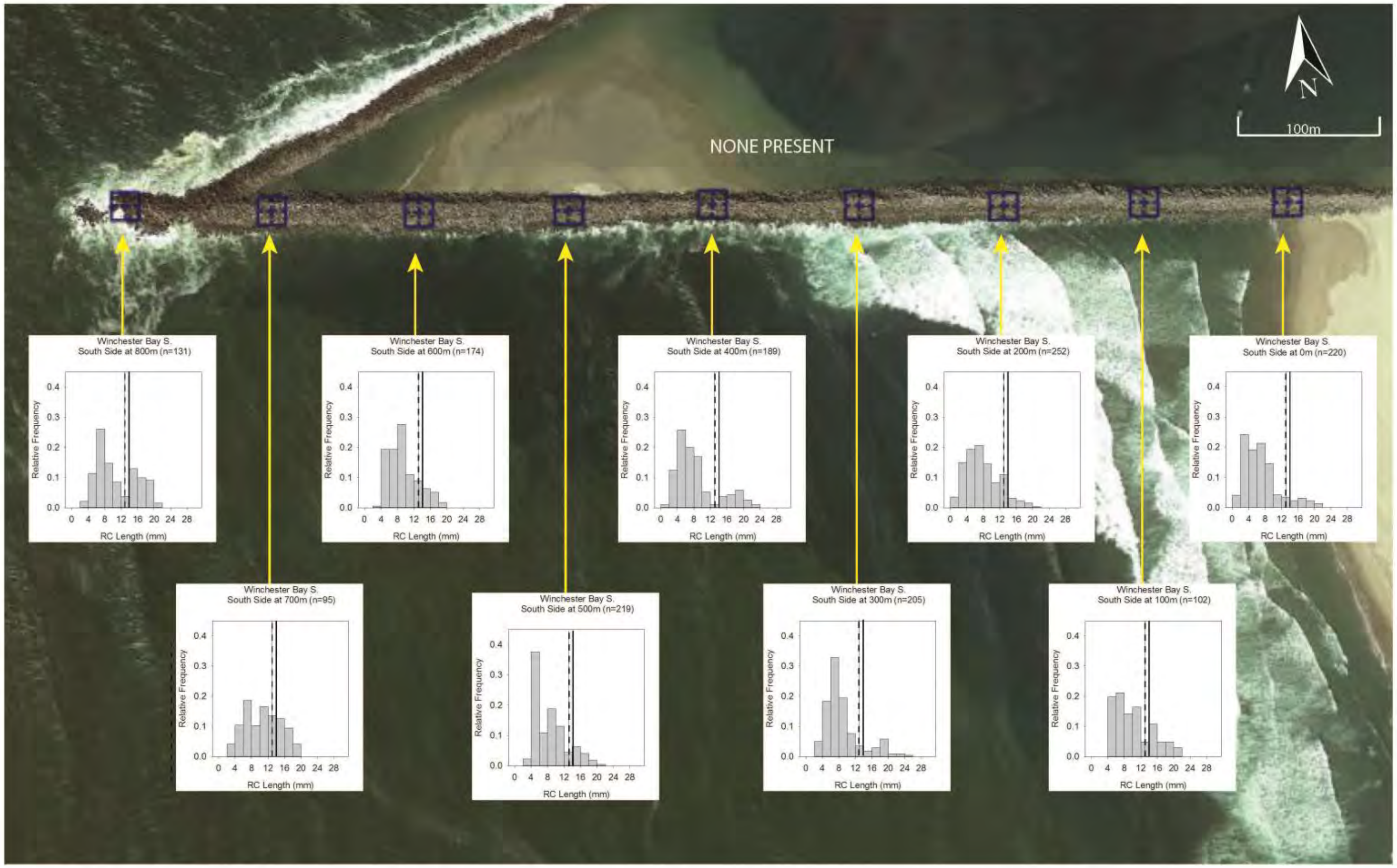


Figure 5. Variations in Size-Frequency Distributions - Histograms represent size-frequency distributions of samples taken at each transect location. Dashed vertical lines show boundary between juvenile and adult populations. Solid vertical lines show size at which barnacles are considered desireable for harvest according to Parada et. al. (2012).

Many thanks to our additional collaborators: OSU Oregon State University, Port Orford Sustainable Seafood, Oregon Fish & Wildlife

II. Summary sheet 2: Coos Bay South Jetty

Coos Bay South Jetty

Length of survey: 550 m
Heading of jetty: 276° magnetic
Lat/Long: 43.3533450, -124.3480190

The Coos Bay south jetty lies south of the entrance to Coos Bay and north of Bastendorff Beach. The Coos Bay estuary is characterized by well-mixed waters fed by the Coos River and approximately 20 lower volume rivers and streams. We observed Pollicipes along the entirety of this survey with the exception of habitat near the high water line on the southern side. It is unknown how far into the bay beyond our survey limits the population extends on the jetty's northern side. Due to time constraints, the northern jetty on the opposing side of the mouth of Coos Bay was not surveyed.

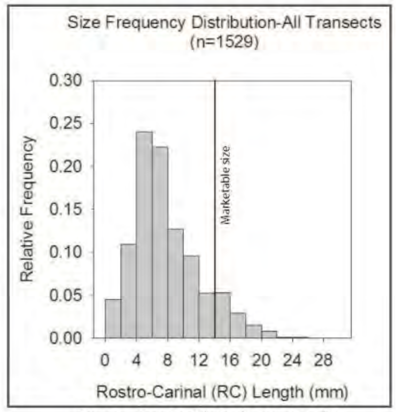


Figure 1. Does not include new recruits.

Gooseneck Barnacle (*Pollicipes polymerus*) Population Status Within Survey
Estimated total harvestable habitat: 10,993 m^2
Average percent cover within habitat: 37% ± SE 4.6%
Avg. adult/juv. pop. density: 6,808.9 ± SE 1,199.7
Est. total pop. density (includes new recruits): 23,071 ± SE 4,065 indv./m^2
% of total population which are of marketable size (>14mm RC): ~4.1%
Est. of available biomass of marketable-sized individuals (2-10 g ea.): 20,588-102,942 kg

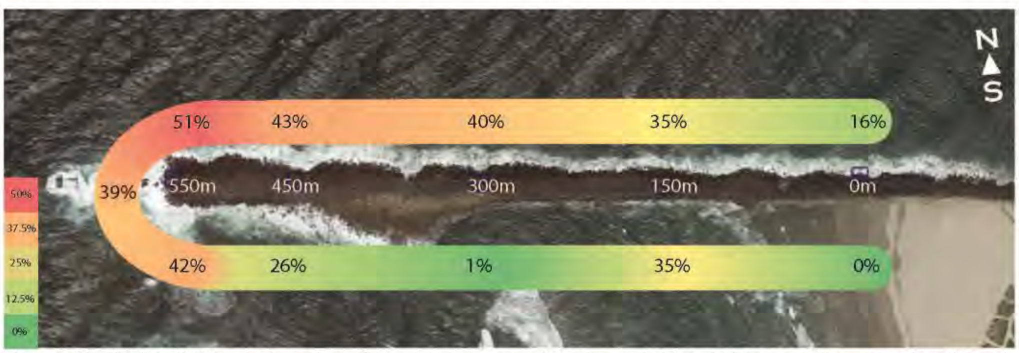


Figure 2. Distribution of % Cover - Figure shows the average percentage of *P. polymerus* habitat which is covered by goosenecks within each transect surveyed. Locations of surveys are marked in white and denote meters from high water line on adjacent shore. Surveys took place on both North and South sides of jetty at marked locations. Color gradient is reflective of percent cover and assumes a linear percentage gradient in areas between transects.

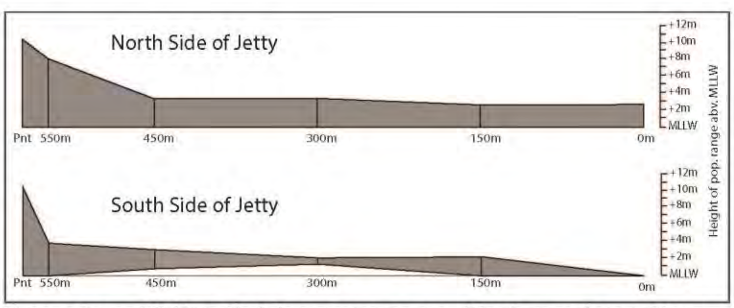


Figure 3. Range of Habitat - Shaded area represents range of *P. polymerus* relative to Mean Lower Low Water (MLLW). Horizontal axis represents locations of transects along jetty and are in meters from high water line on adjacent shore. Vertical axis represents height in meters above MLLW. Note that the entire range of habitat may not be represented if the lower bound was below MLLW. The elevation of the top of the jetty varied along its length, however, it was consistently higher than the extent of *P. polymerus* habitat.

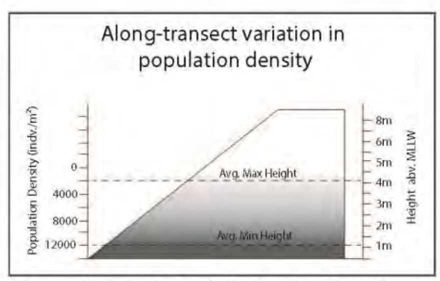


Figure 4. Variation in Population Density - Figure shows cross-section of a transect. Left axis represents population density. Right axis represents height above MLLW. Dashed lines show average max/min height of surveys conducted from all transects. Darker color in gradient represents higher population densities with decreasing tidal height.

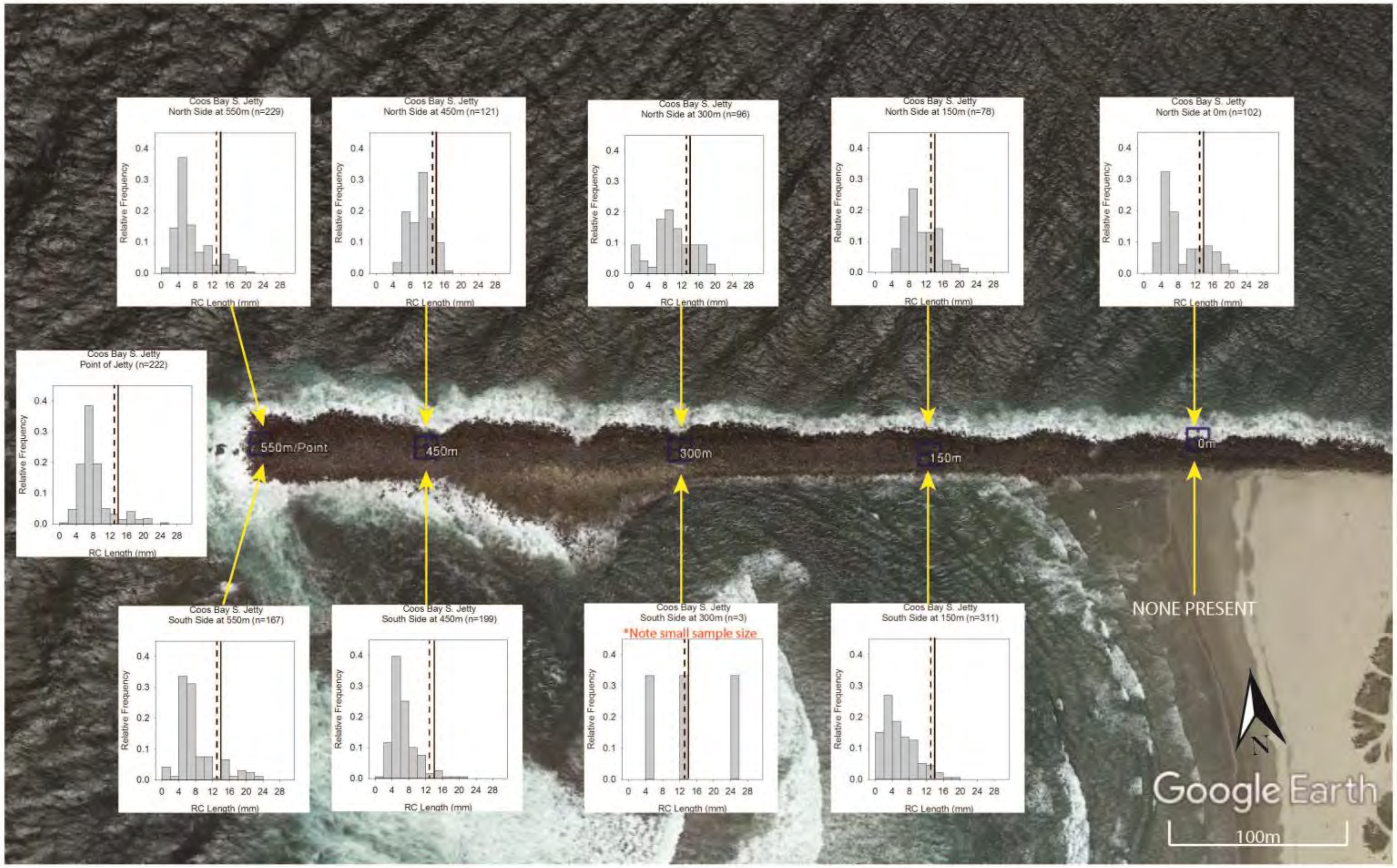


Figure 5. Variations in Size-Frequency Distributions - Histograms represent size-frequency distributions of samples taken at each transect location. Dashed vertical lines show boundary between juvenile and adult populations. Solid vertical lines show size at which barnacles are considered desireable for harvest according to Parada et. al. (2012).

Many thanks to our additional collaborators:

III. Summary sheet 3: Bandon South Jetty

Bandon South Jetty

Length of survey: 200 m
Heading of jetty: 273° magnetic
Lat/Long: 43.122786, -124.429904

The Bandon south jetty is bounded by the mouth of the Coquille River to the north and a sandy shore to the south. The *Pollicipes* population on this jetty extends almost to the high water line on its southern side, but is constrained to only the most distal portion of the northern side. There is another jetty to the north of the mouth of the Coquille River, but due to time constraints we were unable to survey this jetty.

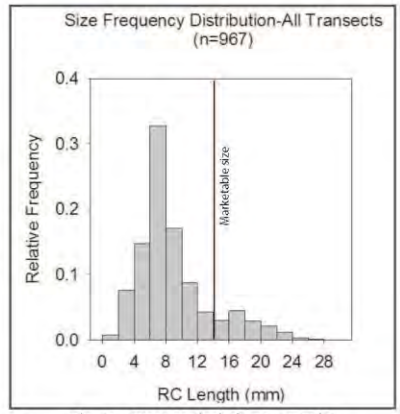


Figure 1. Does not include new recruits.

Gooseneck Barnacle (*Pollicipes polymerus*) Population Status Within Survey
Estimated total harvestable habitat: 1,576 m²
Average percent cover within habitat: 37% ± SE 6.3%
Avg. adult/juv. pop. density: 6,637.5 ± SE 1,121.5
Est. total pop. density (includes new recruits): 89,641 ± SE 15,146 indv./m²
% of total population which are of marketable size (>14mm RC): ~1.2%
Est. of available biomass of marketable-sized individuals (2-10 g ea.): 3,253-16,267 kg

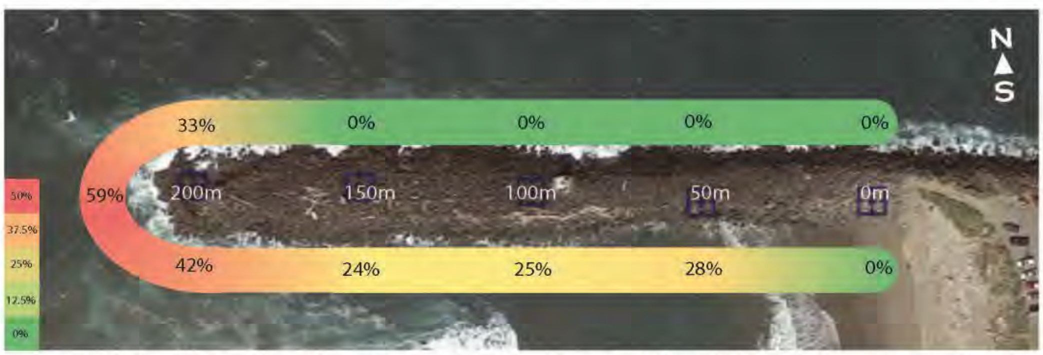
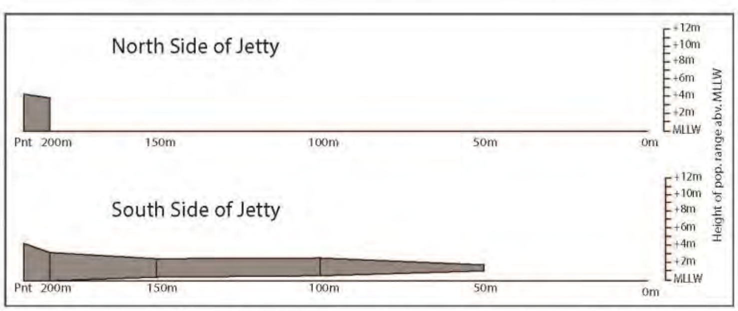


Figure 2. Distribution of % Cover - Figure shows the average percentage of *P. polymerus* habitat which is covered by goosenecks within each transect surveyed. Locations of surveys are marked in white and denote meters from high water line on adjacent shore. Surveys took place on both North and South sides of jetty at marked locations. Color gradient is reflective of percent cover and assumes a linear percentage gradient in areas between transects.



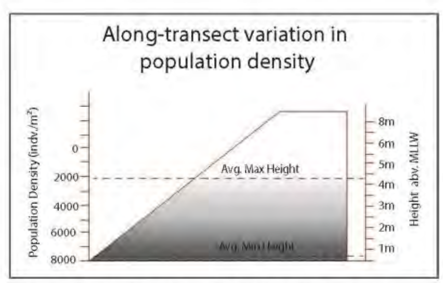


Figure 3. Range of Habitat - Shaded area represents range of *P. polymerus* relative to Mean Lower Low Water (MLLW). Horizontal axis represents locations of transects along jetty and are in meters from high water line on adjacent shore. Vertical axis represents height in meters above MLLW. Note that the entire range of habitat may not be represented if the lower bound was below MLLW. The elevation of the top of the jetty varied along its length, however, it was consistently higher than the extent of *P. polymerus* habitat.

Figure 4. Variation in Population Density - Figure shows cross-section of a transect. Left axis represents population density. Right axis represents height above MLLW. Dashed lines show average max/min height of surveys conducted from all transects. Darker color in gradient represents higher population densities with decreasing tidal height.

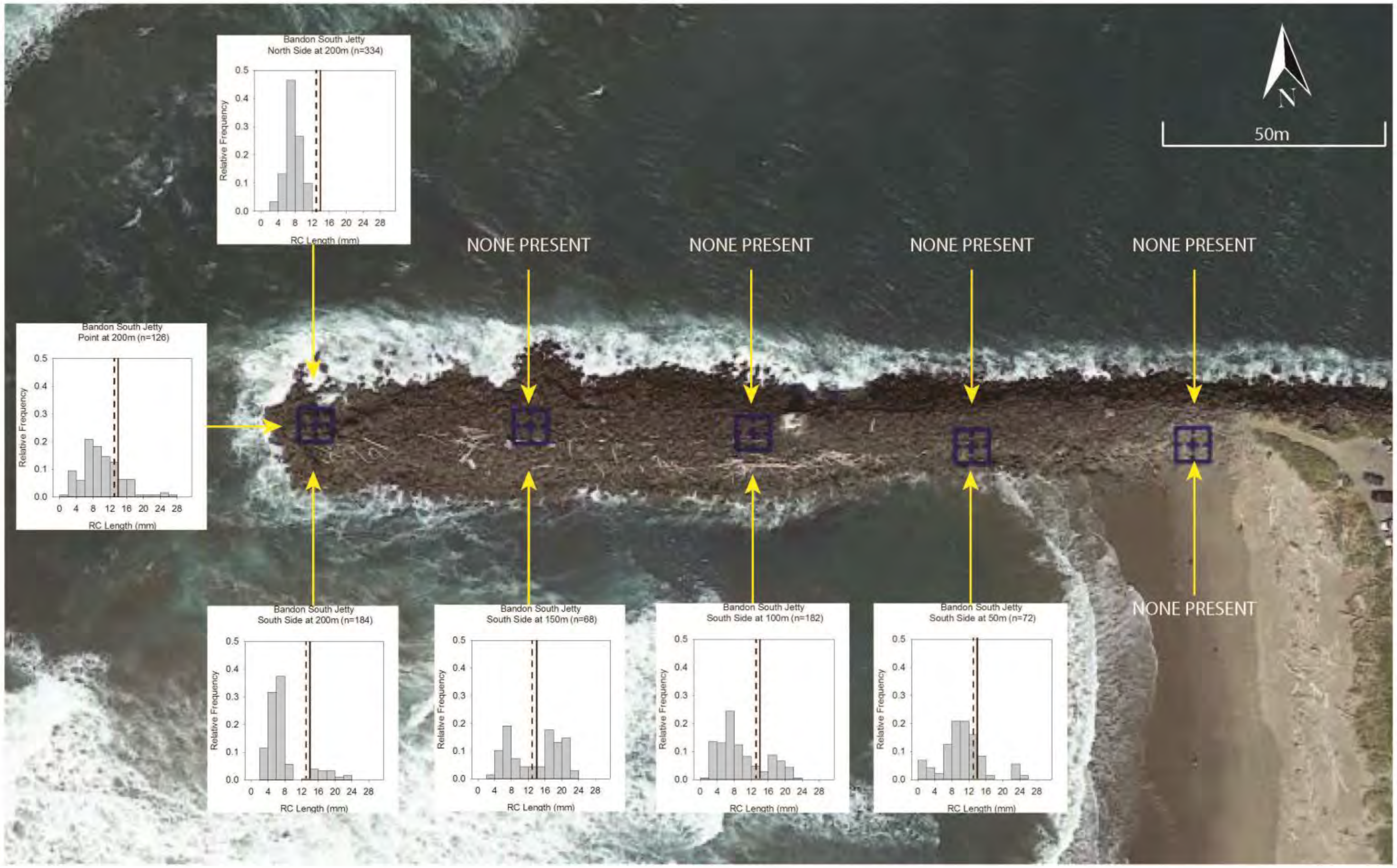


Figure 5. Variations in Size-Frequency Distributions - Histograms represent size-frequency distributions of samples taken at each transect location. Dashed vertical lines show boundary between juvenile and adult populations. Solid vertical lines show size at which barnacles are considered desireable for harvest according to Parada et. al. (2012).

Many thanks to our additional collaborators:

IV. Summary sheet 4: Port Orford Jetty

Port Orford Jetty

Length of survey: 150 m
Heading of jetty: 105° magnetic
Lat/Long: 42.738149, -124.497998

The Port Orford Jetty is a small, curved structure which provides shelter for the Port Orford dry dock. Unlike the other jetties surveyed, this one is not adjacent to the entrance of a bay or sandy beach. Its orientation and location on the Oregon coast exposes its southern side to ocean waves while its northern side faces the more protected port. *Pollicipes* were only present on the southern side of this jetty.

Gooseneck Barnacle (*Pollicipes polymerus*) Population Status Within Survey
Estimated total harvestable habitat: 1,954 m²
Average percent cover within habitat: 16% ± SE 4.1%
Avg. adult/juv. pop. density: 3,044.4 ± SE 662.8
Est. total pop. density (includes new recruits): 29,931 ± SE 6,517 indv./m²
% of total population which are of marketable size (>14mm RC): ~1.9%
Est. avail. biomass of marketable-sized individuals (2-10 g ea.): 2,222-11,108 kg

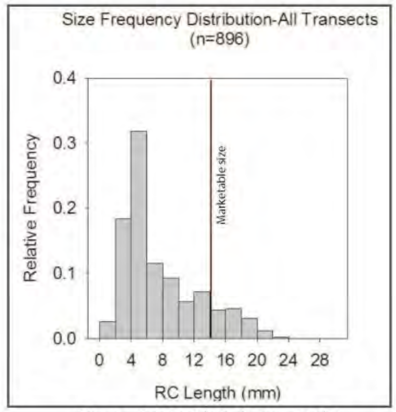


Figure 1. Does not include new recruits.

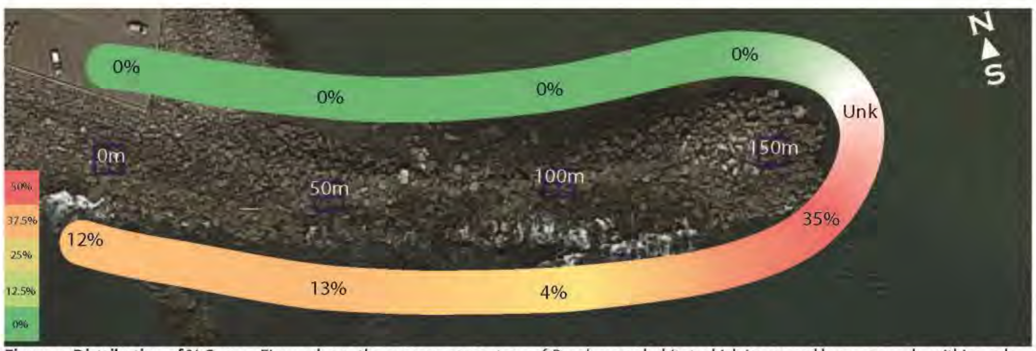
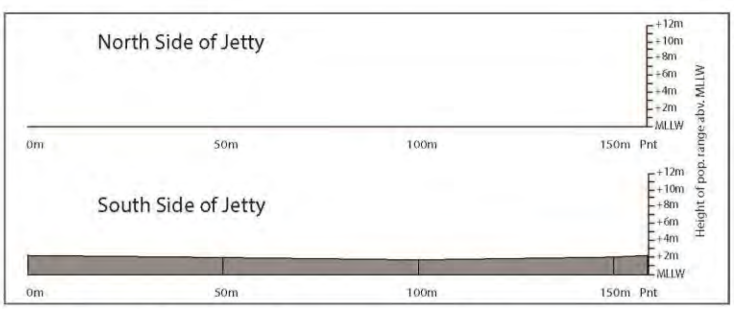


Figure 2. Distribution of % Cover - Figure shows the average percentage of *P. polymerus* habitat which is covered by goosenecks within each transect surveyed. Locations of surveys are marked in white and denote meters from high water line on adjacent shore. Surveys took place on both North and South sides of jetty at marked locations. Color gradient is reflective of percent cover and assumes a linear percentage gradient in areas between transects.



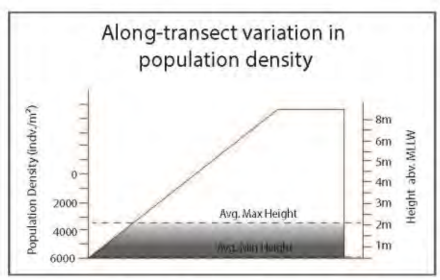


Figure 3. Range of Habitat - Shaded area represents range of *P. polymerus* relative to Mean Lower Low Water (MLLW). Horizontal axis represents locations of transects along jetty and are in meters from high water line on adjacent shore. Vertical axis represents height in meters above MLLW. Note that the entire range of habitat may not be represented if the lower bound was below MLLW. The elevation of the top of the jetty varied along its length, however, it was consistently higher than the extent of *P. polymerus* habitat.

Figure 4. Variation in Population Density - Figure shows cross-section of a transect. Left axis represents population density. Right axis represents height above MLLW. Dashed lines show average max/min height of surveys conducted from all transects. Darker color in gradient represents higher population densities with decreasing tidal height.

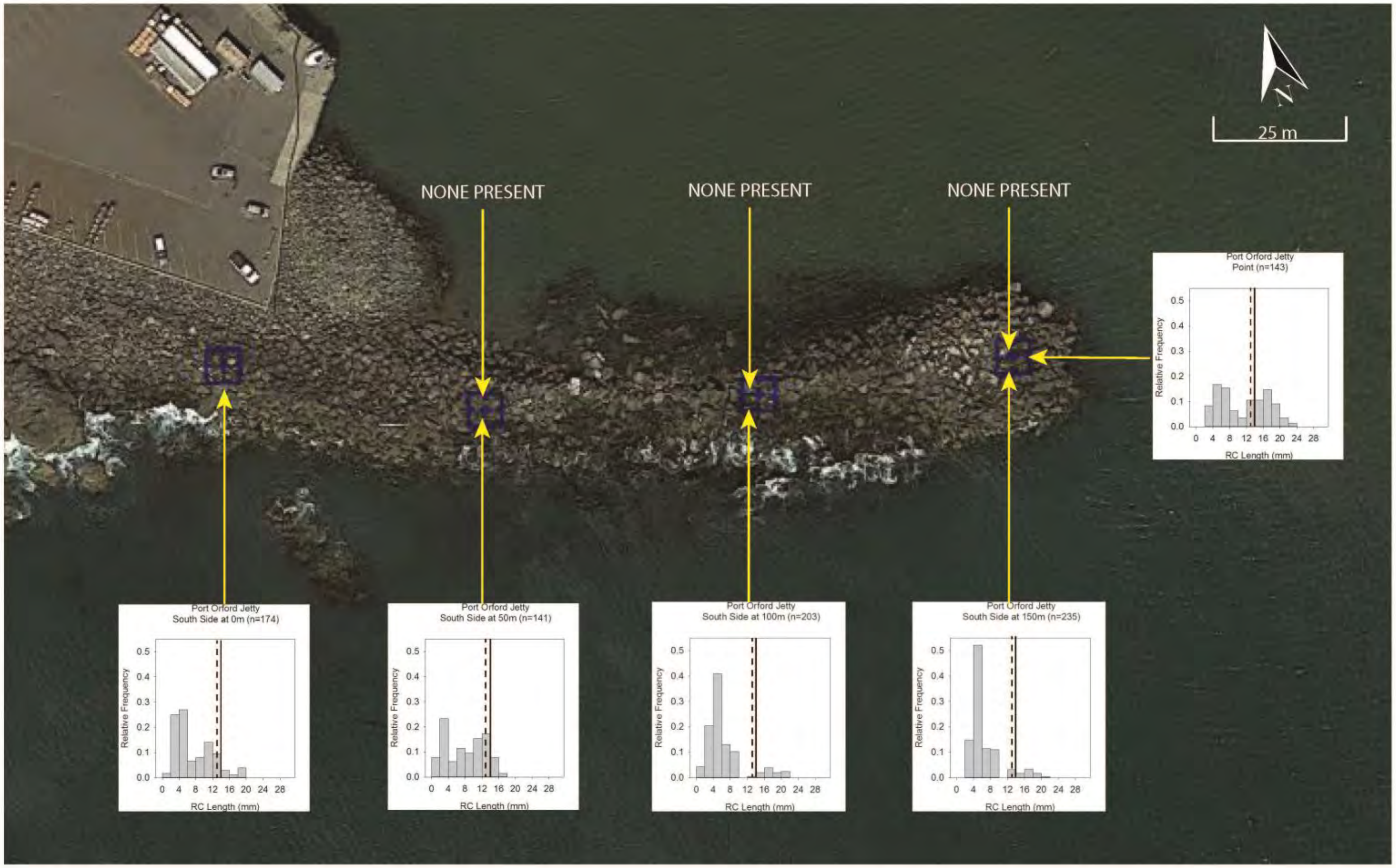


Figure 5. Variations in Size-Frequency Distributions - Histograms represent size-frequency distributions of samples taken at each transect location. Dashed vertical lines show boundary between juvenile and adult populations. Solid vertical lines show size at which barnacles are considered desireable for harvest according to Parada et. al. (2012).

Many thanks to our additional collaborators:

V. Summary sheet 5: Gold Beach North Jetty

Gold Beach North Jetty

Length of survey: 350 m
Heading of jetty: 209° magnetic
Lat/Long: 42.421383, -124.431973

The Gold Beach north jetty lies to the northwest of the mouth of the Rogue River. Opposite the river, the jetty sits adjacent to a sandy shore. There were no *Pollicipes* observed on the river side of the jetty. The population was constrained to between the point of the jetty and <100 m from the high water line on the north side. Another jetty sits on the southern side of the mouth of the Rogue River. We surveyed this jetty but did not observe any *Pollicipes*.

Gooseneck Barnacle (*Pollicipes polymerus*) Population Status Within Survey
Estimated total harvestable habitat: 2,101 m²
Average percent cover within habitat: 34% ± SE 5.8%
Avg. adult/juv. pop. density: 7,729.4 ± SE 1,114
Est. total pop. density (includes new recruits): 24,928 ± SE 3,593 indv./m²
% of total population which are of marketable size (>14mm RC): ~2.6%
Est. of available biomass of marketable-sized individuals (2-10 g ea.): 2,697-13,483

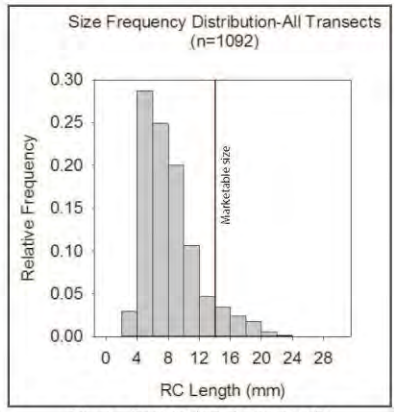


Figure 1. Does not include new recruits.

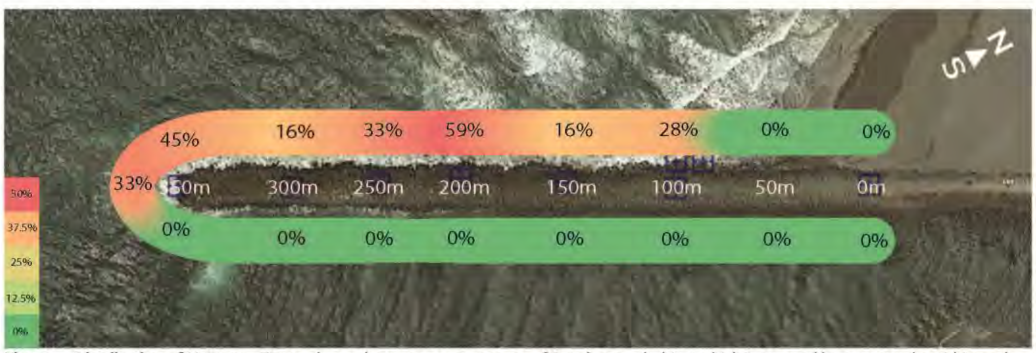
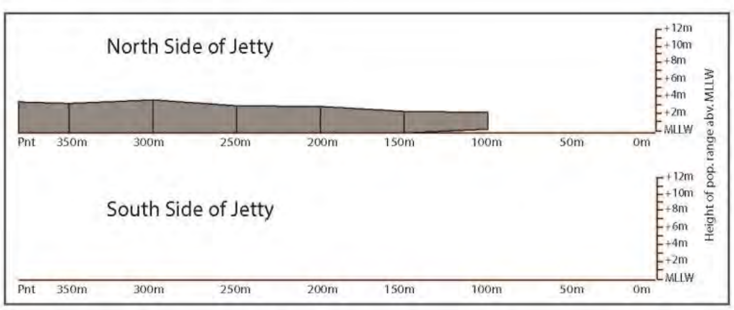


Figure 2. Distribution of % Cover - Figure shows the average percentage of *P. polymerus* habitat which is covered by goosenecks within each transect surveyed. Locations of surveys are marked in white and denote meters from high water line on adjacent shore. Surveys took place on both North and South sides of jetty at marked locations. Color gradient is reflective of percent cover and assumes a linear percentage gradient in areas between transects.



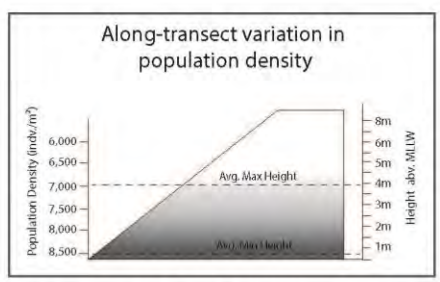


Figure 3. Range of Habitat - Shaded area represents range of *P. polymerus* relative to Mean Lower Low Water (MLLW). Horizontal axis represents locations of transects along jetty and are in meters from high water line on adjacent shore. Vertical axis represents height in meters above MLLW. Note that the entire range of habitat may not be represented if the lower bound was below MLLW. The elevation of the top of the jetty varied along its length, however, it was consistently higher than the extent of *P. polymerus* habitat.

Figure 4. Variation in Population Density - Figure shows cross-section of a transect. Left axis represents population density. Right axis represents height above MLLW. Dashed lines show average max/min height of surveys conducted from all transects. Darker color in gradient represents higher population densities with decreasing tidal height.

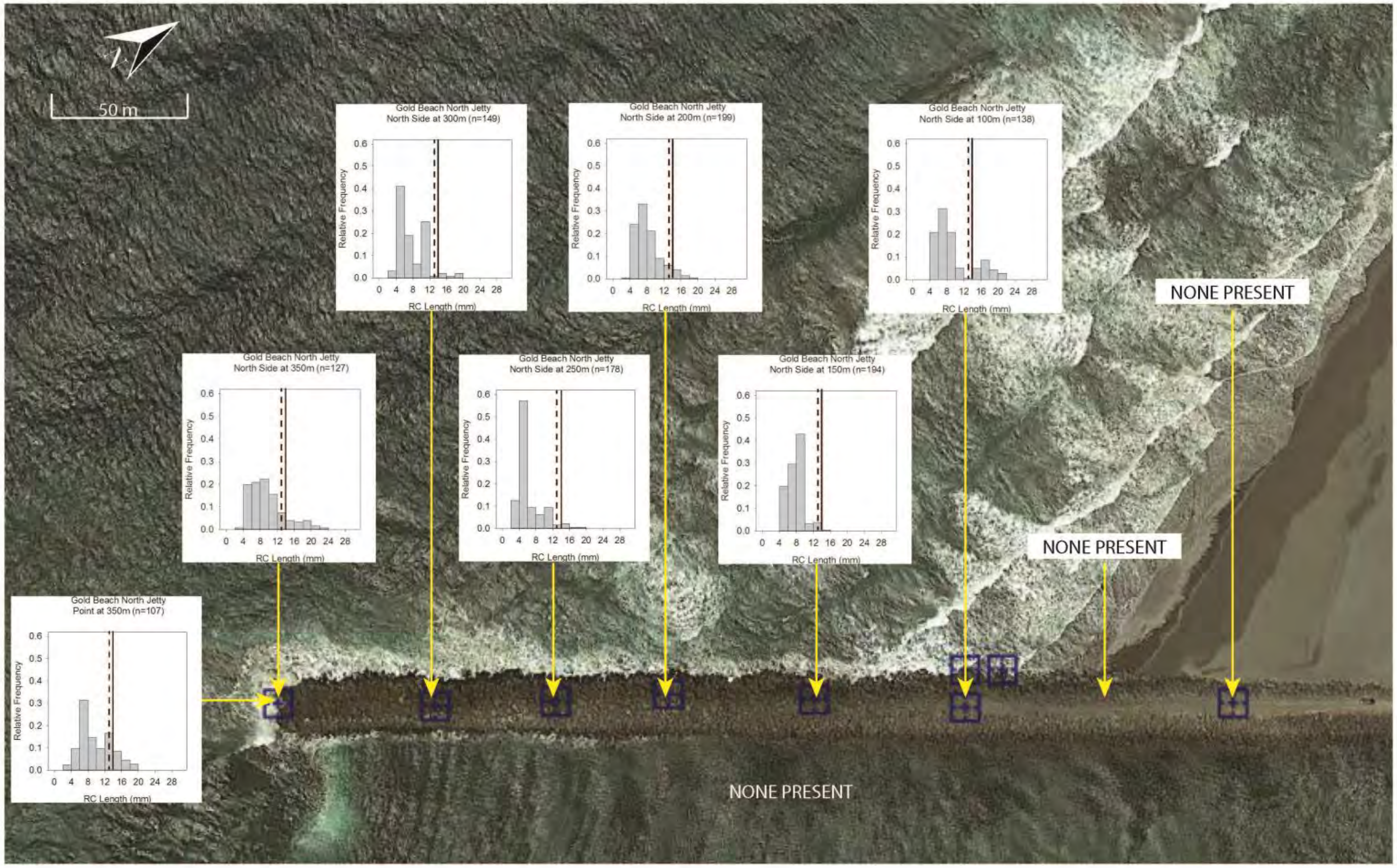


Figure 5. Variations in Size-Frequency Distributions - Histograms represent size-frequency distributions of samples taken at each transect location. Dashed vertical lines show boundary between juvenile and adult populations. Solid vertical lines show size at which barnacles are considered desireable for harvest according to Parada et. al. (2012).

Many thanks to our additional collaborators:

VI. Summary sheet 6: Brookings North Jetty

Brookings North Jetty

Length of survey: 310 m
Heading of jetty: 196° magnetic
Lat/Long: 42.044243, -124.271743

The Brookings jetties sit adjacent to the mouth of the Chetco River, and are generally oriented north and south. Here we identify the north jetty as the one which sits farther north along the shore, on the west bank of the river mouth. Within the entire survey, we only observed *Pollicipes* on the most distal end of the north jetty. The population consisted of mostly smaller individuals. We did not observe any *Pollicipes* on the southern jetty.

Gooseneck Barnacle (*Pollicipes polymerus*) Population Status Within Survey
Estimated total harvestable habitat: 521 m^2
Average percent cover within habitat: 21% ± SE 5.5%
Avg. adult/juv. pop. density: 5,392.9 ± SE 1,390.8
Est. total pop. density (includes new recruits): 20,353 ± SE 5,249 indv./m^2
% of total population which are of marketable size (>14mm RC): ~1.0%
Est. of available biomass of marketable-sized individuals (2-10 g ea.): 207 - 1,033 kg

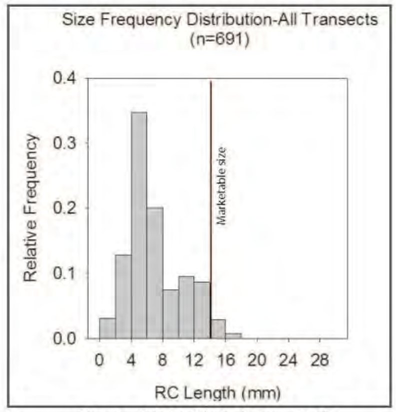


Figure 1. Does not include new recruits.

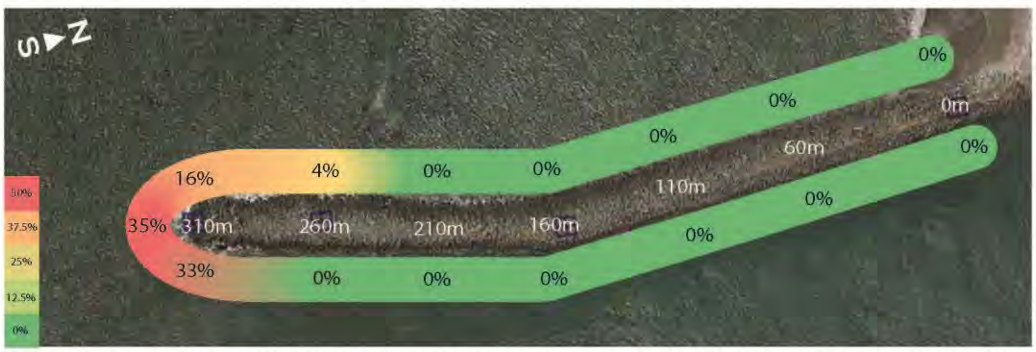


Figure 2. Distribution of % Cover - Figure shows the average percentage of *P. polymerus* habitat which is covered by goosenecks within each transect surveyed. Locations of surveys are marked in white and denote meters from high water line on adjacent shore. Surveys took place on both North and South sides of jetty at marked locations. Color gradient is reflective of percent cover and assumes a linear percentage gradient in areas between transects.

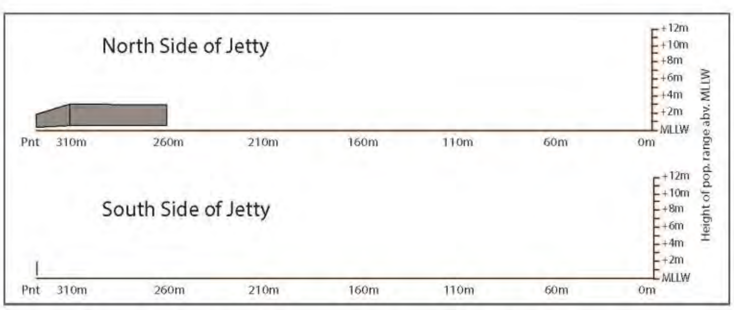


Figure 3. Range of Habitat - Shaded area represents range of *P. polymerus* relative to Mean Lower Low Water (MLLW). Horizontal axis represents locations of transects along jetty and are in meters from high water line on adjacent shore. Vertical axis represents height in meters above MLLW. Note that the entire range of habitat may not be represented if the lower bound was below MLLW. The elevation of the top of the jetty varied along its length, however, it was consistently higher than the extent of *P. polymerus* habitat.

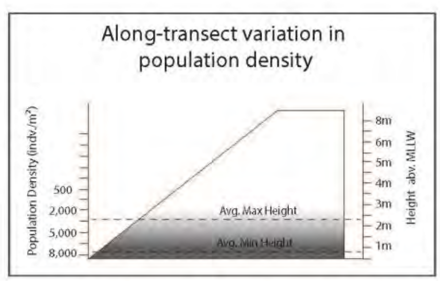


Figure 4. Variation in Population Density - Figure shows cross-section of a transect. Left axis represents population density. Right axis represents height above MLLW. Dashed lines show average max/min height of surveys conducted from all transects. Darker color in gradient represents higher population densities with decreasing tidal height.

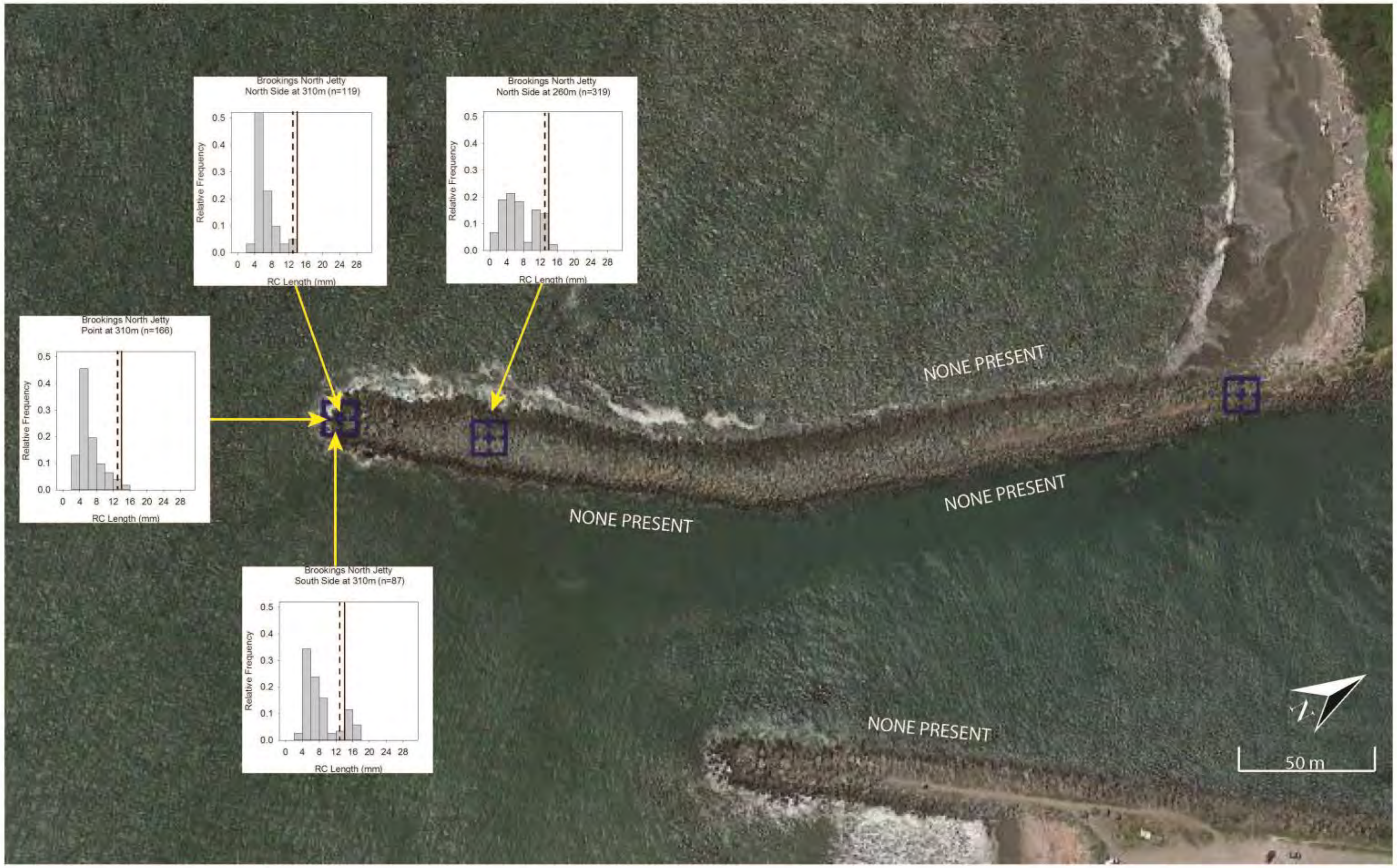


Figure 5. Variations in Size-Frequency Distributions - Histograms represent size-frequency distributions of samples taken at each transect location. Dashed vertical lines show boundary between juvenile and adult populations. Solid vertical lines show size at which barnacles are considered desireable for harvest according to Parada et. al. (2012).

Many thanks to our additional collaborators:

B: Jetty ANOVAS

ALL JETTIES					
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Significance**
Jetty	**Total Barnacles**	5	1.6367	0.1543	
	Density (barnacles / cm^2)		1.5465	0.1795	
	% Cover		0.834	0.5277	
	Patches per m^2		2.8813	0.01661	*
	RC length		20.144	2.20E-16	***
	Recruits per Peduncle		33.418	2.20E-16	***
Meters along Jetty	**Total Barnacles**	16	1.1215	0.3426	
	Density (barnacles / cm^2)		1.0466	0.4135	
	% Cover		0.4049	0.9792	
	Patches per m^2		1.39055	0.2038	
	RC length		8.6395	2.20E-16	***
	Recruits per Peduncle		8.5382	2.20E-16	***
Meters along Transect	**Total Barnacles**	6	6.0147	1.33E-05	***
	Density (barnacles / cm^2)		6.3212	6.93E-06	***
	% Cover		0.3686	0.8978	
	Patches per m^2		3.0995	0.007075	**
Tidal Height (MLLW)	**Total Barnacles**	1	7.0407	0.008882	**
	Density (barnacles / cm^2)		3.4741	0.06442	
	% Cover		8.00E-04	0.9769	
	Patches per m^2		2.1071	0.1488	
Patches per m^2	**Total Barnacles**	1	0.1628	0.6872	
	Density (barnacles / cm^2)		1.0965	0.2968	
	% Cover		0.011	0.9149	
% Cover	**Total Barnacles**	1	1.3104	0.2543	
	Density (barnacles / cm^2)		0.3952	0.5306	
	Patches per m^2		0.0115	0.9149	
Density (barnacles / cm^2)	**Total Barnacles**	1	241.6	2.20E-16	***
	% Cover		0.3984	0.529	
	Patches per area		0.4491	0.5039	
Total Barnacles	**Density (barnacles / cm^2)**	1	241.6	2.20E-16	***
	% Cover		1.3104	0.2543	
	Patches per m^2		0.1628	0.6872	

COOS BAY SOUTH JETTY					
Variable 1	Response Variable	Df	F value	P(>F)	Significance
Meters along Jetty	Total Barnacles	4	1.0887	0.3819	
	Density (barnacles / cm^2)		0.8617	0.4994	
	% Cover		1.0276	0.411	
	Patches per m^2		0.7708	0.5537	
	RC length		0.2074	0.8129	
	Recruits per Peduncle		21.527	9.83E-09	***
Meters along Transect	Total Barnacles	6	3.5539	0.01105	*
	Density (barnacles / cm^2)		2.6578	0.03913	*
	% Cover		2.258	0.07052	
	Patches per m^2		0.381	0.8841	
Tidal Height (MLLW)	Total Barnacles	1	2.5683	0.1195	
	Density (barnacles / cm^2)		2.0962	0.158	
	% Cover		3.2772	0.08028	
	Patches per m^2		0.5859	0.45	
Patches per m^2	Total Barnacles	1	0.0017	0.9671	
	Density (barnacles / cm^2)		0.0026	0.9596	
	% Cover		2.3775	0.1336	
% Cover	Total Barnacles	1	19.193	0.0001328	***
	Density (barnacles / cm^2)		21.436	6.61E-05	***
	Patches per m^2		2.3775	0.1336	
Density (barnacles / cm^2)	Total Barnacles	1	61.328	9.72E-09	***
	% Cover		21.436	6.61E-05	***
	Patches per area		0.0026	0.9596	
Total Barnacles	Density (barnacles / cm^2)	1	61.328	9.72E-09	***
	% Cover		19.193	0.0001328	***
	Patches per m^2		0.0017	0.9671	

BANDON SOUTH JETTY					
Variable 1	Response Variable	Df	F value	P(>F)	Significance
Meters along Jetty	Total Barnacles	5	1.1611	0.347	
	Density (barnacles / cm^2)		1.1475	0.352	
	% Cover		1.7229	0.2017	
	Patches per m^2		0.4056	0.7504	
	RC length		7.0742	1.79E-05	***
	Recruits per Peduncle		10.174	1.37E-07	***
Meters along Transect	Total Barnacles	5	21.714	1.87E-07	***
	Density (barnacles / cm^2)		4.9001	0.004345	**
	% Cover		11.886	1.97E-05	***
	Patches per m^2		0.6765	0.6462	
Tidal Height (MLLW)	Total Barnacles	1	14.632	0.0008168	***
	Density (barnacles / cm^2)		6.2085	0.02002	*
	% Cover		24.077	5.27E-05	***
	Patches per m^2		0.8827	0.3568	
Patches per m^2	Total Barnacles	1	0.0361	0.8508	
	Density (barnacles / cm^2)		1.2525	0.2742	
	% Cover		0.4277	0.5194	

BANDON SOUTH JETTY					
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Significance**
% Cover	**Total Barnacles**	1	28.589	1.73E-05	***
	Density (barnacles / cm^2)		23.319	6.42E-05	***
	Patches per m^2		0.4277	0.5194	
Density (barnacles / cm^2)	**Total Barnacles**	1	55.447	1.10E-07	***
	% Cover		23.319	6.42E-05	***
	Patches per area		1.2525	0.2742	
Total Barnacles	**Density (barnacles / cm^2)**	1	55.447	1.10E-07	***
	% Cover		28.589	1.73E-05	***
	Patches per m^2		0.0361	0.8508	

BROOKINGS SOUTH JETTY					
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Significance**
Meters along Jetty	**Total Barnacles**	1	0.711	0.421	
	Density (barnacles / cm^2)		1.4124	0.2651	
	% Cover		2.1032	0.1809	
	Patches per m^2		0.2217	0.6489	
	RC length		1.3938	0.2396	
	Recruits per Peduncle		22.631	4.58E-04	***
Meters along Transect	**Total Barnacles**	3	1.6334	0.2665	
	Density (barnacles / cm^2)		1.1907	0.3804	
	% Cover		1.1143	0.4056	
	Patches per m^2		0.6614	0.6015	
Tidal Height (MLLW)	**Total Barnacles**	1	8.2032	0.01865	*
	Density (barnacles / cm^2)		7.1455	0.02549	*
	% Cover		4.0191	0.07597	
	Patches per m^2		0.8547	0.3794	
Patches per m^2	**Total Barnacles**	1	0.152	0.7057	
	Density (barnacles / cm^2)		1.43988	0.2608	
	% Cover		0.0039	0.9516	
% Cover	**Total Barnacles**	1	97.697	3.94E-06	***
	Density (barnacles / cm^2)		26.58	0.0005986	***
	Patches per m^2		0.0039	0.9516	
Density (barnacles / cm^2)	**Total Barnacles**	1	57.783	3.32E-05	***
	% Cover		26.58	0.0005986	***
	Patches per area		1.4398	0.2608	
Total Barnacles	**Density (barnacles / cm^2)**	1	57.783	3.32E-05	***
	% Cover		97.697	3.94E-06	***
	Patches per m^2		0.152	0.7057	

GOLD BEACH NORTH JETTY					
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Significance**
Meters along Jetty	**Total Barnacles**	5	2.261	0.098	
	Density (barnacles / cm^2)		1.9191	0.1471	
	% Cover		1.2059	0.3506	
	Patches per m^2		0.5877	0.7094	
	RC length		3.9633	0.001676	**
	Recruits per Peduncle		8.0212	3.82E-07	***
Meters along Transect	**Total Barnacles**	3	1.9393	0.1594	
	Density (barnacles / cm^2)		0.1843	0.9057	
	% Cover		3.0038	0.05762	
	Patches per m^2		2.927	0.06183	
Tidal Height (MLLW)	**Total Barnacles**	1	1.6939	0.2079	
	Density (barnacles / cm^2)		3.3309	0.08296	
	% Cover		0.0096	0.923	
	Patches per m^2		2.1417	0.1589	
Patches per m^2	**Total Barnacles**	1	3.0156	0.09784	
	Density (barnacles / cm^2)		1.1479	0.2967	
	% Cover		8.6502	0.008076	**
% Cover	**Total Barnacles**	1	0.8549	0.3662	
	Density (barnacles / cm^2)		1.4773	0.2384	
	Patches per m^2		8.6502	0.008076	**
Density (barnacles / cm^2)	**Total Barnacles**	1	32.301	1.46E-05	***
	% Cover		1.4773	0.2384	
	Patches per area		1.1479	0.2967	
Total Barnacles	**Density (barnacles / cm^2)**	1	32.301	1.46E-05	***
	% Cover		0.8549	0.3662	**
	Patches per m^2		3.0156	0.09784	

PORT ORFORD JETTY					
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Significance**
Meters along Jetty	**Total Barnacles**	3	2.6155	0.1223	
	Density (barnacles / cm^2)		1.2634	0.3184	
	% Cover		5.118	0.01051	*
	Patches per m^2		0.4576	0.7154	
	RC length		10.856	3.31E-08	***
	Recruits per Peduncle		14.989	8.13E-11	***
Meters along Transect	**Total Barnacles**	5	0.546	0.739	
	Density (barnacles / cm^2)		0.0347	0.9992	
	% Cover		0.5796	0.7152	
	Patches per m^2		3.5114	0.02666	*
Tidal Height (MLLW)	**Total Barnacles**	1	0.5603	0.4633	
	Density (barnacles / cm^2)		0.0098	0.9223	
	% Cover		0.7263	0.4047	
	Patches per m^2		3.1425	0.09231	
Patches per m^2	**Total Barnacles**	1	2.0084	0.1726	
	Density (barnacles / cm^2)		0.5947	0.4501	
	% Cover		0.0654	0.8009	

PORT ORFORD JETTY					
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Significance**
% Cover	**Total Barnacles**	1	31.971	1.88E-05	***
	Density (barnacles / cm^2)		12.17	0.002458	**
	Patches per m^2		0.0654	0.8009	
Density (barnacles / cm^2)	**Total Barnacles**	1	11.595	0.00297	**
	% Cover		12.17	0.002458	**
	Patches per area		1.4398	0.2608	
Total Barnacles	**Density (barnacles / cm^2)**	1	11.595	0.00297	**
	% Cover		31.971	1.88E-05	***
	Patches per m^2		2.0084	0.1726	

WINCHESTER BAY SOUTH JETTY					
Variable 1	**Response Variable**	**Df**	**F value**	**P(>F)**	**Significance**
Meters along Jetty	**Total Barnacles**	8	0.4437	0.8815	
	Density (barnacles / cm^2)		0.474	0.8163	
	% Cover		1.2143	0.3362	
	Patches per m^2		0.9861	0.4728	
	RC length		1.9648	0.04884	*
	Recruits per Peduncle		6.9454	1.01E-08	***
Meters along Transect	**Total Barnacles**	4	2.4543	0.07091	**
	Density (barnacles / cm^2)		2.0617	0.115	
	% Cover		0.5438	0.705	
	Patches per m^2		3.7965	0.01465	*
Tidal Height (MLLW)	**Total Barnacles**	1	10.78	0.00268	**
	Density (barnacles / cm^2)		6.61	0.01554	*
	% Cover		0.1561	0.6957	
	Patches per m^2		18.889	0.0001552	***
Patches per m^2	**Total Barnacles**	1	0.8263	0.3708	
	Density (barnacles / cm^2)		0.0965	0.7583	
	% Cover		0.0235	0.8792	
% Cover	**Total Barnacles**	1	0.2846	0.5978	
	Density (barnacles / cm^2)		0.0306	0.8623	
	Patches per m^2		0.0235	0.8792	
Density (barnacles / cm^2)	**Total Barnacles**	1	155.27	3.61E-14	***
	% Cover		0.0306	0.8623	
	Patches per area		0.0965	0.7583	
Total Barnacles	**Density (barnacles / cm^2)**	1	155.27	3.61E-13	
	% Cover		0.2846	0.5978	
	Patches per m^2		0.8263	0.3708	

C: Additional Figures and Tables

Figure C.1: Scatterplots of patchiness (patches/m^2) at a given tidal height (meters, MLLW) on each individual jetty; pattern of fewer patches at lower tidal heights is less consistent than pooled data and ANOVAs suggest. Each jetty has a distinct trend.

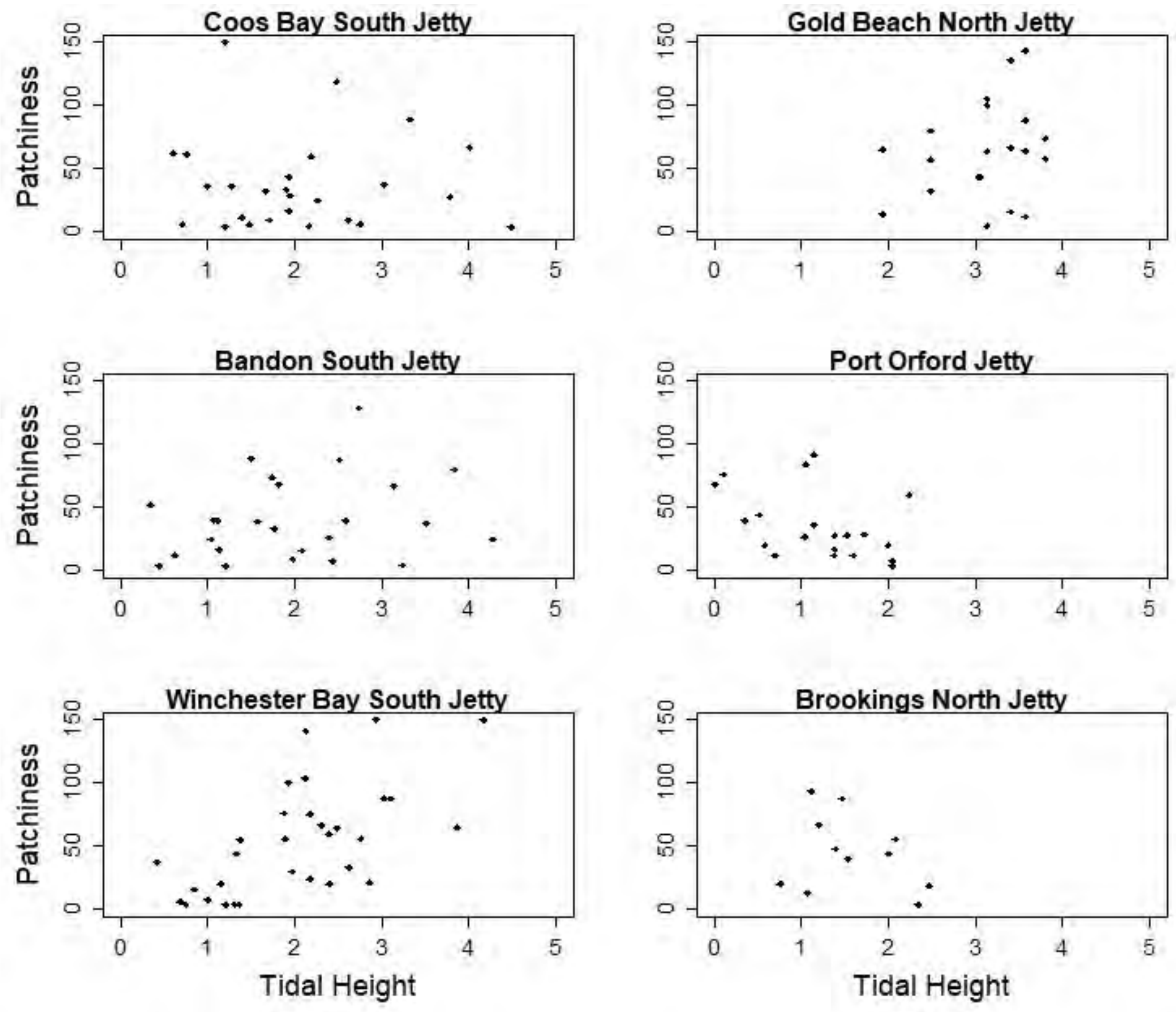


Figure C.2: Estimated coefficients and p-values for the regression model predicting density of substrate-settled goosenecks per square meter given a habitat location's vertical position in tidal height (Mean Lower Low Water) and lateral position along a jetty in meters from the shoreline high water level. Model visual given in Figure 8.

Variable	Estimated coefficient	t-value	P(>|t|)
Tidal Height (MLLW)	-865.402	-2.552	0.0118
Meters along Jetty	6.144	2.433	0.0162
Intercept	6877.215	6.774	3.19e-10

Figure C.3: Rostra-corinal (RC) lengths (mm) of substrate-settled individuals sampled at each transect along four jetties where RC length was statistically correlated with distance along a jetty from the high water survey start mark (p≤0.05).

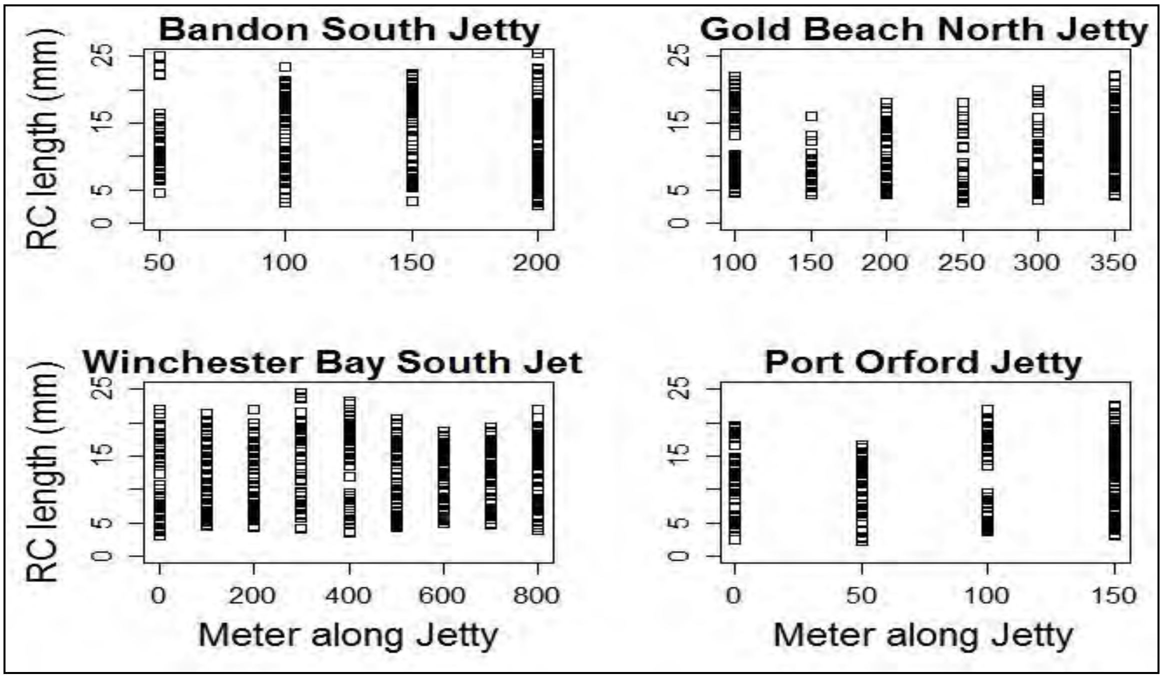


Figure C.4: Numbers of recruits (RC 1-3 mm) on the peduncles of substrate-settled individuals sampled at each transect along four jetties where RC length was statistically correlated with distance along a jetty from the high water survey start mark (p≤0.001).