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Pinto Abalone Recovery Project
2017 Final Report to the Skagit MRC
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September 29th, 2017

Introduction

The pinto (northern) abalone, *Haliotis kamtschatkana*, is the primary abalone species indigenous to Washington waters. Populations are severely depleted and considered functionally extinct because the current number and distribution of reproductive wild abalone is too low and too widely distributed to maintain a sustainable population. The current threatened state of the Washington pinto abalone population is largely due to anthropogenic factors, including overharvesting during the legal recreational fishery and poaching during the 1980-90s (Bouma 2007). Populations in Washington state never supported a commercial fishery for abalone. Between 1992 and 2017, the density of pinto abalone declined by 98% at 10 index sites in the San Juan Archipelago (SJA) even after the closure of the recreational fishery in 1994 (Rothaus et al. 2008, WDFW unpublished data). Insignificant numbers of juvenile recruits have been observed and the average size of abalone continues to increase (Rothaus et al. 2008, Bouma et al. 2012, WDFW unpublished data). Both of these measures indicate likely recruitment failure of pinto abalone in areas of historical presence. They are now listed as a U.S. Federal Species of Concern, a Washington State Candidate Species and Species of Greatest Conservation Need and as a Canadian Endangered Species (PSRF 2014).

Abalone are broadcast spawning invertebrates, gametes undergo fertilization in the water column. After a 7-10 day planktonic larval phase, the larvae go through metamorphosis and settle onto rocks encrusted with pink coralline algae. Juveniles prefer rocky reef and cobbled substrates with crack and crevice habitat to hide in. This large marine snail occurs primarily in the shallow subtidal zone, although they have been found in depths up to 100 ft (NOAA 2007). The abalone diet changes during different life stages; larval abalone are lecithotrophic while planktonic, small juvenile abalone primarily graze on the diatom and bacterial biofilm, while the adults feed on various species of macroalgae.

The apparent recruitment failure and complete lack of recovery for this species is thought to be largely due to the Allee effect (Allee et al. 1949). The Allee effect can occur when existing animals are not able to find each other and reproduce successfully; a low population density means less successful reproduction and a positive feedback loop that leads to eventual population extinction. Babcock and Kessing (1999) estimated that the minimum density is

0.15 abalone/m^2 in order for successful reproduction to occur. Extensive sampling has shown that the remaining San Juan Archipelago pinto abalone population is not dense enough to facilitate the reproduction necessary for the population to recover naturally.

Steps are being taken in an effort to help restore the pinto abalone population in northern Puget Sound waters. Puget Sound Restoration Fund (PSRF), with oversight from the Washington Department of Fish & Wildlife (WDFW), has developed a conservation aquaculture program designed to supplement depleted wild stocks. Adult broodstock abalone are collected from the wild and brought into hatcheries located at the NOAA Mukilteo and Manchester Research Stations. These animals are spawned in the laboratory to produce larval and juvenile abalone for future outplanting and to provide early life stages for a variety of laboratory experiments. Almost 9200 of these healthy, genetically diverse hatchery produced juvenile abalone have been outplanted to six rocky reef sites in Skagit County waters from 2009 to 2017 (plus an additional 5800 abalone at six sites in San Juan County). A summary of the numbers of abalone outplanted to the Skagit County sites appears in Table 1. Surveys of these outplant sites to monitor survival, growth and movement have been conducted at least annually from 2009 through 2017 to provide estimates of survival and growth of abalone released into the wild. Methods and results of surveys prior to 2017 can be found in annual WDFW, PSRF and Skagit MRC summary reports as well as project reports by Shannon Point Marine Center (SPMC) students (Bergman 2009, Pratt and Dinnel 2010, Hester et al. 2011, Benolkin et al. 2012, Walker et al. 2013).

Table 1. Number of juvenile pinto abalone outplanted at Skagit County locations from 2009 through 2017 by site and year.

Site	**2009**	**2011**	**2013**	**2014**	**2015**	**2016**	**2017#**	**Total by Site**
Burrows Island West	304	321	0	358	218	0	0	**1201**
Burrows Island South	257	350	0	358	218	0	456	**1639**
Allan Island West	260	330	0	358	218	0	431	**1597**
Allan Island South	309	305	0	358	218	0	454	**1644**
South Cypress Reef	0	0	0	0	726	600	0	**1326**
Cypress Head	0	0	0	0	726	601	458	**1785**
Total by Year	**1130**	**1306**	**0**	**1432**	**2324**	**1201**	**1799**	**9192**

Outplant efforts described in this report.

The pinto abalone recovery project in Washington State is a long-term collaboration between county, state and federal agencies, NGOs, universities, and tribes. This group includes researchers, technicians, managers, students and facilities support from the WDFW Central Shellfish team; Puget Sound Restoration Fund; Western Washington University's

Shannon Point Marine Center (SPMC); the NOAA Mukilteo & Manchester Research Stations; the University of Washington, School of Aquatic & Fishery Sciences (UW); outreach facilities such as the Port Townsend Marine Science Center, Bellingham Marine Life Center and others. Annual funding to PSRF from WDFW supports consistent progress in abalone hatchery and restoration activities. This support has been supplemented by additional funding in 2016-2017 from the NOAA Protected Resources Division that increases hatchery capacities and field efficiencies. In 2016-2017, the Skagit County Marine Resources Committee (Skagit MRC) elected to continue supporting monitoring activities at the previously seeded Skagit County sites (South and West Burrows Island, South and West Allan Island, South Cypress Reef and Cypress Head) and to sponsor another round of seeding at some of these outplant sites.

The primary objective of the abalone recovery project is the production of genetically diverse disease-free hatchery raised larval and juvenile pinto abalone for supplementation and restoration of wild stocks, focusing on maintaining the genetic integrity and health of wild populations. In addition to managing the abalone conservation aquaculture program, PSRF collaborates with WDFW on all associated field efforts including outplant site surveys, restoration strategy field trials and juvenile outplanting. The following report summarizes project accomplishments related to Skagit MRC's grant agreement #SEANWS-2016-SkCoPW-00003 Task 5 during the time period from October 2016-September 2017.

Hatchery Management

Juvenile pinto abalone for outplanting in 2017 were produced and reared by PSRF with Skagit MRC support at the NOAA Mukilteo Research Station. These animals were designated for introduction at four sites in Skagit County (Table 1). Hatchery responsibilities to produce abalone for outplanting projects included coordination, supervision and implementation of daily coverage, weekly maintenance and regular aquaculture activities at the NOAA Mukilteo Research Station. Specific tasks necessary to produce juvenile abalone for outplanting include:

- Tank cleaning & filter changes.
- Water quality monitoring—temperature, salinity, pH, dissolved oxygen and total gas pressure.
- Seawater supply to the hatchery, nursery and grow-out greenhouse was buffered with sodium carbonate to elevate pH above 8.0. This required regular probe calibration, controller/dosing pump maintenance and production of buffering solution.
- Animal health monitoring—mortalities and live juveniles sampled for histology and molecular diagnostics as part of comprehensive hatchery health screening.

- Abalone maintenance—inventory, measuring, weighing, tagging and genetic sampling.
- Systems updates—plumbing, pump & heater maintenance, tank rack construction, etc.
- Supervision and direction over student, intern and technician research projects.
- Production—broodstock conditioning, induced spawning, larval rearing, juvenile grow-out and diatom/macroalgal culture.

While the pinto abalone conservation aquaculture program has had a long history at the NOAA Mukilteo Research Station, it has also become clear in recent years that as the program grows and recovery efforts are scaled up, hatchery facility needs are increasing. The NOAA Manchester Research Station and PSRF collaborated to develop and operate a new state-of-the-art shellfish hatchery in Port Orchard, which was opened in 2014 and named the Kenneth K. Chew Center for Shellfish Research and Restoration. Objectives for this new facility have been focused on unique conservation aquaculture of ecologically and economically important native shellfish species. Facilities and expertise include systems for microalgae and diatom production, spawning/breeding programs, larviculture, shellfish nursery and grow-out, ocean acidification research and water quality monitoring.

PSRF has been working diligently over the past year to expand the Shellfish Center by adding a 1500 ft^2 shellfish nursery building, providing ideal space to accommodate development of novel aquaculture techniques and expansion of ongoing abalone aquaculture production for restoration. PSRF has designed and constructed a large-scale culture system for post-set and early nursery culture of pinto abalone. The culture system contains 80 flat-bottomed, round tanks stacked vertically (4 high). Each tank is outfitted with its own seawater supply, air supply, and drain line. Water quality is particularly important for early stage post-set abalone. Seawater is particle filtered to 5 micron and UV-sterilized when necessary, and heated/chilled to maintain optimal culture temperatures between 10-14°C throughout the year. We continuously monitor pH (durafet), temperature, salinity, dissolved oxygen, total gas saturation and flow rate of the seawater inflow to the new nursery and grow-out building. We also have the capability to install a carbonate injection system similar to what currently exists on the Mukilteo abalone seawater supply to automatically buffer the seawater to maintain seawater pH above 8.0. Water quality metrics are data logged on a centralized computer system and relays are installed to alert hatchery staff to system malfunctions or poor water quality. The Manchester nursery system allows for a wide array of culture schemes and will potentially triple our current abalone production capacity at the existing Mukilteo hatchery facility.

PSRF moved abalone broodstock to the Manchester hatchery in May & June 2017 and all induced spawning attempts this summer were conducted at the new facility. Production efforts were highly successful as several spawning attempts produced more than 3 million larvae from

15 families competent for settlement into 74 aquaculture tanks in the new nursery building. Field experiments are ongoing to determine the possibility of outplanting juvenile abalone at a younger age (described later in this report) and based on results from this study the post-larval cohort produced this summer will be available for introduction to restoration sites during either the summer of 2018 or the early spring of 2019.

Juvenile Outplanting in Skagit County

In March & April 2017, the Washington state pinto abalone recovery team completed the seventh outplant of juvenile abalone from our conservation aquaculture program since 2009. Personnel for this outplant consisted of researchers from WDFW, PSRF, and SPMC. The primary objective of the pinto abalone conservation aquaculture program is to "do no harm" to existing wild stocks of pinto abalone and therefore extreme care was taken during the restoration outplants described here to introduce a genetically diverse and disease free cohort of abalone.

Nearly 1800 juvenile pinto abalone were outplanted to clean rocky reef habitat on April 18th, 2017 at Cypress Head, Burrows South, Allan West and Allan South, four of the six restoration sites within Skagit County (Table 1, Fig. 1). Established in 2009 and 2015 respectively, the Burrows Bay and Cypress Island restoration sites, with funding support in part from the Skagit MRC, have now been seeded with a total of 9192 juvenile abalone to date. Abalone destined for these sites in 2017 were not tagged as all possible tag number and color combinations available were used on the animals outplanted there in previous years. Future mark-recapture efforts at existing Skagit County recovery sites will require new tag styles and methodologies.

Monitoring surveys, described in the following sections of this report were completed before new abalone were released onto the sites. The remaining two restoration sites in Skagit County (Burrows West and South Cypress Reef) were not overseeded in 2017. Recent analysis of outplant monitoring data suggests evidence that some sites should not receive continued overseeding due to poor survival (Table 4). Metrics for this determination include the percentage survival at one year post-outplant and the percentage of outplant success (the percentage of animals that have reached reproductive maturity, 50 mm shell length, divided by the number outplanted to the site at least a year prior to the survey). These discontinued sites will continue to be surveyed each year along with the overseeded sites to confirm proper designation as non-productive.

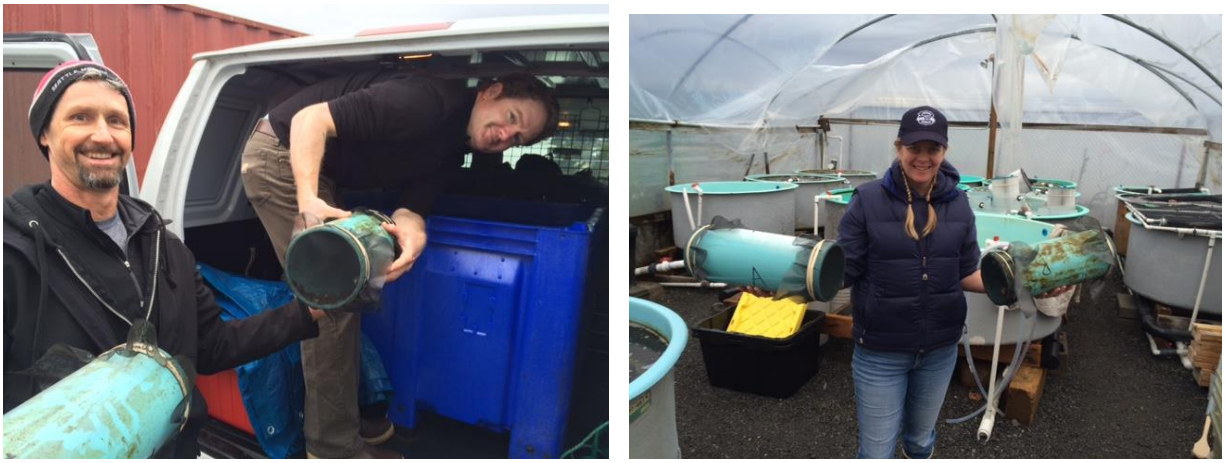


Figure 1. WDFW crew participate in loading juvenile abalone for outplant to Skagit County restoration sites in 2017.

The 2017 juvenile cohort introduced to Skagit County sites represented 9 new genetically distinct families, produced from six female and eight male broodstock parents (Table 2). All of the introduced abalone during the recent effort were from the 2015 hatchery cohort. The mean shell length (SL) of abalone released to these four sites in 2017 was 20.4 mm. A total number of 9192 individuals from 88 unique genetic families have now been introduced to six different juvenile outplant sites in Skagit County. As a whole, the pinto abalone recovery program has introduced more than 15,000 juvenile abalone from 96 families to 12 sites in both Skagit and San Juan Counties.

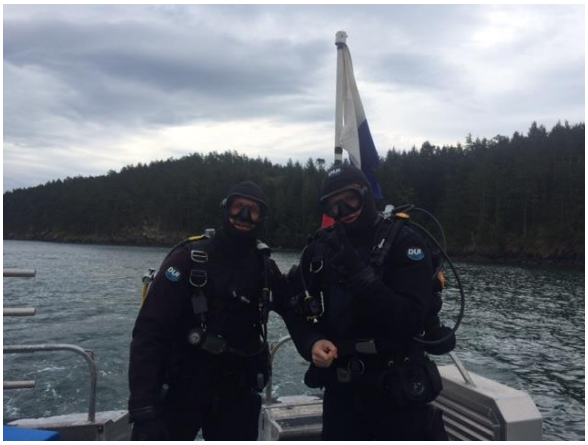
Table 2. All juvenile abalone outplanted to Skagit County in 2017 arranged by family. Family designation includes female and male parent identification.

Family (F x M), Year Class	Total	Mean Shell Length (mm)
Or25 x Or07 '15	76	14.4
Or31 x Y33, Or01, Y36 '15	226	21.0
Or34 x Or01 '15	164	29.2
Or17 x Or33 '15	396	23.0
Or17 x Or07 '15	12	16.8
Or17 x Or29 '15	279	17.7
Or17 x Or12 '15	245	16.8
Or27 x Or01 '15	273	10.5
Or20 x Or14 '15	128	34.4
Total & Mean Shell Length (mm):	**1799**	**20.4**

Juvenile Abalone Outplant Site Monitoring-Cypress, Burrows and Allan Islands

Between February-April, 2017, PSRF divers participated with WDFW in dive surveys investigating survival, growth and emergence of hatchery reared pinto abalone introduced to the six restoration sites in Skagit County, located along the shorelines of Cypress, Burrows and Allan Islands. Survey set-up included locating the four permanently marked plot corners, extending a survey tape measure around the plot to establish a perimeter, and installing weighted lines to distinguish 2 m survey lanes across the plot. To investigate possible emigration beyond the outplant plot, and replicating similar perimeter sweeps initiated in 2016, surveys this year included the addition of a 2 m lane around the outside perimeter of the each plot. This additional perimeter lane effectively doubles the amount of area surveyed at each site during a standard survey. Monitoring efforts in earlier years had opportunistically surveyed outside the plot when there was available dive time, but the measured, consistent and complete perimeter surveys that began last year produce a tremendous amount of informative emigration data not acquired previously.

Divers meticulously conducted non-invasive surveys (boulders were not moved or flipped over) of each lane, including the full perimeter sweep. Dive lights and small mirrors were used to investigate cracks, crevices and overhangs. The shell length and presence/absence of tags including tag number and color if identifiable were recorded for all abalone observed. Notes were also taken on where each observation was made within the plot lane (deep, mid or shallow) and how the animal was oriented within the substrate (cryptic, semi-cryptic or emergent). Empty abalone shells from mortalities were collected, measured and observed for tags when encountered and then removed from the plot.



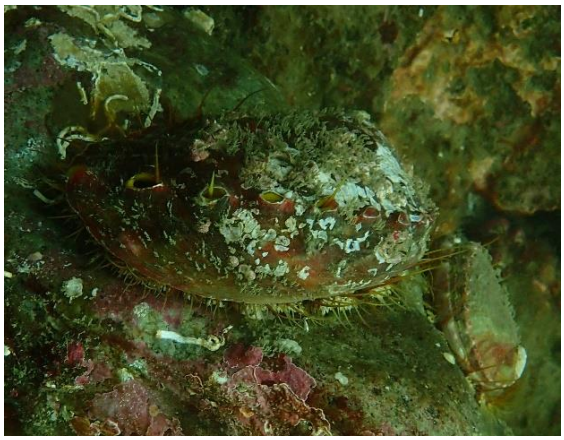


Figure 2. Divers prepare to survey restoration sites in March 2017. Pinto abalone observed on one of the plots.

The monitoring surveys at the six Cypress, Burrows and Allan Island sites in 2017 found a total of 372 abalone of which 30% were found outside of the plot boundaries (Table 3). The largest number of abalone (n=104 combined on and off plot) were found at the Cypress Head site and the plot density at this site was 1.02 abalone/m^2. Mean shell length of observed abalone for all six plots combined was 78.9 mm. Abalone as small a 25 mm and as large a 152 mm were observed during the surveys. The overall mean density of the observed abalone on-plot was 0.50/m^2, with individual plots ranging from 0.12 to 1.02 abalone/m^2 (Table 3).

Table 3. Juvenile abalone outplant survey data at six sites in Skagit County from February-April 2017. SL=maximum shell length measurement.

Site	Plot Area (m^2)	On Plot (n)	Plot Density (Ab/m^2)	Perimeter Area (m^2)	Off Plot (n)	Perimeter Density (Ab/m^2)	Mean SL (mm)
Burrows South	98.2	37	0.38	96.8	26	0.27	92.0
Burrows West	75.3	9	0.12	84.8	13	0.15	91.1
Allan South	102.5	38	0.37	97.2	20	0.21	95.2
Allan West	90.0	65	0.72	93.2	22	0.24	90.5
South Cypress Reef	77.9	29	0.37	87.4	9	0.10	49.1
Cypress Head	79.3	81	1.02	162.6*	23	0.14	55.6
Total	**523.2**	**259**	**0.50**	**622.0**	**113**	**0.18**	**78.9**

*The perimeter survey area at Cypress Head was expanded in 2017 by adding four additional 2 m horizontal survey lanes beyond the deep perimeter lane of the plot due to a number of abalone observations beyond the perimeter.

Table 4. Outplant success defined at the six restoration sites in Skagit County. SL=abalone shell length.

Site	Total Outplanted (Pre-2017)	Current # >50 mm SL	% Outplant Success*	Continued Overseeding
Burrows South	1183	34	2.9%	Yes
Burrows West	1202	8	0.7%	No
Allan South	1190	37	3.1%	Yes
Allan West	1166	65	5.6%	Yes
South Cypress Reef	1326	12	0.9%	No
Cypress Head	1327	52	3.9%	Yes
Total	**7394**	**207**	**2.8%**	

*Outplant success over time is defined by the percentage of animals over 50 mm SL at each site divided by the number of abalone outplanted to that site at least a year prior to the survey.

Younger Abalone Outplant Experiment-Allan Island

Introduction

Since restoration outplants began in 2009, the standard size and age of cultured abalone at release has been approximately 20 mm shell length and 18 months old. This target size at outplant is based on early pilot outplant studies conducted by WDFW, PSRF, and UW in 2007-2008 and takes into account typical hatchery production and field schedules during which abalone are produced during the spring/summer season and outplanted during the late-winter field season 16-20 months later.

This outplant strategy entails significant demands on time and resources within the hatchery (technician labor, equipment and supplies, pump maintenance, utility costs for heating and lighting, feed requirements etc.). In addition to the high demands of time and resources, there are other potential drawbacks to rearing juveniles in the hatchery for as long as 18 months prior to release. Holding animals in a captive breeding program can lead to both hatchery acclimation and hatchery selection. First, abalone acclimated to the hatchery setting may be less fit for survival in the wild through less effective predator avoidance and foraging/feeding efforts. Second, by outplanting abalone thriving in the hatchery for up to 18 months we may be inadvertently selecting beneficial hatchery life traits and selecting against or weakening those traits that are beneficial for survival in the wild. Earlier release from our aquaculture program onto restoration sites in the wild could reduce both hatchery acclimation and selection. Younger outplants would also reduce the burden of cost and resource utilization necessary for longer culture periods, immediately increasing our production capabilities and efficiencies.

PSRF has hypothesized it is possible to introduce hatchery reared abalone to the wild at an earlier life stage than typical in our restoration efforts in the San Juan Islands to date. A significant bottleneck to survival in the hatchery occurs during the post-larval stage from 0-3 months after larval settlement and metamorphosis. During this time, post-larval abalone are highly sensitive to density, competition, optimal diet, water quality changes, bacterial loads and handling stress from tank cleaning. By successfully culturing post-set abalone through this tenuous life stage in the hatchery, the animals may be robust enough to outplant as juveniles as early as 9 months instead of waiting 18 months or longer before release.

Methods

With funding support from WDFW, Skagit MRC, NOAA and the Hall Family Foundation, a younger juvenile abalone outplant experiment to test this hypothesis was initiated in early 2017.

Much of the infrastructure was already in place for this experiment. A cohort of pinto abalone from seven genetically distinct families produced between June-September 2016 at the Mukilteo hatchery provided an opportunity to use these early stage juveniles in the outplant trial. We selected an ideal experimental field site along the northwest shorelines of Allan Island near several of our successful juvenile outplant sites in Skagit county. Outplant introduction methods and follow-up survey methods for this trial have been tested and in place from previous later stage juvenile abalone outplants.

Six outplant modules were constructed, each from a double-stacked commercial crab trap with all internal fishing gear removed but exterior frames and wire mesh intact to create replicable introduction habitats with known volume. The modules were filled with coralline algae encrusted cobble, spaced 30 m apart and placed in a line along the along the shoreline contour and at the same depth elevation. Three of these young abalone modules (YAMs 1, 3 & 5) were replicates placed in the water and seeded with 9 month-old abalone (mean SL=8 mm) in April 2017. This first batch of early stage juveniles from Mukilteo were loaded into 4" PVC tubes, similar to existing outplant strategies, transported from the hatchery to the field, nested into the cobble within each YAM and released into the cobble complex within the module. Three additional replicates (YAMs 2, 4 & 6) were placed in the water and seeded with abalone as the second age treatment in September 2017. This second batch of animals had remained in nursery tanks at the hatchery for an additional five months, and were outplanted with identical methods in September 2017 as 14 month-old juveniles (mean SL=14 mm). Animals in both experimental age groups were from the same seven family cohorts to reduce the confounding effects of lineage on the experiment. Additionally, two control modules (crab trap and cobble included) were set up in culture tanks at the Mukilteo hatchery and seeded with 9 month and 14 month juveniles in April and September 2017 respectively with similar methods to the field modules. Nearly 800 early stage juvenile abalone were used for the two age treatment outplants and lab controls.

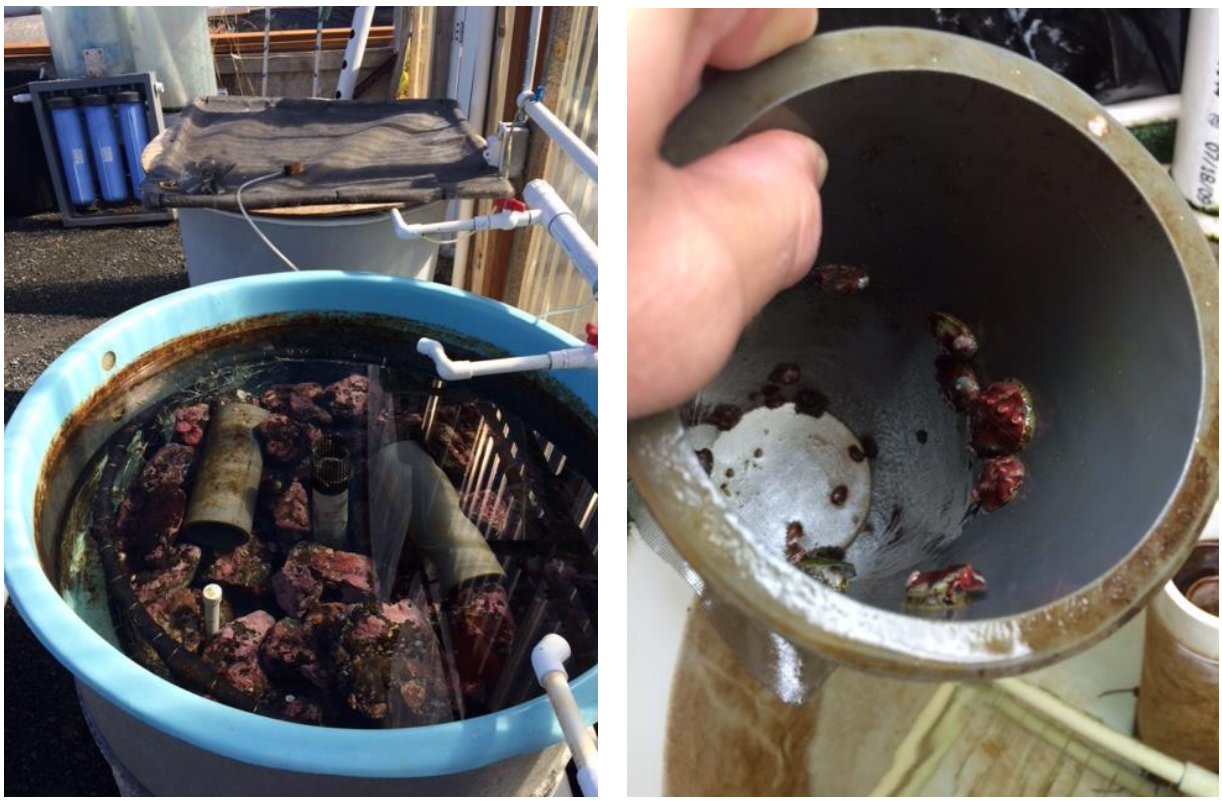


Figure 3. 14 month-old hatchery reared juvenile abalone are introduced to a lab control module at the NOAA Mukilteo Research Station as part of the early stage juvenile outplant experiment.

Subsequent monitoring of the first age treatment began in September. The initial survey plan was to observe one replicate from each age treatment on six month intervals. Divers determine survival by deconstructing modules *in situ.* Each rock is carefully removed and inspected for the presence of juvenile abalone, which are measured using calipers. Afterward, the module is carefully reconstructed. A three meter perimeter of surrounding substrate is also invasively sampled by divers, lifting, turning and examining each piece of cobble, to locate individuals that have possibly left the YAMs. The hatchery control module seeded with 9 month-old juveniles was also surveyed for survival and growth in September.

This pilot-scale outplant trial of earlier stage juvenile abalone follows the timeline below. Dates are approximate, and funding beyond September 2017 is to be determined.

- June-September 2016, induced spawning at Mukilteo hatchery to produce young cohort.
- October 2016-March 2017, post-larval/early juvenile nursery culture at Mukilteo hatchery.
- March 2017, divers investigate & confirm northwest Allan Island experiment site.
- April 2017, outplant of 9 month-old juveniles (~8mm shell length) to YAMs 1, 3, 5.

- September 2017, outplant of 14 month-old juveniles (~14mm shell length) to YAMs 2, 4 & 6. Monitoring survey #1 at ~6 months post-outplant (younger age treatment only).
- March 2018, monitoring survey #2 at 12 months and 6 months, respectively, post-outplant (both age treatments).
- August 2018, monitoring survey #3 at 18 months and 12 months, respectively, post outplant (both age treatments).
- September 2018, final analysis and summary of survey results.

Early Results

A thorough survey of YAM #1 including deconstruction of the module and invasive observation of all substrate up to 3 m from the YAM was conducted in September 2017. Only 2 abalone were observed within the module, and no abalone were observed in the surrounding habitat. This is a survival rate for juveniles 9 months-old at outplant over the first five months of the experiment of 2% in this particular module. While the experimental design calls for observation of one replicate every 6 months, it was necessary to survey a second replicate to determine if the poor survival was module or site specific. A thorough survey of YAM #3 including deconstruction of the module and invasive observation of all substrate up to 3 m away revealed 24 abalone within the module and none outside the module. This is a survival rate for juveniles 9 months-old at outplant of 22%, significantly better than the first module surveyed. Most of the abalone seen during these two surveys were located in the top third of substrate within the YAMs and were also oriented on clean, coralline encrusted portions of the cobble.

The hatchery control module, set up with a similar crab trap cobble complex and seeded with the same group of 9 month-old abalone in April was also surveyed in September. Each piece of substrate removed from the tank and observed closely for survival. 59 abalone were counted and measured in this control, a survival rate of 58% over the five months since seeding. In comparison, the juvenile batch that was held in standard nursery culture at the hatchery while waiting to be outplanted as the second age treatment had a survival rate of 63%, similar to the survival described in the lab control.

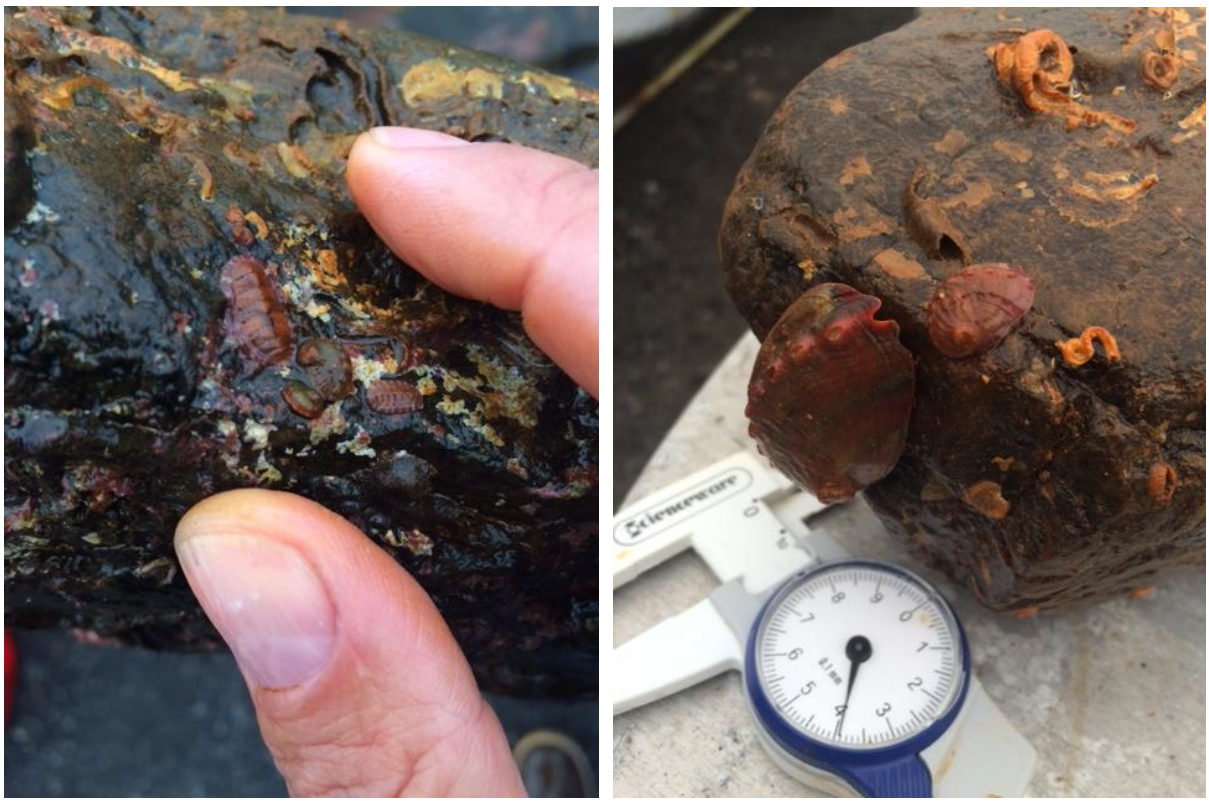


Figure 4. Juvenile abalone from the early stage juvenile outplant experiment are counted and measured on the lab control module in September 2017.

Discussion

The concept of outplanting hatchery raised juvenile abalone is not a new one. Work to enhance natural fisheries for abalone by seeding juveniles began about 3 decades ago in Japan (Uki 1981). Tateishi et al. (1978) found a 9-month survival rate of 48.6% for small (14 mm) outplanted abalone. Saito (1984) determined that 2-3 year survival of hatchery seed was 5-10% (versus 20-25% for naturally set seed). Kojima (1995) found survival rates ranging from 12-51% over a 2-6 year period for 15-40 mm seed. In addition to work in Japan, there have been other seeding projects in Australia, Taiwan, New Zealand and along the coast of California (reviewed by Tegner and Butler 1989; see Table 3 in PSRF 2014). Outplanted abalone survival rates associated with these projects have been highly variable (0-77%), depending on outplant size, location and species. Two early experimental projects in the Strait of Juan de Fuca with juvenile pinto abalone seed found survival rates of 7-12% after one year (Rothaus, unpub. data, WDFW; Stevick 2010).

As of 2017, 9192 juvenile pinto abalone have been out planted at six Skagit County sites. Of these, we now have survival estimates for abalone planted in 2009, 2011, 2014, 2015 and 2016 which total 7393 animals. Of this total, 372 abalone were observed during 2017

monitoring surveys at the Burrows, Allan and Cypress Island outplant sites. This translates to a survival rate of 5% for those animals. However, this is a very conservative estimate of survival due to the fact that juvenile abalone are very cryptic and are often hidden by the complex nature of their habitat. This has been confirmed by repetitive SCUBA surveys at several outplant sites in previous years, including South Cypress Reef, Cypress Head, Burrows South and Allan West. These repetitive surveys revealed that there were as many as 61% more abalone present when compared to a single survey. Further, all of the surveys in Skagit County have been non-invasive (i.e., no rocks were moved to reveal hidden abalone). Two previous studies in Washington state compared non-invasive with invasive (rocks moved to find hidden abalone) surveys at the same sites and found that the non-invasive surveys found only about 31% of those pinto abalone actually present (Rothaus, unpub. data, WDFW; Stevick 2010). The authors of those studies suggested that this "show factor" of 31% can be used to adjust the results of non-invasive surveys (at least for smaller abalone). Even this show factor is conservative as it does not account for the abalone that have emigrated off the plot and been observed within the plot perimeter. If we apply this "show factor" to the most recent survey of Skagit County plots, the estimated survival rate of 5% could be much higher.

Regardless of the actual survival rate, we do know that the current abalone densities at five of the six Skagit County outplant plots now exceed the postulated minimum density (0.15 abalone/m^2; Babcock and Kessing [1999]) needed to sustain successful spawning and egg fertilization. Pinto abalone become reproductive at a size of 50 mm SL, and given that the mean SL of abalone observed at these sites is 78.9 mm, it is likely there is successful spawning occurring there.

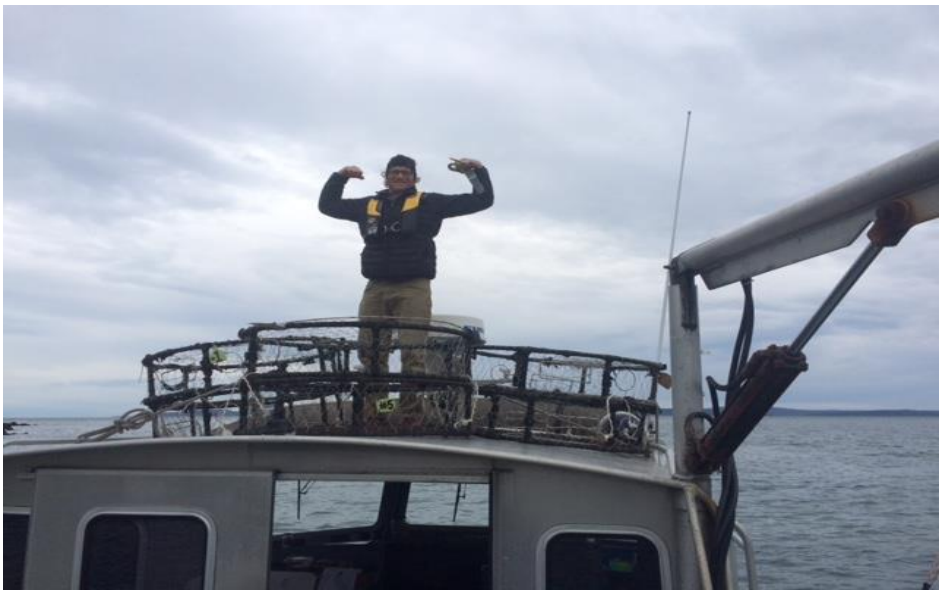


Figure 5. Experimental modules to be filled with cobble and seeded with juvenile abalone are prepared for deployment by PSRF personnel.

Our study examining the possibility of outplanting juvenile abalone to restoration sites at an earlier age and smaller size will inform future restoration strategies, direct hatchery production and potentially increase our capacity to scale up our recovery efforts. While survey results from the first examination of the 9 month-old outplant (2% and 22% survival respectively on two of the three replicates after five months in the water) may not fully meet our expectation for a successful outplant, it is still too early in the trial to determine whether outplanting younger abalone is productive or not. The next set of surveys, scheduled for March 2018, will provide an opportunity to exhaustively examine all three replicates from the first age treatment and also give us our first indication of survival rates for the second age treatment (14 month old juveniles). With continued support, PSRF will fine-tune methodologies for outplanting success and long term recovery of the species within the San Juan Archipelago.

Future abalone enhancement work envisioned by Skagit MRC and PSRF in Skagit County waters include: 1) continued occasional monitoring surveys of the plots already seeded to optimize future seeding location selection, 2) continued outplants at some of the extant plots plus creation of new plots in promising locations, 3) off-plot surveys at various distances to assess abalone migration patterns and to monitor for settlement of abalone from natural spawning, 4) continued monitoring and analysis of the younger juvenile abalone outplant experiment at Allan Island and 5) possible further exploration of "larval seeding", which deploys late stage larvae that have been conditioned to settle into complex natural habitats (or into special rock-containing modules in which larvae can settle, grow and emigrate from).

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