Development of a Mechanical Aid to Remove Biofouling from an Artificial Reef

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Abstract

Cleaning of articiial reefs prior to deployment of juvenile abalone is a crucial, but costly, component of the abalone sea ranching practice developed by Ocean Grown Abalone (OGA). This paper outlines the methodology for developing and evaluating the feasibility of an innovative bristle based cleaning solution to remove the constraints limiting cleaning of the reef. This is achieved by matching brush force to the abalone adhesion to the reef and intercepting fouling at an early stage of development where less force is required. Experiments establishing abalone adhesion to the substrate and subsequently suitable brush parameters are established. The adhesion of oyster spat, juvenile oysters, is tested in order to determine the window of opportunity, scale of equipment required and ultimately preliminary feasibility of the cleaning concept.

1. Introduction

Ocean Grown Abalone Ltd (OGA) is an innovative aquaculture company pairing the practices of sea ranching and habitat construction to grow high value ocean grown Greenlip Abalone in Flinders Bay, Western Australia. Sea ranching refers to the practice of releasing juveniles into an unenclosed marine environment for harvest at a larger size (Bell et al., 2008). OGA constructed and operates the world's largest privately owned artificial reef consisting of more than 10,000 reef modules, referred to as Abitats, designed to promote Abalone habitation (Adams, 2015). Juvenile, 18-month-old, Greenlip abalone are deployed onto the reef to grow for 2-4 years before they are harvested. After construction of the reef, it was noticed that the survival of abalone, particularly juveniles, was falling year on year. This observation was attributed to the accumulation of macrofouling on the Abitat modules, reducing habitat availability for newly deployed juveniles.

To combat fouling, commercial divers manually scrape clean the surfaces between abalone prior to deployment of new juveniles, in a yearly rolling cycle (deploy-harvest-clean). Abalone of various size and ages are therefore ever present on the Abitats. OGA's cleaning problem is unique in the aquaculture/marine industry as not all benthic organisms, namely the abalone, are to be removed from the substrate. This has historically required a "selective" cleaning approach. In the 2019-2020 financial year manual scraping accounted for 54% of the dive time on the Flinders Bay, as can be seen in figure 1, a large component of which can be attributed to the hard Ostrea Angasi fouling the reefs.

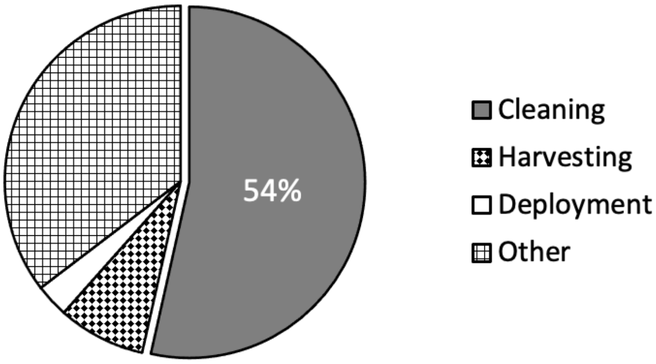

Figure 1 Proportion of dive time spent on particular critical tasks during the 2019-2020 financial year

No tooling exists for cleaning artificial reefs as OGA are pioneering the practice. Biofouling management strategies in the aquaculture sectors generally fall within three categories listed in descending order of preference (i) aversion (ii) prevention and (iii) treating of biofouling (Bannister et al., 2019; Fitridge et al., 2012). Aversion and preventative techniques are naturally preferred due to their relatively low input and high impact but are unsuitable in OGA's application. Aversion cannot be achieved due to the logistics of lifting 10,000, 300kg Abitat in a small window. Heavy metal or tributyltin-based biocidal coatings dominating the preventative maritime industry but are known to leach into the shellfish flesh (MCINTOSH et al., 2005). Ablative based coatings reduce fouling adhesion to the substrate which would simultaneously compromise the abalone's primary defence mechanism, its high adhesive strength and protective shell.

Abalone's adhesion is one of the greatest non-permanent adhesives in the animal kingdom, found to exceed that of the well-studied gecko adhesion in a study by Li et al., (2018). The strength of the adhesion stems from the Van der Waals and capillary forces generated by the nano-scale fibrils found on the pedal foot increasing compliance with the substrate (Lin et al., 2009). Abalone's adhesion to a substrate is dependent on the properties of the substrate namely, Young's contact angle, roughness parameter and frictional coefficient (Li et al., 2018). This paper proposes a brush tool and method of cleaning that leverages the abalone's relatively high adhesion and the seasonal spawning of Ostrea Angasi to that can intercept oyster fouling without having to avoid abalone, thereby increasing tooling effective cleaning area previously restricted. To test the feasibility of this cleaning method and develop tooling for OGA's purpose the following objectives are required. (i) establish greenlip abalone adhesion to the Abitat (ii) Experimentally determine the brush parameters abalone can withstand (iii) Establish scale of machinery required to intercept Ostrea Angasi during the early phase of their development.

2. Materials and Method

Several experiments are required to complete the objectives set out above, each following on from the previous, ultimately evaluating the feasibility and provide design inputs for further development of the cleaning method and tooling.

2.1. Abalone Adhesion

The Abitat, a 35MPa hardness cast concrete structure, is vastly different to the glass, acrylic, steel, and PTFE substrates tested in Li et al., (2018). Green lipped abalone are a ‘rough water’ species preferring turbulent water habitats at depths between 10-25m (Joll, 1996). The Haliotis Discus Hannai, studied by Li, are generally found in 1-5m depth of depth. This suggestes the Greenlip abalones adhesion may exceed that of the shallower species. As both the substrate and abalone are vastly different to those tested in Li et al., (2018) new tests are required

Hatchery reared juvenile Greenlip abalone ranging between 40-50mm in length are kept in tank at the Western Australian Fisheries and Marine Research Laboratory staffed by the Department of Primary Industries and Regional Development (DPIRD). The abalone are fed, and the tank cleaned on alternating days. A hitch point is adhered to the heart of the abalones shell, away from the respiratory pores. Next, the abalone are tagged and placed on a translucent acrylic plate to photograph the ventral side of the abalone. ImageJ is used to calculate the pedal foot area, adhesive area, of the abalone. The shell length is also recorded. A segment of an Abitat is recovered from the sea floor in Flinders Bay. Once at the surface the Abitat substrate was cleaned by scraping and water jet cleaning its surface in preparation for adhesion testing.

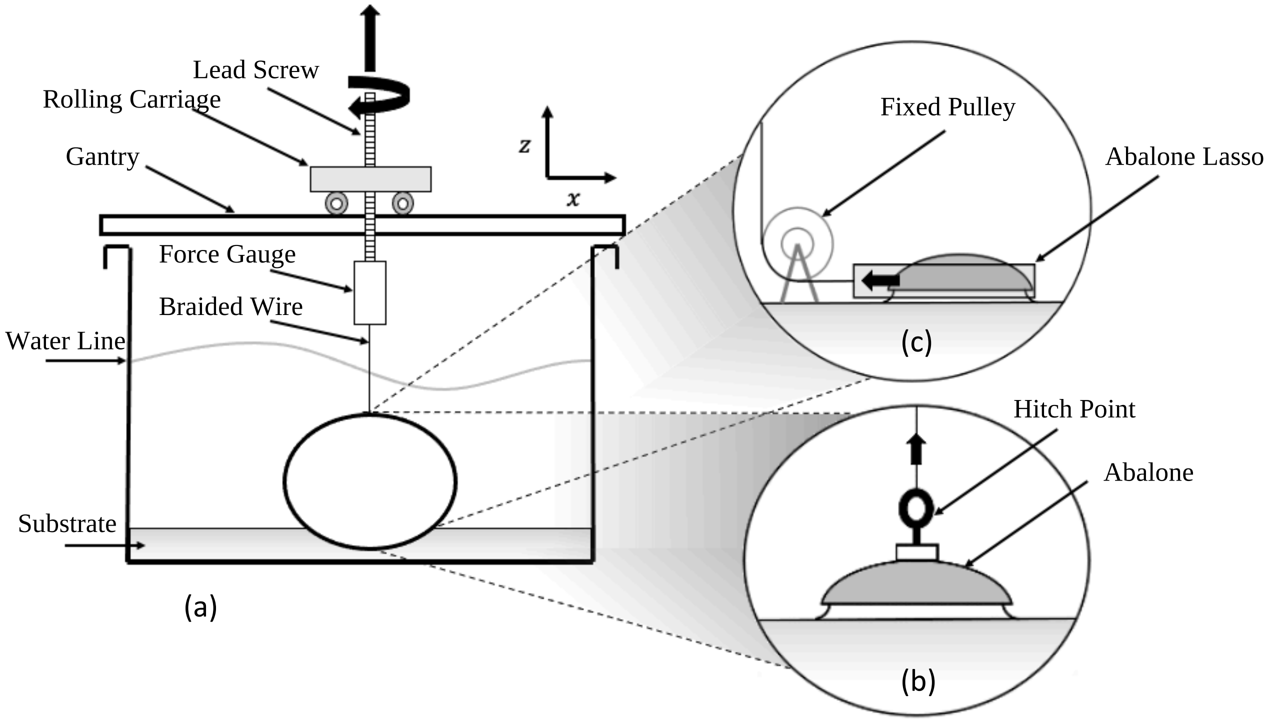

Figure 2 **(a)** Abalone adhesion test apparatus (b) Normal abalone adhesion test configuration (c) Shear abalone adhesion test condiguration

2.1.1. Abalone Adhesion Testing

The force measurement technique is based on that of Li’s work with alternation made based on preliminary adhesion trials on a group of Roe abalone. A normal and shear test are performed. The normal test links the hitch point, and ultimately the abalone, via a hook and braided wire cable, see figure 2.b, to the force gauge (FGD-100) suspended below a free moving gantry in the x-y plane (figure 2.a). The shear adhesion test used a lasso to pull the abalone parallel to the surface using a fixed pulley mounted to the substrate, see Figure 2.c. A quasistatic load is applied by lifting the force gauge using a powered lead screw. The pedal foot area measured and adhesion force between abalone and substrate (F_n, F_s) is used to calculate the adhesion strength, using equations (1) and (2);

$$\sigma_n = \frac{F_n}{A} \tag{1}$$

$$\sigma_s = \frac{F_s}{A} \tag{2}$$

2.2. Experimental Determination of Brush Parameters

Brush force is dependent on a number of parameters including brush types, coefficient of friction, bristle density, angle, stiffness, standoff distance, geometry, and inter-brush bristle dynamics. Making it difficult to predict which brush parameters are critical for OGA's application, none of the models available consider the hydrodynamic forces. To experimentally determine the brush parameters suitable for use in conjunction with the abalone on the reef a mimic abalone is created representing the adhesion of lowest 25% of the abalone population, representing the overall percentage of abalone lost in the first month after abalone deployment in trials (Adams, 2013). This assumes the mortality of an abalone is directly dependent on the adhesion of the abalone.

Greenlip abalone shells are collected in the range of 40 - 120mm in length, representing most abalone on sea ranch. The abalone's pedal foot area, and ultimate bulk shear pull off strength is then calculated, based on the pedal foot area and shell length relationship measured in section 2.1. The bulk shear strength is then extrapolated assuming a linear increase in abalone adhesion with pedal foot area. A 1.6mm thick double-sided pressure sensitive adhesive is used to simulate the abalones shear adhesion. The thickness and elasticity of the adhesive decrease the sensitivity to eccentric loads, peel adhesion, as explained by Goland and Reissner (Goland & Reissner, 1944). The amount of PSA required is evaluated through trial and error, with the test validated by using the shear test method from section 2.1. The adhesive is stuck between two polished 316L stainless steel coupons. The concrete is rebated and one stainless steel coupon is stuck withing the concrete, flush with the surface. The other is adhered to the inside of the abalone shell, shown by the cross-section, in figure 3.

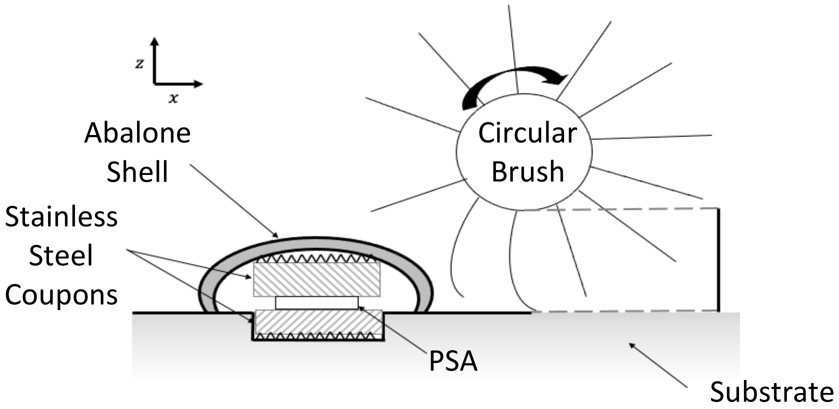

Figure 3 Crossection showing the componets of the mimic abalone used in testing to determine brush parameters.

2.2.2. Experimental Brush Test

Brush testing was focused on circular brushes, as the shear force is evenly distributed on the surface, and they lend themselves to scalable application. Parameters of interest are gauge, material, filament density and standoff distance. Two different bush materials are to be tested, stainless steel and nylon, with 2 gauges of each and 3 differing offsets considered.

2.3. Oyster Adhesion

Australian flat oysters are the hardest fouling element found on the Abitat of OGA's ranch and therefore become the benchmark for fouling to be removed. Oyster adhesion to ship hulls and coatings has been studied, however adhesion to natural or substrates resembling that of the Abitat have not. Adhesion at early stages of development of oyster spat is of interest in this project. Sydney rock oysters, Saccosrea Glomerata, are used in place of Australian flat oyster, Ostrea Angasi, as they are readably available, and their adhesion likely exceeds that of the flat Oyster. Oysters are sourced through the DPIRD three weeks after spawning, with the oyster larvae added to tanks with horizontally suspended Abitat substrate promoting adhesion of the larvae to the underside. Temperature and oxygen are monitored, and the larvae fed for optimal growth, to establish a worst-case scenario.

Oyster adhesion in shear is measured based on ASTM test method D5618. The test is to be performed weekly on a randomly selected subsample of the oyster spat present on the substrate for two months following initial settlement. The area of the spat is calculated using ImageJ, with the assistance of a microscope. 10N and 100N digital force gauges are used to apply a shearing force to the oyster, via a shearing probe, until the shell fully separates from the substrate surface. The force is ramped up at a rate of 4.5 N/s

3. Results and Discussion

The window of opportunity to intercept the fouling can then be calculated using the bulk adhesion force measured for the oysters throughout the early period, and a discretised cantilever beam model is used predicting the force applied to the oyster spat by a singular bristle. A MATLAB simulation calculates the shear force imparted to the oyster spat, accounting for the kinetic friction between the nylon bristles and the substrate. This simplified model ignores the effects of inter-bristle mechanics, the complex geometry of the spat, and hydrodynamic effects on the bristles and oyster spat, as the profile of the oyster is extremely low and the hydrodynamic effect can be assumed to be negligible.

$$F_s = F_{bs} * d * A_t \tag{3}$$

The period in which the opportunity to intercept oyster adhesion arises between the point in time the oysters are initial settling and the point at which the bulk brush force is insufficient to exceed the bulk shear off force of the oyster spat. Once the interception window is established the scale of the equipment required can be calculated based on OGA's diving protocols and number of Abitats to be serviced.

4. Conclusions and Future Work

The success of cleaning largely relies on predicting and monitoring spat fall, to intercept the oysters whilst their adhesion is still weak. OGA will have to monitor the gonad growth and brooding of the flat oysters in Flinders Bay to deploy equipment at the most effective time although spawning can be predicted to less accurately using water temperature.

A small-scale brushing tool is to be developed prior to further development of the described cleaning technique to verify the effectiveness at removing flat oysters during the interception window and to ensure abalone are not removed. Once the small-scale tool verifies the cleaning method, design of the final scale of solution can commence with confidence.

5. Acknowledgments

This project would not have been possible without the support and guidance of so many faculty members at UWA, chief among whom, my supervisor Dr Andrew Guzzomi. Thank you to the OGA team, Joel Durrell, Sam Henry, Brad Adams and of course the divers. Without you this opportunity simply would simply not exist, and all have contributed greatly. Thank you to Lachlan Strain, Anthony Hart, Michel Bermudes and Aisling Fontanini from the DPIRD for the assistance in the multidisciplinary aspects of this project, time, facilities, and equipment. Lastly and certainly not least thank you Dr Jeremy Leggoe and Amanda Bolt for your support and, at times, patience.

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