Development of a juvenile abalone monitoring method

Craig Mundy, Sarah Pyke, Jaime McAllister and Hugh Jones

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In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

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1 Acknowledgments

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2 Executive Summary

The blacklip abalone *Haliotis rubra rubra* contribute more than 80 % of the annual wild abalone harvest across southern Australia. Blacklip abalone typically inhabit cryptic space (e.g. beneath boulders) until they reach size at maturity at around five years of age, and in Tasmania are not fully emergent until sizes greater than the Legal Minimum Length (LML). This key life history trait creates significant challenges in identifying potential changes in stock levels due to inter-annual recruitment strength. Thus recruitment failure or poor year classes are not detectable until abalone are already at a size to enter the fishery, giving little warning of a potential reduction in fishable biomass. Monitoring of cryptic abalone (2+ to 4+ year classes) however, provides an earlier warning of major change in cohort size, and offer the benefit of having passed the early vulnerable post-settlement stage.

A simple Abalone Recruitment Module (ARM), utilising a flat black polyethylene plate, was designed at IMAS; the deployment systems and performance of ARMs across a range of habitats was tested in this project. A direct attachment method using stainless steel expansion inserted into a shallow 8mm diameter hole drilled with a hydraulic impact drill was robust to significant wave energy conditions, although the type of underlying rock (granite, sandstone, mudstone) was a major contributor to the ability of ARMs to survive storm events. Cost of ARM materials is low at ~ $50 per ARM, and all materials are readily available across Australia. Installation is relatively straight forward with up to 40 ARMs installed in a single day by an experienced team.

The ARMs provided data on cryptic blacklip abalone in a size range (10 mm - 100 mm) that is poorly captured by transect or quadrat based fishery independent surveys. Abundance of abalone recruits on the ARMs was reasonably stable across the three year study period, but showed high levels of local variation within sites, and among adjacent sites at each location. High densities of abalone recruits were consistently observed under several individual ARMs at each sampling period suggesting micro-site choice when installing ARMs can have a substantial impact on the data obtained.

A sample size of 20 replicate ARMs was used at each site in this study in order to address perceived high levels of local scale variation. Effect Size and Minimum Detectable Difference calculations suggest that even with a relatively large sample size, power to detect change is limited to a magnitude of 80 % to 100 % changes in abundance. We recommend that sample sizes of at least 20 should be maintained to account for high local scale variation in recruit abundance.

Density of juvenile abalone observed under ARMs was inversely related to habitat complexity. The most plausible explanation for this pattern is that where there is an abundance of high quality natural habitat for cryptic abalone, the ARMs have a limited ability to attract recruits, from natural surroundings. In addition to the high levels of local-scale variation in recruit abundance, this effect of habitat complexity on recruit density observed under ARMs, gives demonstrable support for the argument that this type of sampling should be considered in the context of relative change, and should not be used as the basis for absolute estimates of abundance or biomass.

This project has demonstrated that ARMs can provide cost-efficient high quality data on abundance of juvenile abalone across the range of habitat types observed on commercially productive abalone reefs. The suggested use of the ARM method is to monitor recruit abundance at key indicator sites within the fishery, but not as a state wide tool for monitoring overall recruit abundance.

3 Introduction

Over the past three decades the Eastern Zone Abalone Fishery in Tasmania has experienced several large fluctuations in catch and catch rates. In addition to periods of intense historical fishing, there have also been environmental perturbations and changes on Tasmania's east coast which may be affecting productivity. In particular, two significant marine heat waves has raised the concern that climate change (Oliver et al. 2017) may be bringing increased volatility in recruitment, with an already depleted stock. This concern around recruitment is reinforced by observations from commercial abalone fishers because the downward trend in catch rates appears to be preceded by relatively few abalone below or at the minimum legal length. Conversely, recovery in catch rates is always perceived as being preceded by observations of large numbers of abalone approaching the minimum legal length.

Being able to respond to climate change driven changes in recruitment is currently difficult because, in Tasmania, the length at which abalone become 'emergent' and therefore visible to both researchers and fishers is typically at about the same size as the Legal Minimum Length (LML), or around six to eight years of age. Full emergent behaviour is usually not evident until abalone have reached a size greater than the LML (IMAS unpublished data). Thus recruitment failure or poor year classes are not detectable until abalone have entered the Eastern Zone fishery, giving little warning of a potential reduction in fishable biomass. As a result there's no opportunity for management to consider an adjustment of catch limits before a period of low recruitment enters the fishery.

When recruitment to the fishery fails, the fishery is reliant on existing older year-classes already in the fishery, leading to a rapid decrease in fishable biomass. The capacity to measure inter-annual variation in sub-LML year-class strength would provide valuable prior warning of biomass decline. Data obtained from a pre-recruit monitoring program that captures inter-annual changes in pre-recruit abundance could provide valuable fishery-independent data to inform TAC setting which is currently heavily reliant on fishery dependent data. Application of assessment and Management Strategy Evaluation (MSE) models are both limited due to the absence of data on early year-class abundance patterns, and will be improved by access to quantitative information on pre-recruits.

Previous work on recruitment in Australia has focused on either the settlement phase (Nash et al. 1995, Mundy et al. 2010), or on rolling boulders to find cryptic juvenile abalone (Prince et al. 1987). However, processing of abalone larval collector samples is labour-intensive and early post-settlement stages (0 – 3 months) are typically subject to high mortality rates, thus even strong biological recruitment events at settlement may not progress to large cohorts within the fishery. Destructive sampling by rolling boulders is also time consuming, and only feasible where the substrate can be moved to make the cryptic space accessible. This excludes many important reef systems from a potential survey program, and may lead to bias in recruitment estimates especially given blacklip abalone's highly spatially defined population structure. Monitoring of intermediate size abalone 2+ to 4+ year classes however, provides a warning of major change in cohort size prior to being detected by industry, and offer the benefit of having passed the early vulnerable post-settlement stage. It is this cryptic juvenile stage that is targeted in this project.

Artificial structures referred to as "Abalone Recruitment Modules" (ARM) for monitoring changes in the abundance of abalone have been trialled with some success in Canada and California (Davis 1995, DeFreitas 2003, Rogers-Bennett et al. 2004, Bouma et al. 2012). In addition, a range of ARM designs have been tested by IMAS staff over the past decade which has helped identify an optimum collector design for monitoring juvenile 2+ to 4+ blacklip (*Haliotis rubra rubra*) abalone (~ 20 mm to 80 mm shell length). This design development required testing in different habitats and improvements to the method of deployment on reef substrates. Work is also required to establish a network of these that is effective in terms of statistical power and operational feasibility.

4 Objectives

1. Optimise collector module design for quantifying abundance of juvenile abalone across a range of habitat types
2. Determine links between juvenile abundance observed on modules and abalone in surrounding habitat
3. Estimate expected juvenile abundance on collectors in a ‘normal’ recruitment year using published natural mortality data and known abundance.

5 Methods

5.1 Abalone Recruitment Module Design

Between 2002 and 2012 the IMAS abalone research group trialled a range of alternative Abalone Recruitment Module (ARM) designs, including a range of abalone recruitment modules simulating natural juvenile abalone habitat. These trials indicated that a simple flat plate placed on the reef surface was as or more efficient than complex 3D ARM designs at providing a cryptic space suitable for juvenile abalone of the target size-range (~ 20 mm to ~80 mm). The initial flat plate ARM design used 500 mm square 10 mm steel plates which used the mass of the ARM as the primary mechanism for holding the plate in place. These ARMs successfully collected juvenile abalone at both trial locations in the Black Reef region. However, handling of these heavy plates was problematic both in deployment and in surveying the ARMs. Storm events also caused dislodgement and movement of the plates leading to confounding of small-scale variation in juvenile abundance with temporal change. In addition the steel plates presented issues in terms of cost and longevity. It was therefore evident that alternative material testing and design was required.

5.1.1 Testing of alternative ARM materials and ARM size

Trials of three sizes of square ARMs (250 mm x 250 mm, 400 mm x 400 mm, 500 mm x 500 mm) at George III Rock, fixed by a central pin drilled into the rock, suggested that the mid-size plates (400 mm x 400 mm) were the most suitable for this habitat type (small to medium boulders). This assessment was based on the concept of maximising the surface area of the plates, but still allowing placement of the plates in suitable microhabitats that were likely to be used by cryptic abalone. The larger plate size of 500 mm x 500 mm square was found to be difficult to accommodate in the mixed sized boulder substrate. Furthermore, the trial suggested the square design of the plates was inappropriate as the plate corners fouled with weed and led to plate dislodgment. Following the field trial of square plates, 400 mm diameter round plates were developed and successfully trialled in several habitat types designated in the project (boulder, slab and low profile mixed bottom). In the boulder and slab habitat it would be possible to utilise a large plate dimension, but in order to provide comparison with the low profile mixed bottom a standardized plate size was deemed advisable.

Preference for different ARM materials by juvenile abalone was determined by tank testing at the IMAS Taroona facility between December 2014 and February 2015, following the experimental design outlined by Olabarria et al. (2002). These tank trials showed that there was no selection preference by juvenile abalone between polyethylene, fibreglass and concrete ARMs, but that these three surfaces were preferred over steel. Polyethylene was selected as the material of choice over fibreglass and concrete based on its ease to manufacture (laser guided cutting), deploy (reduced weight) and price.

5.2 ARM Installation

A detailed description of the ARM design, equipment, and installation procedures is provided in the standard operating procedures (Pyke et al. 2017). A brief overview of the method is provided here. The ARMs are secured to the substrate with a single central pin while three adjustable risers are located on the perimeter to control the gap between the ARM and the substrate (Figure 1, Figure 2). One of the risers is also used to prevent the plate rotating, by locating the riser bolt within a shallow hole drilled into the rock. This also provides increased security in adverse conditions, and ensures the plate is replaced in the same orientation each time. The height of the plate above the rock surface is adjustable using the three risers (Figure 3, Figure 6), and based on evidence of height preference from the tank testing is set to a maximum of 40 mm at one riser, with another riser set at 5mm - 10 mm, providing a gradient of heights below the plate from one side to the other.

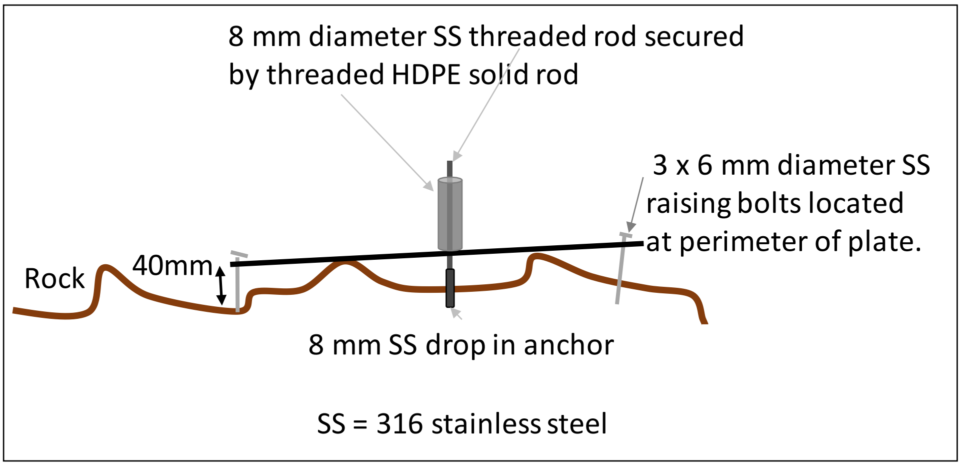

Figure 1. Blacklip abalone juvenile collection plate configuration.

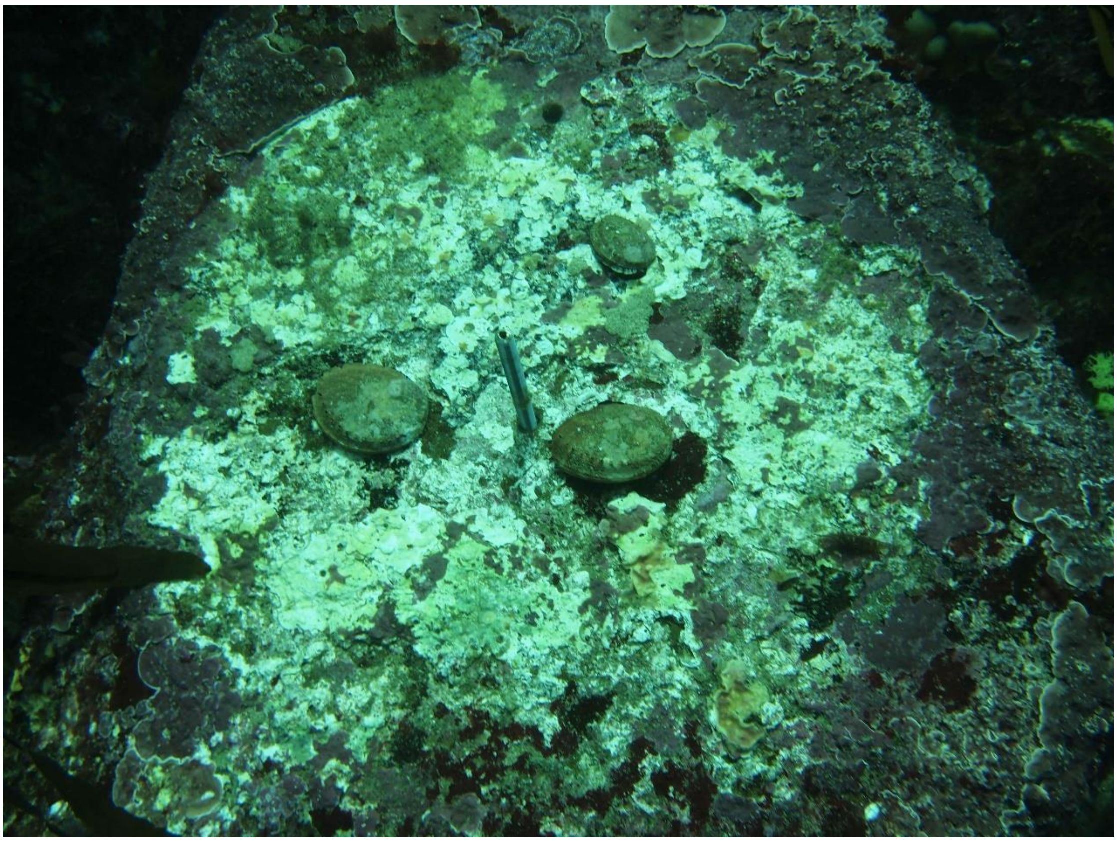

Figure 2. Discoloured coralline algae habitat beneath an ARM several months after installation, along with three juvenile abalone. Central pin and riser locating hole (top centre) are clearly visible.

The ARMs are deployed in a string (*n* = ~ 25) connected to a 50 m length of steel chain (12 mm diameter) via tethers (Figure 4). This ARM deployment system represents a modification on the system developed during FRDC 2005/029 for attaching abalone larval collectors to rocky reef substrate within a defined site. It allows the divers to follow a single ARM string and sample each ARM in turn, reducing the risk of missing replicate ARMs when kelp cover is high, or visibility is reduced. Within the 1st few months of deployment it became apparent that the wire tracers used as tethers were not an effective choice as they had a tendency to sit proud of the substrate and become tangled in weed. The drag effect of the weed subsequently caused some plates to be torn from the bottom with plate and tethers lost. All wire tracers were subsequently replaced with 6 mm chain tethers. Custom 35 mm diameter solid HDPE rods have been designed as a securing method for holding the ARM in place. These are cut to length, drilled and tapped to use as a locking nut (Figure 3). These can be tightened and loosened by hand and reduce the time required to census each ARM. If they become stuck a hole drilled through the top of the rod allows the diver to insert a screwdriver to lever it free.

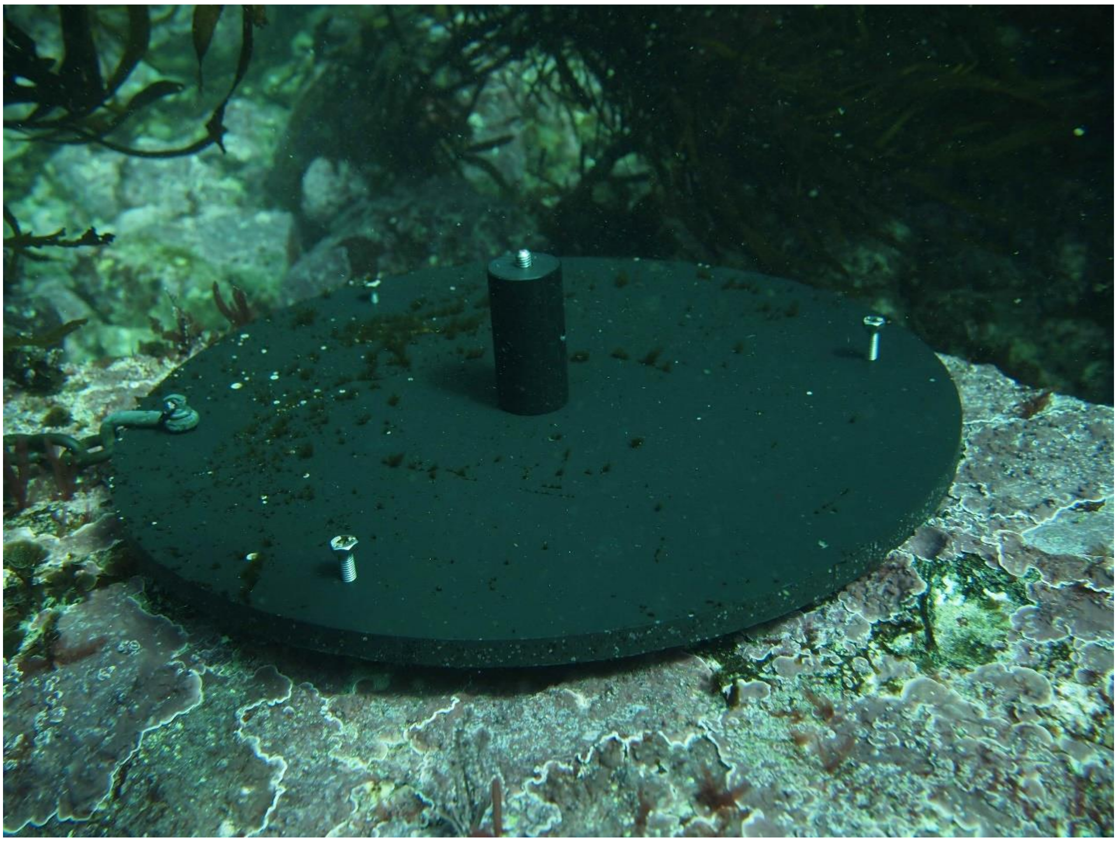

Figure 3. ARM with HDPE locking nut and three riser bolts on the perimeter. Lighter chain tether securing the plate to the main locating chain can be seen on the left.

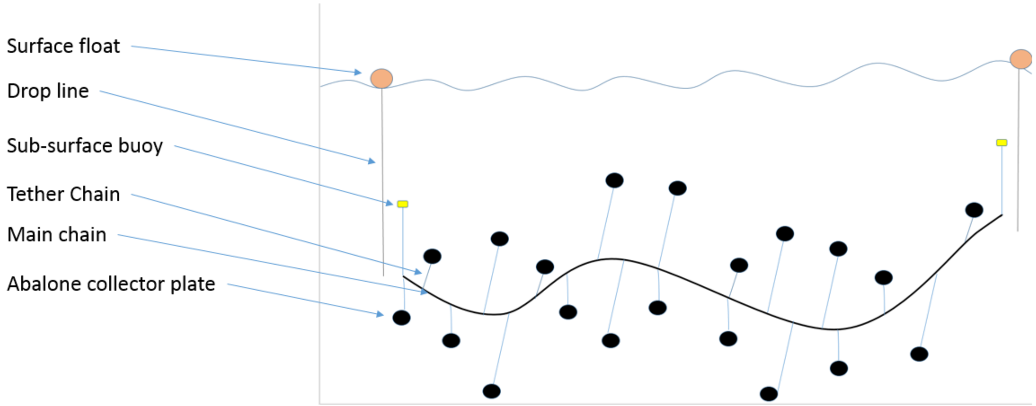

Figure 4. Plan view of central chain, tether chains, and ARMs deployed on a reef.

5.3 Data analysis

All data analyses were conducting using R (R-Core-Team 2017), and data summaries and figures prepared using dplyr (Wickham and Francois 2016) and ggplot2 (Wickham 2009) packages.

5.3.1 Testing of ARM performance

Development of a flexible method for setting collector height above the rock surface was key to allowing a single collector design to be used across the diversity of habitat types within the Tasmanian abalone fishery. The six locations selected for the collectors (Figure 5) incorporated three key habitats; large boulder reefs (The Gardens, Seymour and Black Reef Boulder), mixed low profile bottom (Betsey Island and George III Rock) and slab reef (Black Reef Slab). Geo-referenced fishery data was used to identify potential sites and where possible, ARMs were installed at areas of frequent commercial fishing activity to ensure the sites were representative of the fishery. At each of these sites, two strings with 20 replicate ARMs were installed between April 2015 and July 2015. The first survey of the ARMs post-installation varied depending on weather conditions. Following the second census, all sites were surveyed at four monthly intervals targeting specific periods of the year; Summer (February/March), Winter (July/August), and Spring (October November).

Abundance of juvenile abalone on ARMs were converted to abalone/m^2 to explore trends in mean abundance through time. Size frequency distributions (pooled across replicate strings at each site) were used to examine the size structure of abalone found on the ARMs. To determine if there were small-temporal scale variation in numbers of juvenile abalone using the ARMs as host habitat, variation in abalone abundance were examined over two days (08-09 Oct 2015) at Betsey Island and two weeks (25 Sep-08 Oct 2015) at Betsey Island and Black Reef Boulder and Slab sites (30 Sept-13 Oct 2015).

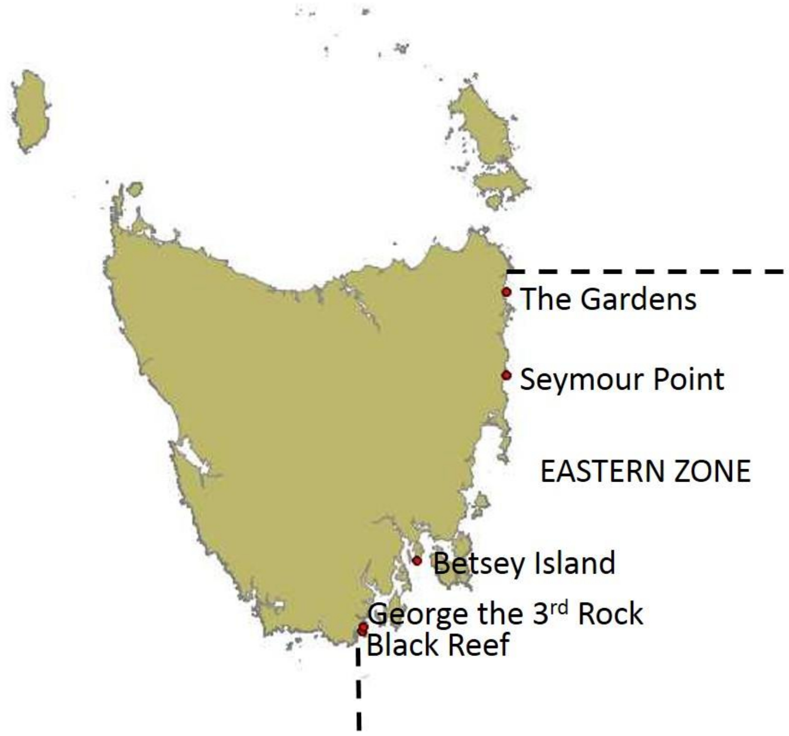

Figure 5. Sites where juvenile ARM strings were established across Tasmania's Eastern Zone Abalone Fishery (dashed lines). Each site consists of two strings of 20 ARMs. Black Reef consists of four strings spread across two habitat types (boulder and slab reef).

5.3.2 Within-site variation among replicate ARMs

By the end of the 2nd year of ARM surveys, it was apparent that at most sites some replicate ARMs had consistently low or high numbers of juvenile abalone. To examine within-site and temporal variation in juvenile abalone counts under replicate ARMs, the data were examined in two ways. Firstly, to determine if juvenile abalone counts were temporally correlated, a scatter plot matrix of abalone counts (< 100mm SL) across each census was done. Secondly, box plots of abalone counts on each replicate ARM were used to examine the median and range of abalone counts observed across the entire time-series (i.e. the different census periods were treated as observations).

5.3.3 Relationship between pre-emergent (juvenile) and post-emergent size classes

While abalone biological and behavioural characteristics suggest there should be a local stock-recruitment relationship, no such relationship has ever been demonstrated for haliotids. As part of this project permanent Fishery-independent survey (FIS) sites were established at the same locations where the ARMs are deployed, and where possible spanned the ARM strings. The FIS sampling program adopted the method developed in FRDC 2015/029 (Mundy et al. 2010). This design uses a 60 m long baseline transect marked by permanent SS ring bolts, with ten replicate 15 m x 1 m belt transects randomly located along the baseline. Randomised numbers (0 m to 59 m in 0.5 m increments) are used to determine the start position of the transect along the baseline and a randomised binary value (left/right) determined the direction of each 15 m belt transect perpendicular to the baseline. Sampling is non-destructive within the belt, and all abalone observed within the belt are measured to the nearest millimetre. Surveys were conducted on the same day as the ARMs are surveyed whenever possible.

Overall abundance of juvenile (data from ARMs), sub-legal abalone (FIS < 138 mm SL), and legal sized abalone (FIS >= 138m m SL) are compared at each site and sampling period to explore overall relationships between emergent and juvenile abalone abundance.

5.3.4 Validation of abalone counts found on ARMs

The bulk of the research described here focused on Objective 1. “Optimise collector module design for quantifying abundance of juvenile abalone across a range of habitat types”. Through Objectives 2 and 3 there was an intention to validate the counts of juvenile abalone under the ARMs, by rolling boulders at sites where that was feasible (Betsy Island, George III) and by comparison of expected juvenile abalone density based on population dynamic model output. With regard to the latter, it was proposed to match observed numbers of juvenile abalone under the ARMs with juvenile abundance derived from population dynamic models utilising local biological parameters and current catch and effort data. It now seems that approach would be fruitless given the strong effect of habitat complexity on juvenile abundance, and the absence of any relationship between juvenile abundance and the three parameters likely to drive a population dynamic model (FIS abundance, catch, CPUE). Assessment models also treat recruitment internally as residuals, and do not output numbers of recruits specifically and the models run at a larger geographic scale such as Zones or Blocks, without account for reef area. Deprived of an understanding of how much habitat of low, moderate, high complexity exist within potential model regions, it would be misleading to attempt to link model outputs to actual juvenile abundance data at isolated local sites. Further inhibiting modeI based calculations is that large spatial differences in abundances under the plates exist between locations with similar habitat complexities suggesting that using habitat complexity as a single additional factor within a model would be insufficient to define recruitment.

Determining abalone abundance by rolling boulders to quantify the cryptic population has been demonstrated to be effective in southern Tasmania (Prince et al. 1987). Here we trialled the method adjacent to the ARM strings at two sites (Betsey Island and George III) in November 2015. At each end of the string of ARMs, five replicate 2 m x 2 m lead weighted rope quadrats were randomly sampled, giving *n* = 10 replicates at each site. Within each quadrat, divers searched all crevices and cracks for abalone and when this was completed, all boulders that could be moved were rolled using a crowbar to expose any further animals. Shell length of animals was binned into 10 mm groupings. Box plots were used to compare median size and size structure of samples collected from the quadrats with samples from the ARMs at the same time period.

5.3.5 Power of sampling design to detect change in recruit density

Abundance of abalone at local scales is often highly patchy leading to large variation among replicate quadrats or transects within a site. This study commenced with a relatively high sample size (n= 20) to ensure that the extent of small-scale variation in recruit abundance was captured, and to avoid the bias associated with chance location of ARMs in very good or very poor locations that can affect studies with small sample size. Effect Size (Greenland et al. 2016) was calculated in two forms; Cohen's D to provide a comparison across locations and Minimum Detectable Difference (Brock et al. 2015) to determine the effect of changing sample size *n* on capacity to detect difference between two means. Cohen's D was calculated using the effsize package (Torchiano 2017).

6 Results

Installation of the final design HDPE circular flat disk ARMs was straight forward in all habitats, and the improved HDPE locking nut assembly enabled easy removal of the plate without tools (Figure 3). Using the final ARM design, the 20 ARMs on each string could be removed and replaced in approximately one hour by a team of two divers. The exact time required was dependent on juvenile abalone numbers under each ARM (Figure 6), with handling and measuring time correlated with the number of juveniles. The anchoring system proved robust to sever weather conditions, with around 15 % of plates dislodged at the Seymour Point and The Gardens locations during a 1 in 100 year storm that affected the Tasmanian east coast in mid-2016 (Figure 7).

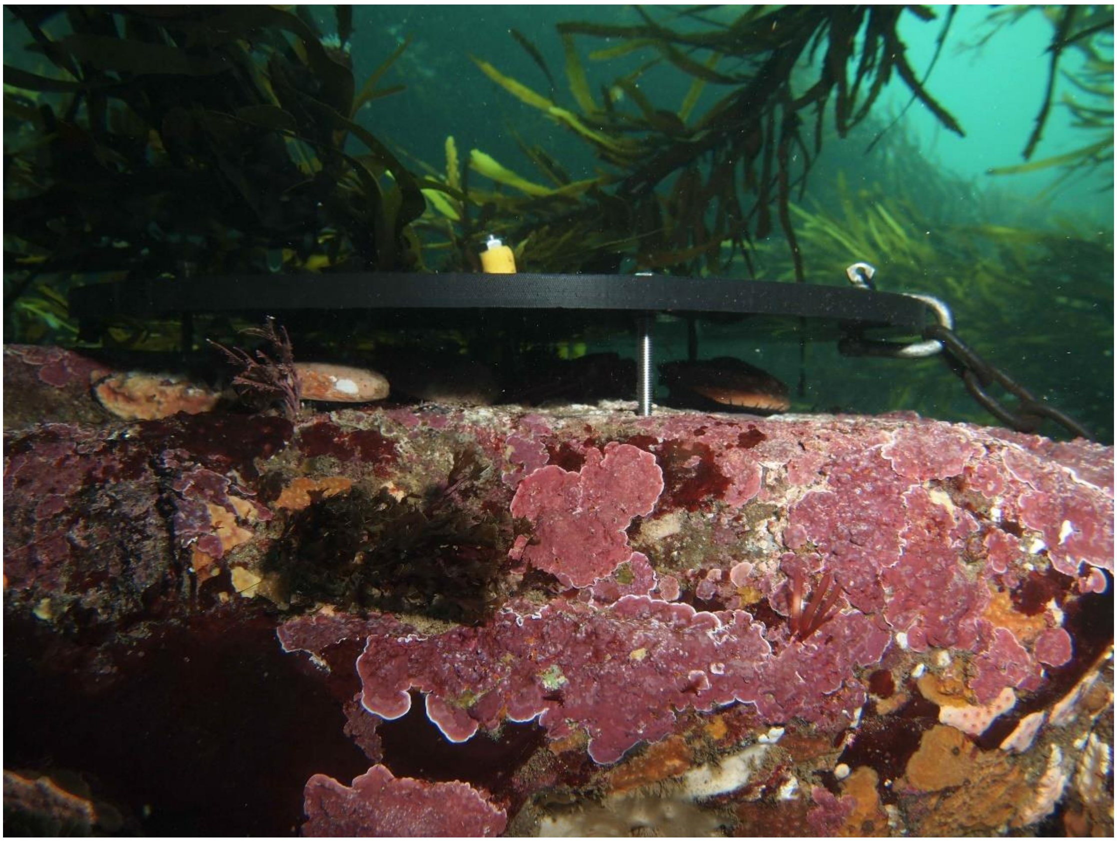

Figure 6. ARM at Black Reef Boulder location.

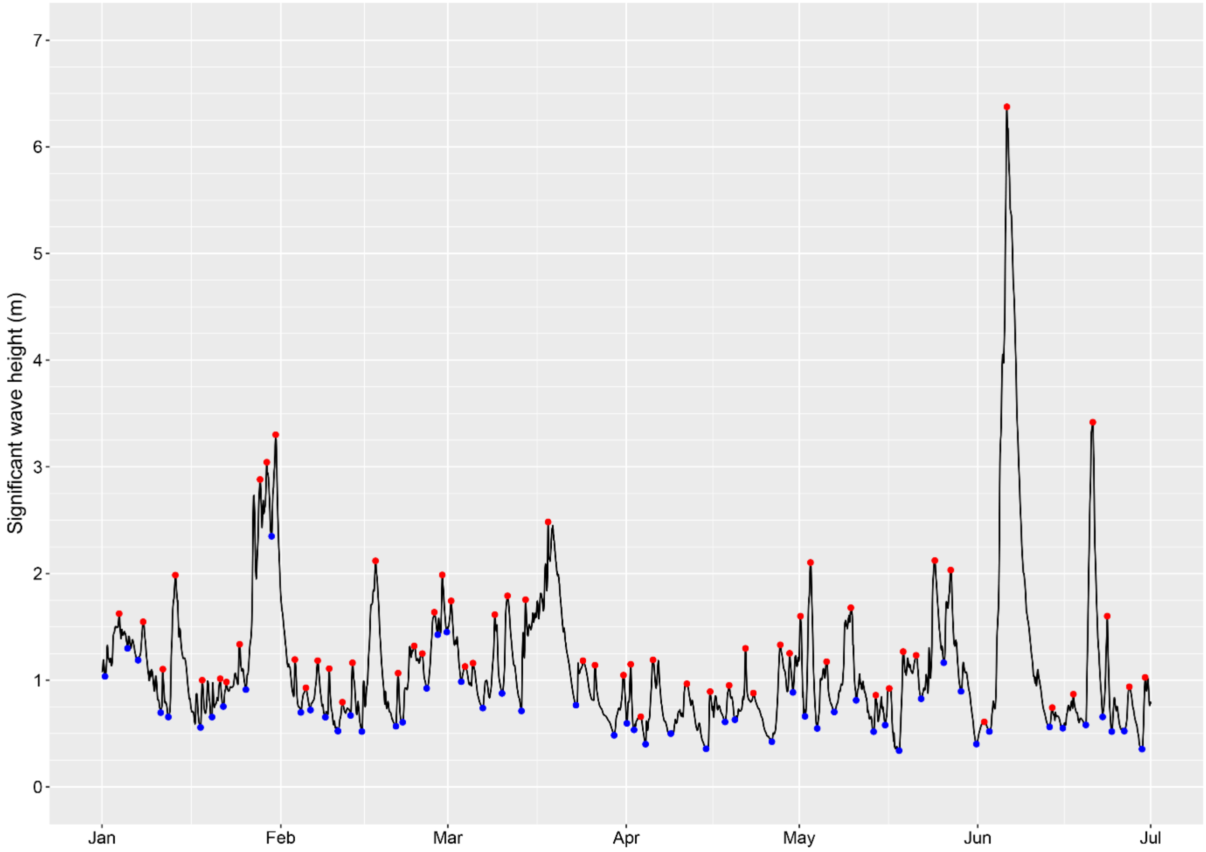

Figure 7. Significant wave height (hs) from Cape Lodi south of Bicheno (East Coast Tasmania), January to July 2016. The peak hs of 6.37 m in June 2016 is the largest wave height for this location in the hindcast reanalysis dataset spanning 1979 to 2016 produced by the Bureau of Meterology (Durrant and Greenslade 2011).

6.1 Evaluating ARM performance

Occupation of the ARMs by juvenile abalone was initially slow, with mean abundance increasing over the first six months and stabilising after around 15 months (Figure 8). The exception to this pattern was at Betsey Island where juvenile abalone occupied the ARMs prior to the first census and were of a similar size structure to those found on later surveys (Figure 9). The modal size class of abalone found on the ARMs was typically 40 mm to 50 mm shell length (SL), with very few abalone larger than 100 mm recorded. Very small animals (less than 20 mm SL) were also observed (Figure 10), and were occasionally very abundant, for example at Black Reef Slab in Winter 2016 (Figure 9). No pattern to the shape of the size structure is immediately evident from the size-frequency histograms, but this may be explored in more detail at a later date through modal progression analyses. The size range of juvenile abalone occupying the ARMs addresses the size band where FIS routinely provide little or incomplete information (10 mm SL to 100 mm SL). In this regard the ARMs designed during this project deliver exactly the information desired from a program seeking to quantify abundance and size of cryptic phase abalone.

The highest density of juvenile abalone found on ARMs (~ 8 to 12 abalone/m^2) was found at Black Reef Slab which has the lowest habitat complexity of all study sites (Figure 11). Sites with medium (low profile reef, small boulders) and high complexity (high profile, medium – large boulders) habitat had variable populations of juvenile abalone, but never as high as the slab habitat at Black Reef. Among the sites with complex habitat and larger boulder structure, overall density of abalone found on the ARMs reflects stock status, with higher catch and catch rates observed at Black Reef (Block 14) and declining catch and catch rates at Seymour Point (Block 29) and The Gardens (Block 30) (Mundy and Jones 2017).

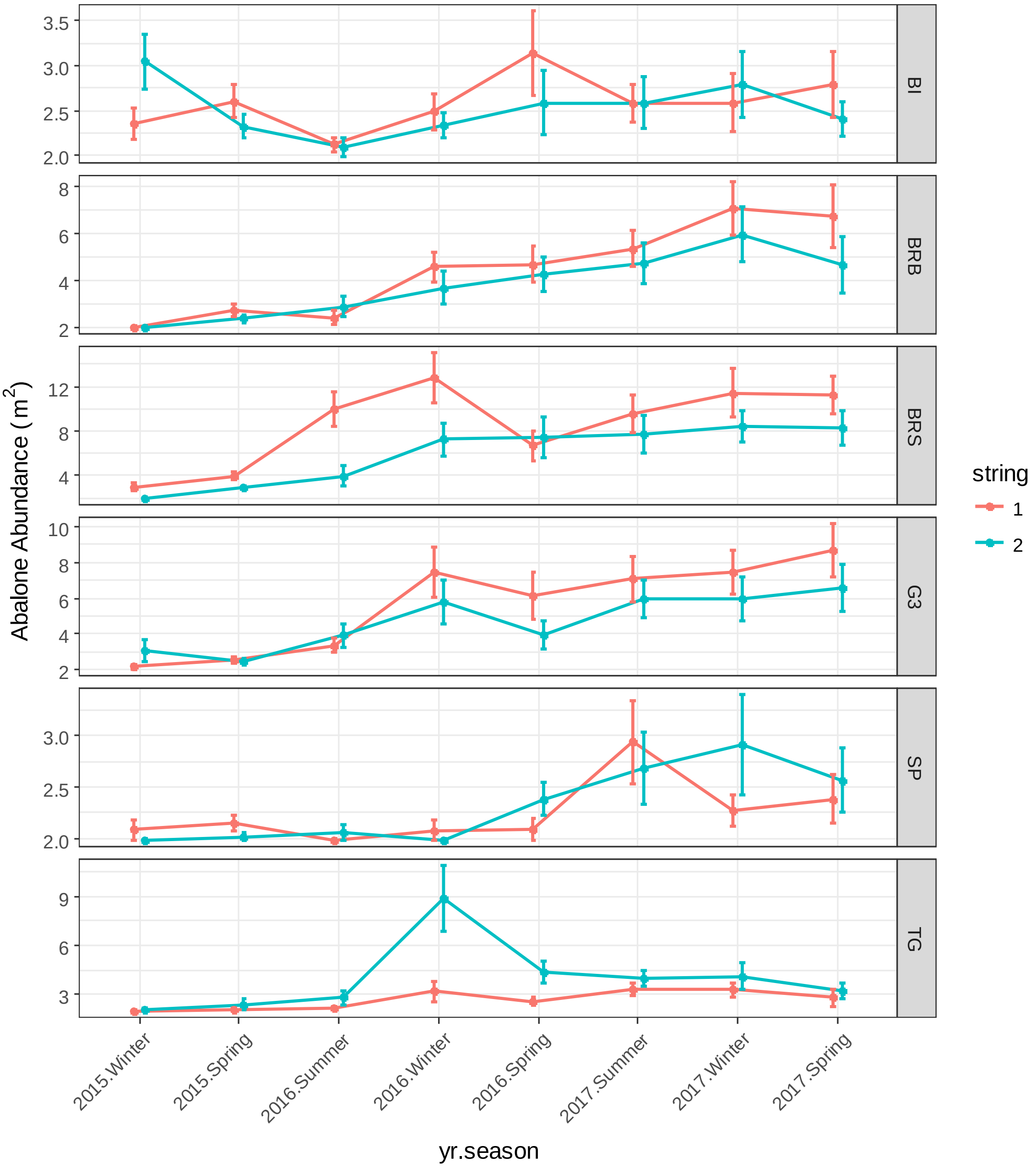

Figure 8. Mean density (m^2) of abalone (+- SE) on ARMs across eight sampling periods and six sites. Each ARM has a planar surface area of 0.503m^2. (BI = Betsy Island, BRB = Black Reef Boulder, BRS = Black Reef Slab, G3 = George III, SP = Seymour Point, TG = The Gardens). Note: mean density/ARM of 2 abalone/m^2 is approximately equal to a mean count of 1 abalone/ARM). Replicate strings (sub-sites) coded by colour.

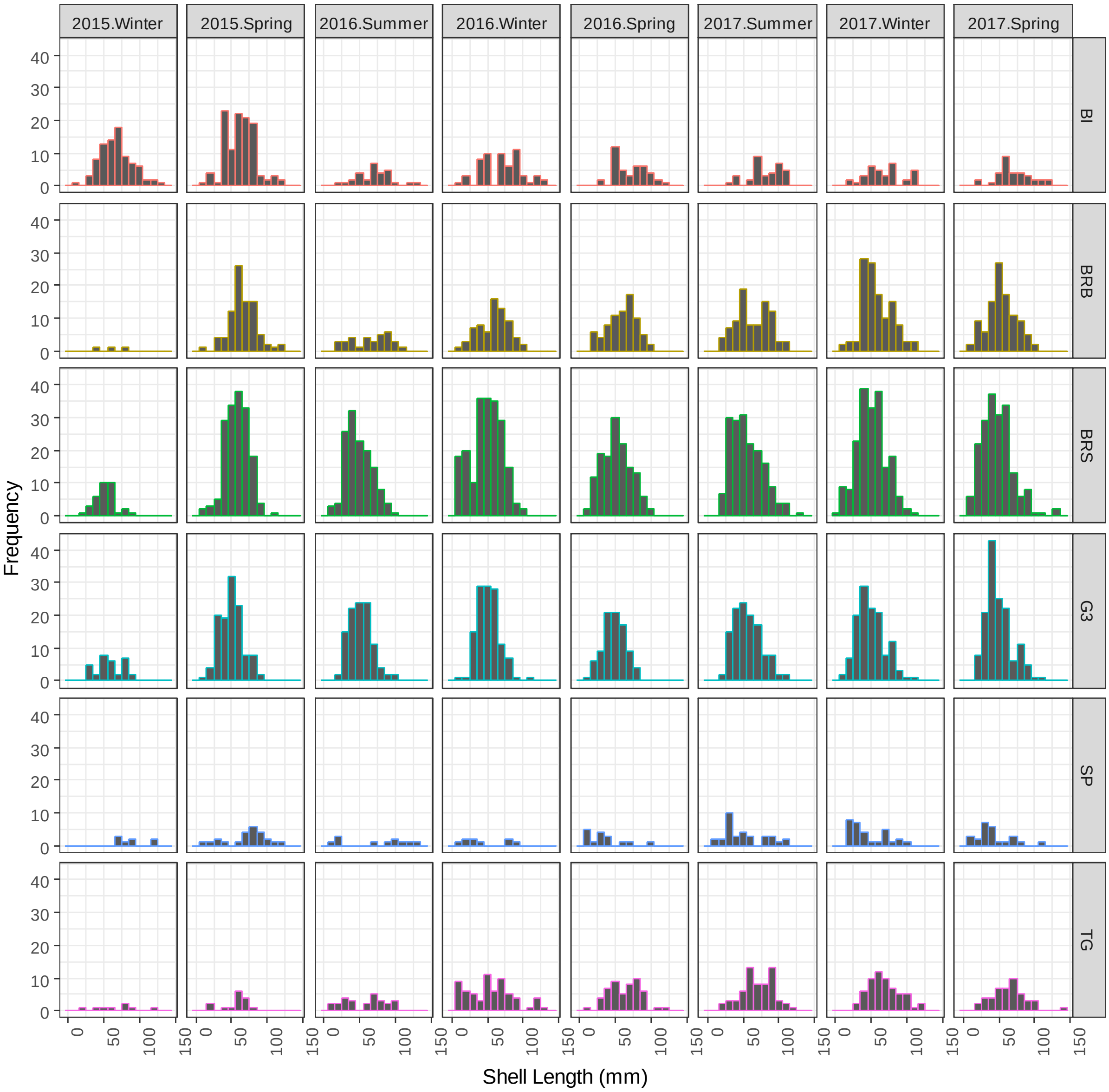

Figure 9. Size frequency of juvenile abalone recorded underneath ARMs at each of eight sampling periods across six sites. (BI = Betsy Island, BRB = Black Reef Boulder, BRS = Black Reef Slab, G3 = George III, SP = Seymour Point, TG = The Gardens).

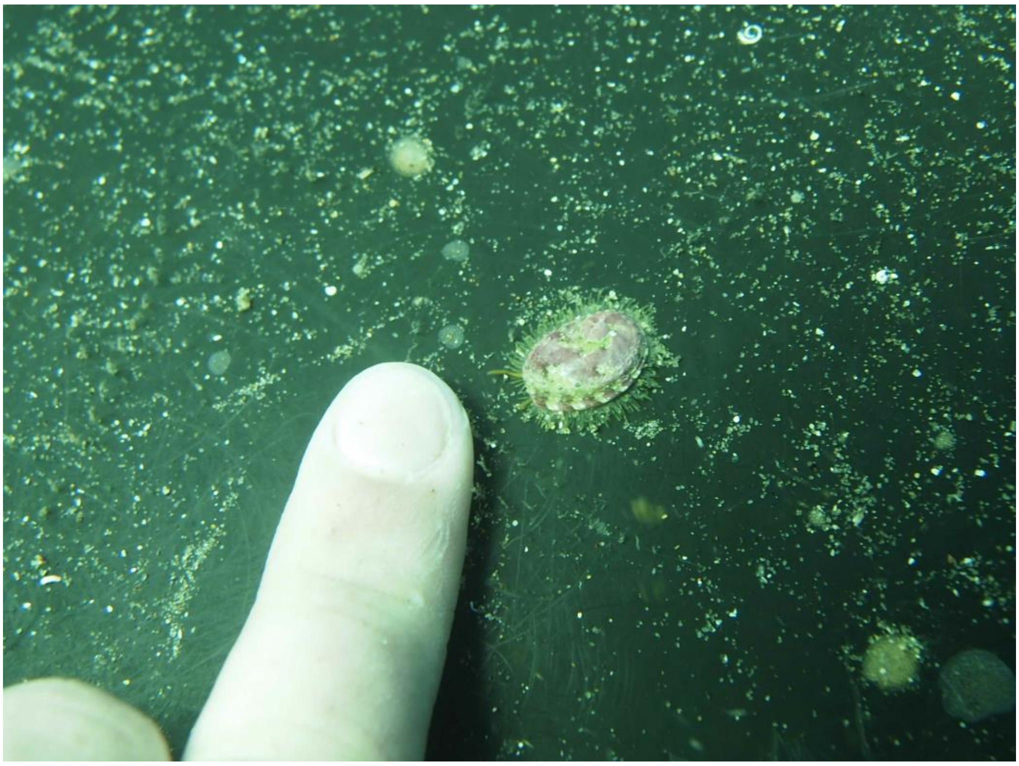

Figure 10. Small juvenile blacklip abalone (~ 10 mm) found on an ARM at Betsey Island.

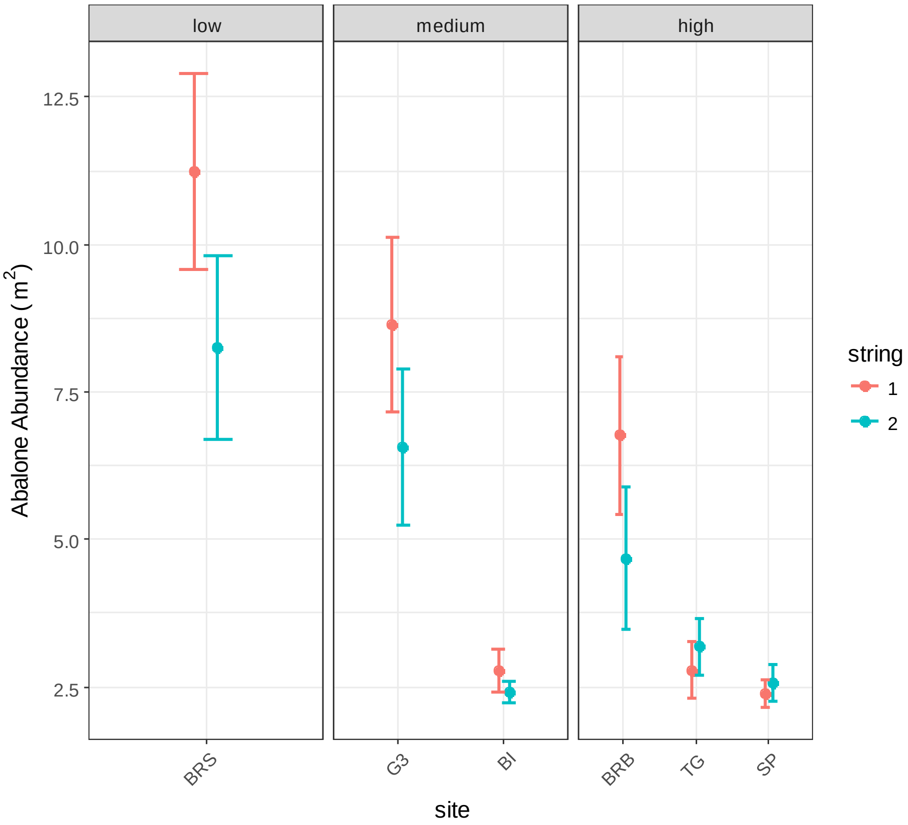

Figure 11. Mean density (m^2) of abalone on ARMS by site grouped into different levels of habitat complexity at the final survey in Spring 2017. Replicate strings (sub-sites) coded by colour.

6.2 Within-site variation among replicate ARMs

Relatively high levels of variation in juvenile abundance among individual ARMs was observed at most sites. Anecdotal evidence of short-time frame (days/weeks) movement of juvenile abalone on small spatial scales (metres to 10s of metres), and patchy abundance at similar spatial scales could explain the level of variation observed. Alternatively, choice of where an ARM was installed, or, characteristics of individual ARMs may affect the number of juvenile abalone occupying an ARM. If the variation was entirely random, with no consistent pattern through time, then it may be inferred that the variation within sampling periods was a function of local scale movement dynamics of juvenile abalone.

Individual ARMs are installed within 2 m of the main locating chain line, and on what appears to the diver to be a suitable location. Mid-way through the project it became apparent that at each site there were individual ARMs that appeared to have consistently high or low numbers of juveniles. Inter-survey correlation of juvenile numbers on ARMS suggested some level of correlation of juvenile abalone on individual ARMs was present among sequential sampling events (Figure 12, Figure 13). However, when the performance (median, range) of individual ARMs over the duration of the study is considered, there is clear evidence that several ARMs consistently have very low counts (0 or 1) of juvenile abalone (Figure 14, Figure 15). There did not appear to be any individual ARMs that consistently had very high counts of juvenile abalone, although using Black Reef Slab and George III Rock as an example, the top five of the 20 replicate ARMs at these sites had high median counts, and rarely had low counts suggesting either the ARM or the ARM location was more attractive to juvenile abalone (Figure 14, Figure 15).

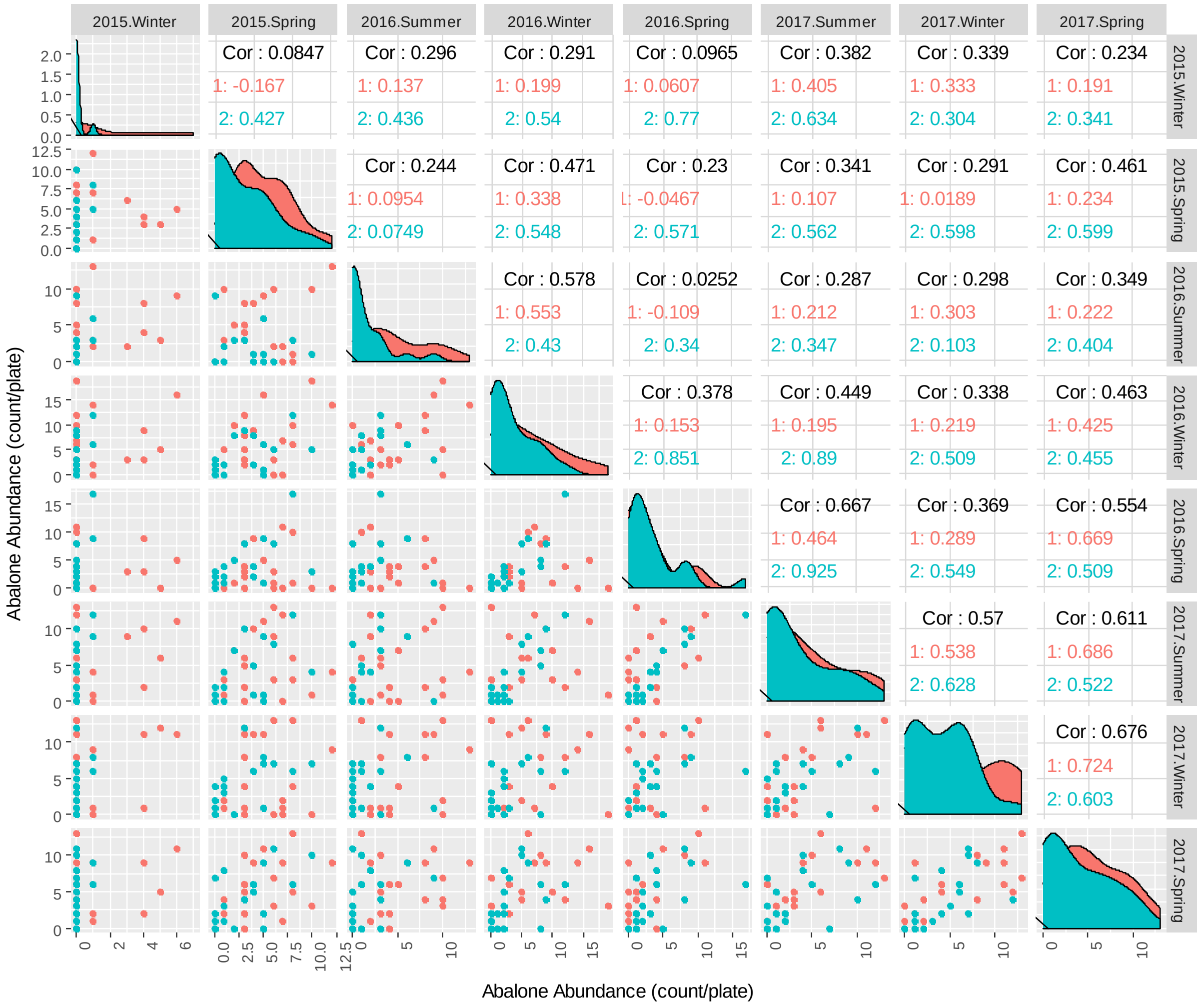

Figure 12. Scatterplot matrix of juvenile abalone count/plate on individual ARMs across sampling events at the low complexity Black Reef Slab site. Colour code (red/blue) indicates replicate strings (1, 2) within each location. Higher levels of correlation were occasionally observed among adjacent sampling events (e.g. Winter 2017 vs Spring 2017).

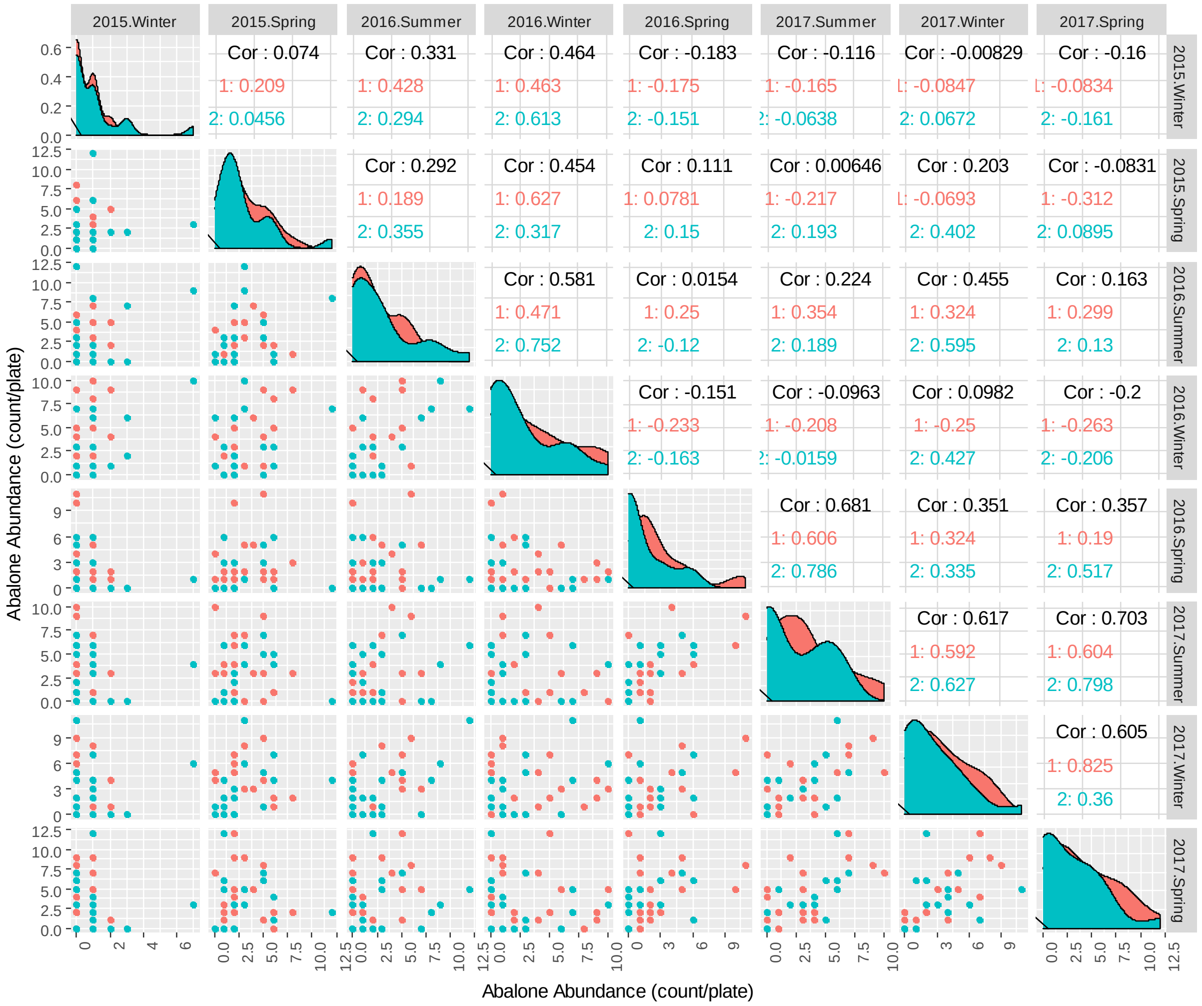

Figure 13. Scatterplot matrix of juvenile abalone count/plate across sampling events at the medium complexity low profile reef on George III Rock. Colour code (red/blue) indicates replicate strings (1, 2) within each location.

6.2.1 Individual ARM performance

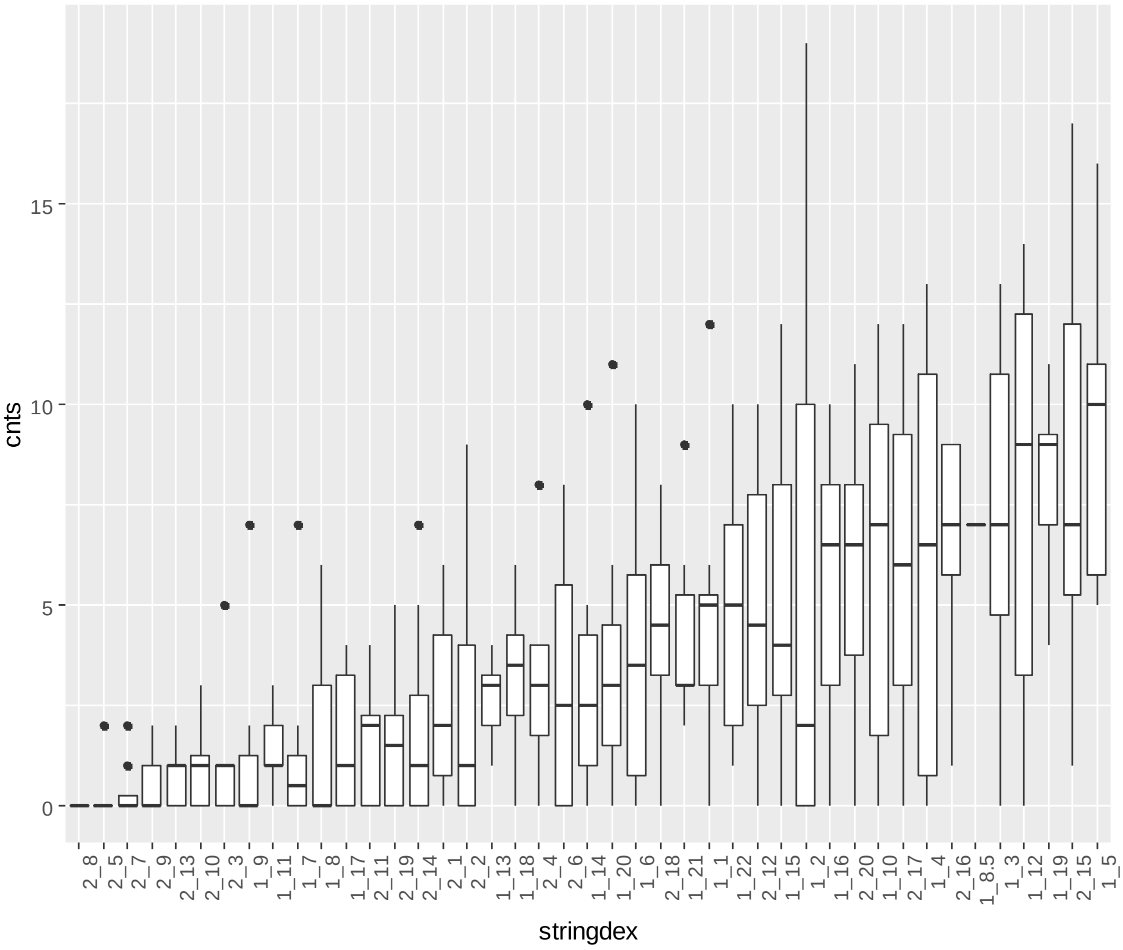

Figure 14. Range of juvenile abalone counts on individual ARMs at Black Reef Slab across the sampling period. Each boxplot summarises data from the eight sampling events.

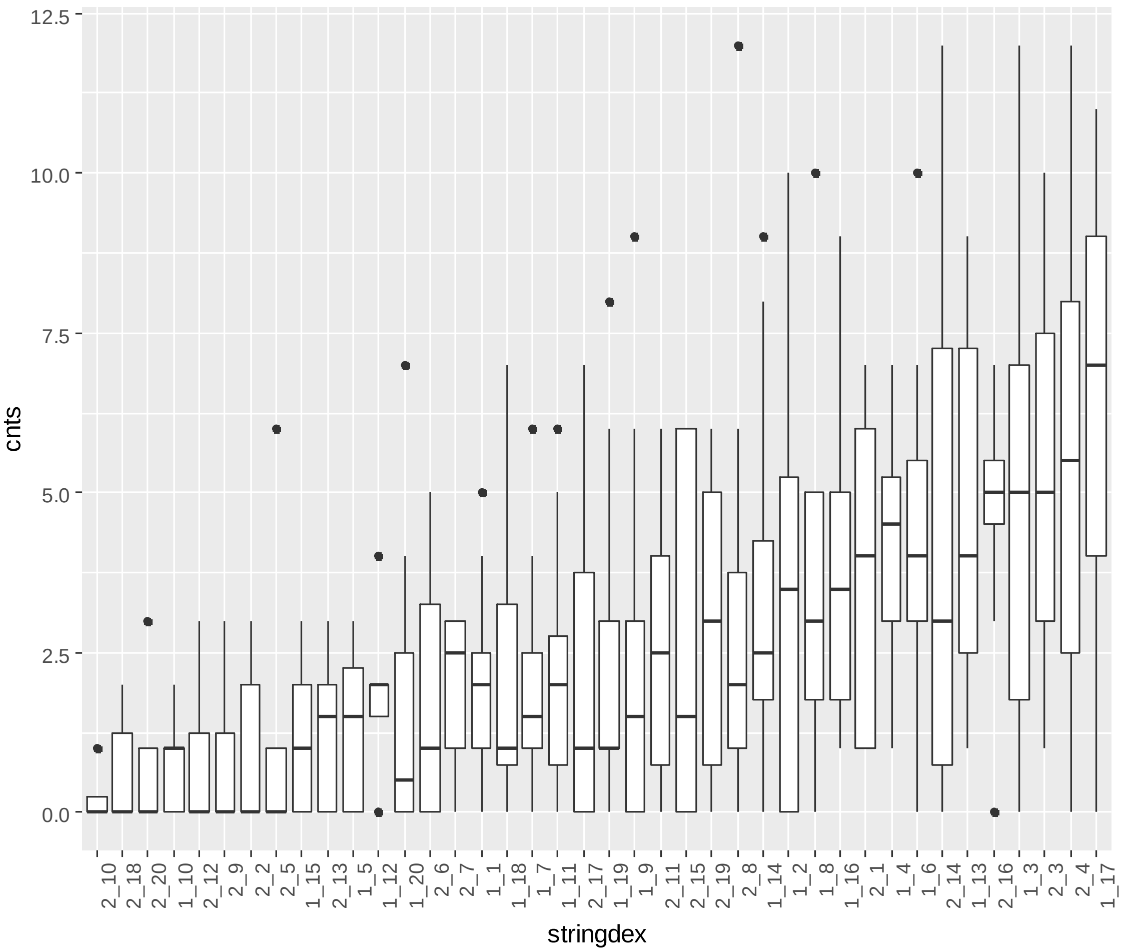

Figure 15. Range of juvenile abalone counts on individual ARMs at George III Rock across the sampling period. Each boxplot summarises data from the eight sampling events.

6.3 Validation of ARM results using the boulder rolling method

A total of 19 and 81 abalone were found in the cryptic space under boulders at Betsey Island and George III respectively. This equates to overall density of 0.475 abalone/m^2 at Betsey Island and 2.025 abalone/m^2 at George III. The density of cryptic abalone observed by rolling boulders at both sites was lower than density estimates obtained from the ARMs. At Betsey Island the boulder rolling method returned densities more than 75 % lower than the abalone density observed under the ARMs at the same time period, whereas at George III boulder rolling achieved densities that were lower but more comparable with abalone densities estimated from the ARMs (Figure 16).

Size structure of abalone found in the cryptic space under boulders was larger and more spatially variable than the size structure of abalone found under ARMs. At Betsey Island, the median abalone size at the two sub-sites was 105 mm and 85 mm (Figure 17), compared to 62.5 mm under the ARMs, while at George III the median size at the two sub-sites was 105 mm and 50 mm compared to 49 mm under the ARMs.

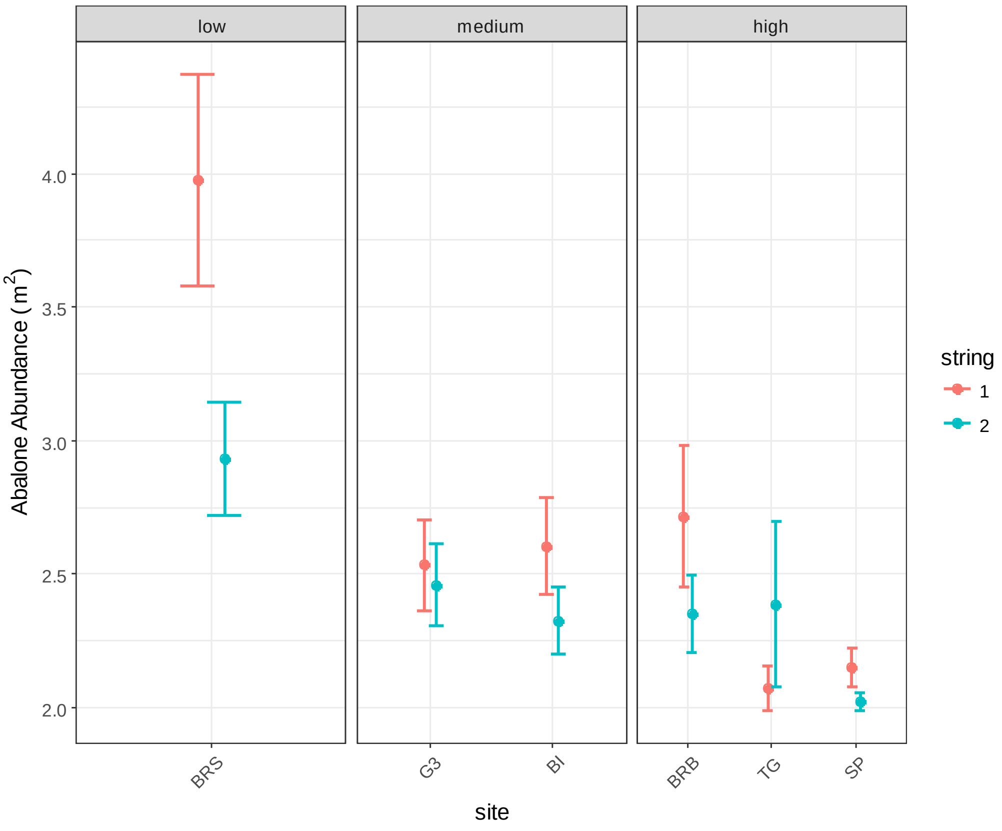

Figure 16. Juvenile abalone density on ARMs in Spring 2015.

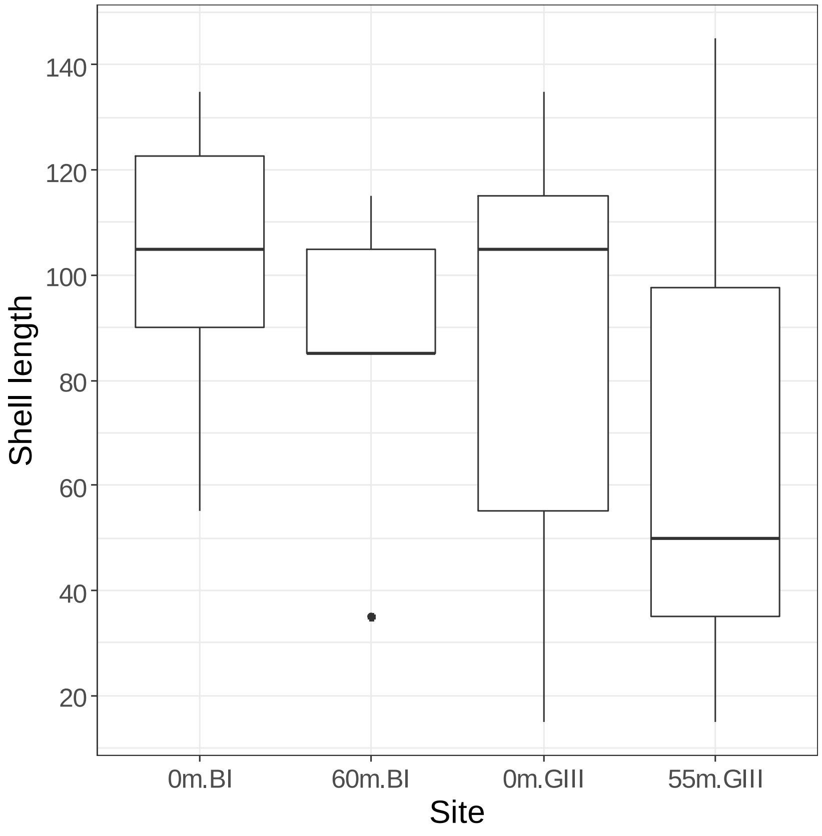

Figure 17. Size structure of abalone recorded during the boulder rolling surveys at Betsey Island (BI) and George III (GIII) reef. Solid bar indicates the sample median, boxes indicate the 25th and 75th percentiles. Sub-sites were examined at either end of the fishery independent survey sites (0 m and 55 m/60 m), and

were kept separate from the areas where the ARMs were deployed so that there was no impact on the ARM time-series associated with the destructive sampling.

6.4 Relationship between cryptic (juvenile) and post-emergent size classes

Stock recruitment relationships have never been convincingly demonstrated in commercially abalone fisheries, perhaps with the exception of Prince et al. (1987). Over the duration of this study, IMAS conducted a Fishery Independent Survey (FIS) as a companion project to the FRDC funded development of the ARM system. Betsey Island had the lowest abalone abundance on the transect surveys (Figure 18) and lowest abundance of juvenile abalone on ARMs (Figure 8). George III Rock had similar high density (per m^2) of juvenile abalone on ARMS to the two Black Reef sites, but much lower density (per m^2) of abalone on the FIS transects (Figure 8, Figure 18).

In terms of overall abundance of juvenile, sub-adult (< 138 mm SL) and adult (>= 138 mm SL) at each site, very little relationship was found between juvenile density and either sub-adult or adult density (Figure 19). The density of legal sized abalone (> 138 mm SL) observed on FIS transects could be considered as a proxy for reproductive biomass, and we might expect a relationship between the density of reproductive abalone at time t, and the density of small juveniles (< 40mm SL) 12 to 24 months later. There was no evidence of a lagged association between reproductive abalone density and juvenile adult density within the small dataset obtained to-date (Figure 20).

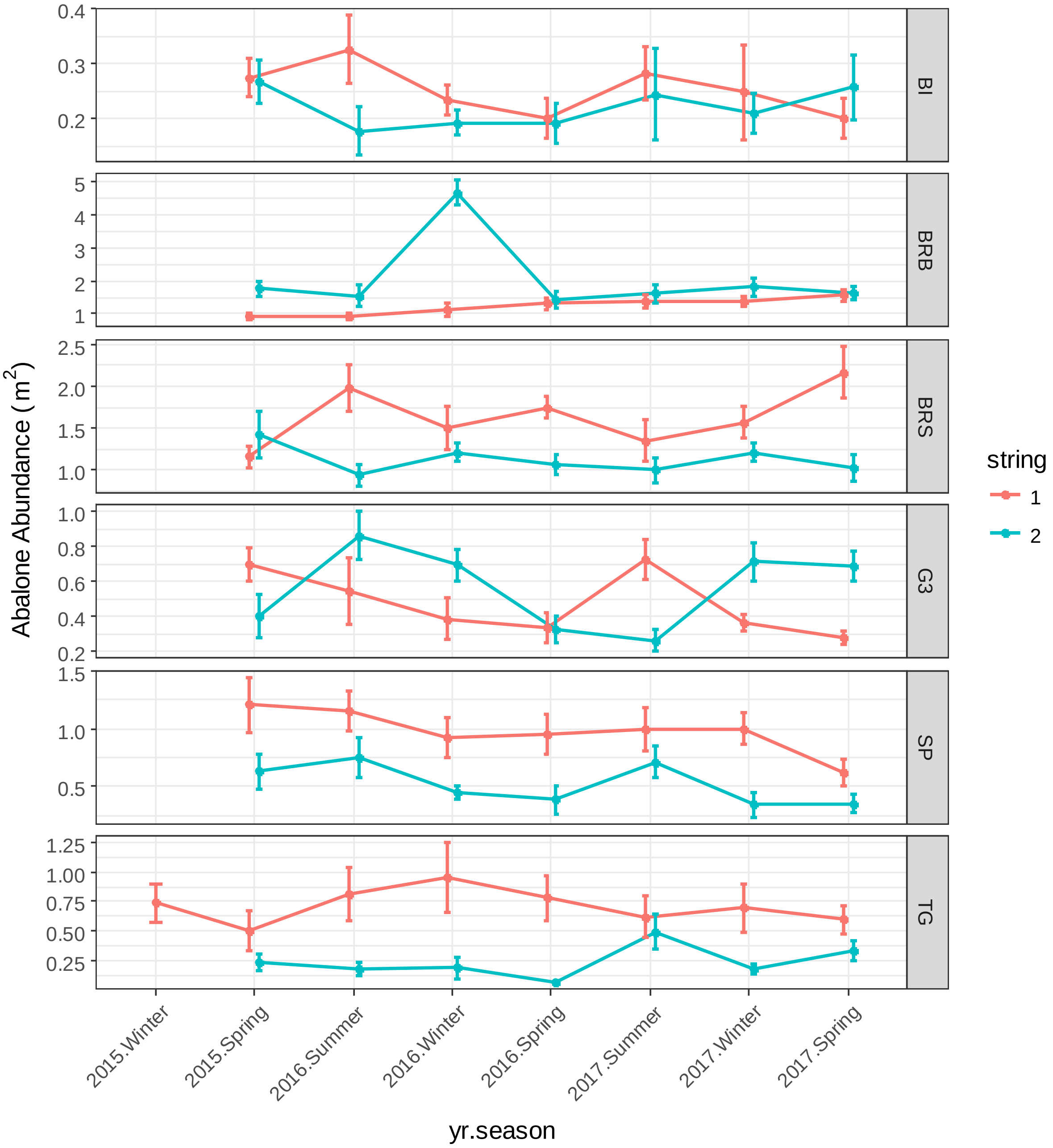

Figure 18. Mean density (m^2) of abalone (+- SE) from fishery-independent surveys across eight sampling periods and six sites (BI = Betsy Island, BRB = Black Reef Boulder, BRS = Black Reef Slab, G3 = George III, SP = Seymour Point, TG = The Gardens).

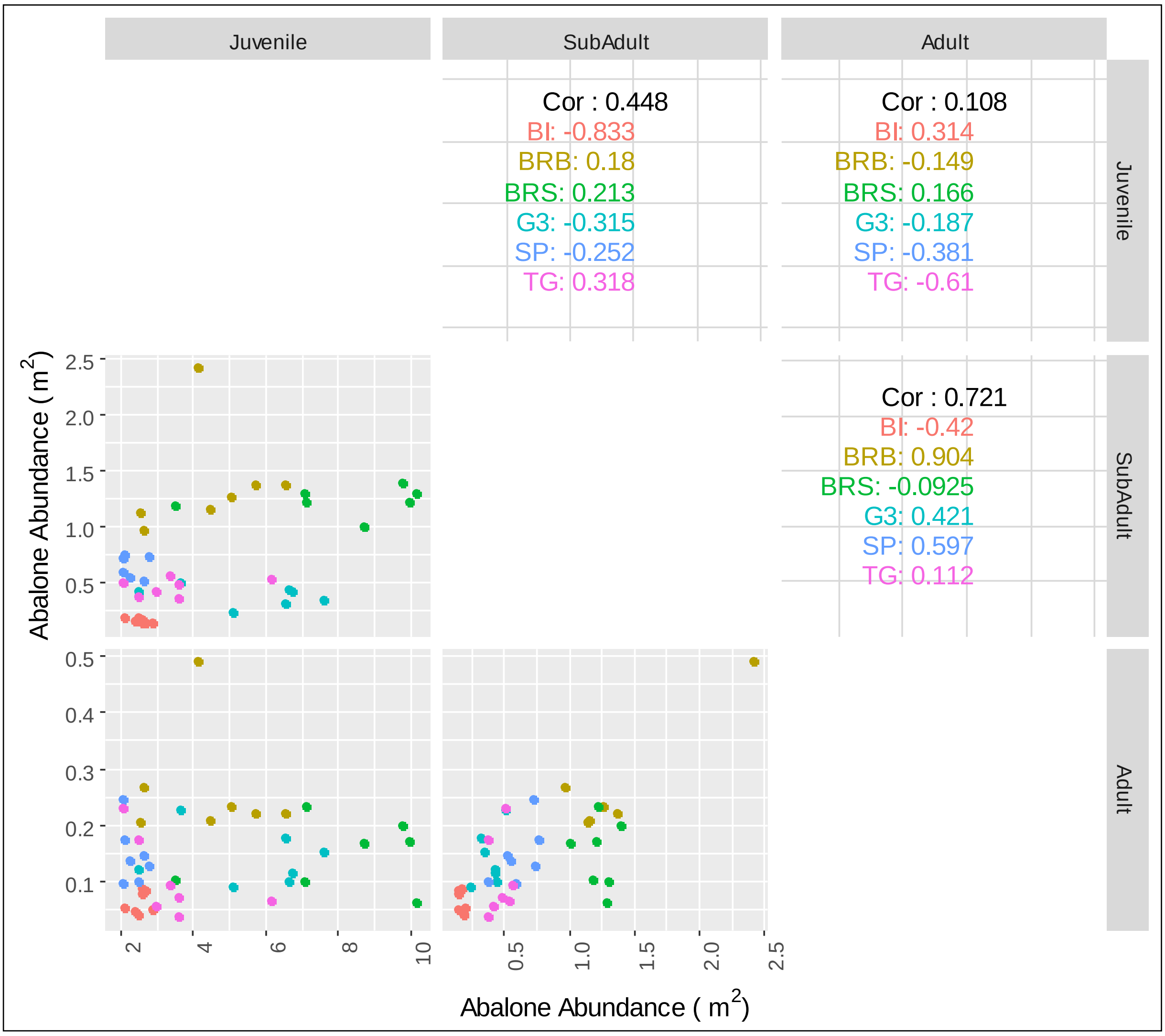

Figure 19. Relationship between abundance of juvenile (ARM data), sub-adult (FIS data) and adult (FIS data) abalone at each of the six study locations. Juvenile data are from the ARMs, while sub-adult and adult abalone are from the Fishery Independent Surveys using belt transects. Sub-adults are smaller than the Legal Minimum Length (LML) (< 138 mm SL), and adults are above the LML. Sites are colour coded (BI = Betsy Island, BRB = Black Reef Boulder, BRS = Black Reef Slab, G3 = George III, SP == Seymour Point, TG = The Gardens). Multiple dots of a single colour represent different sampling events at a location.

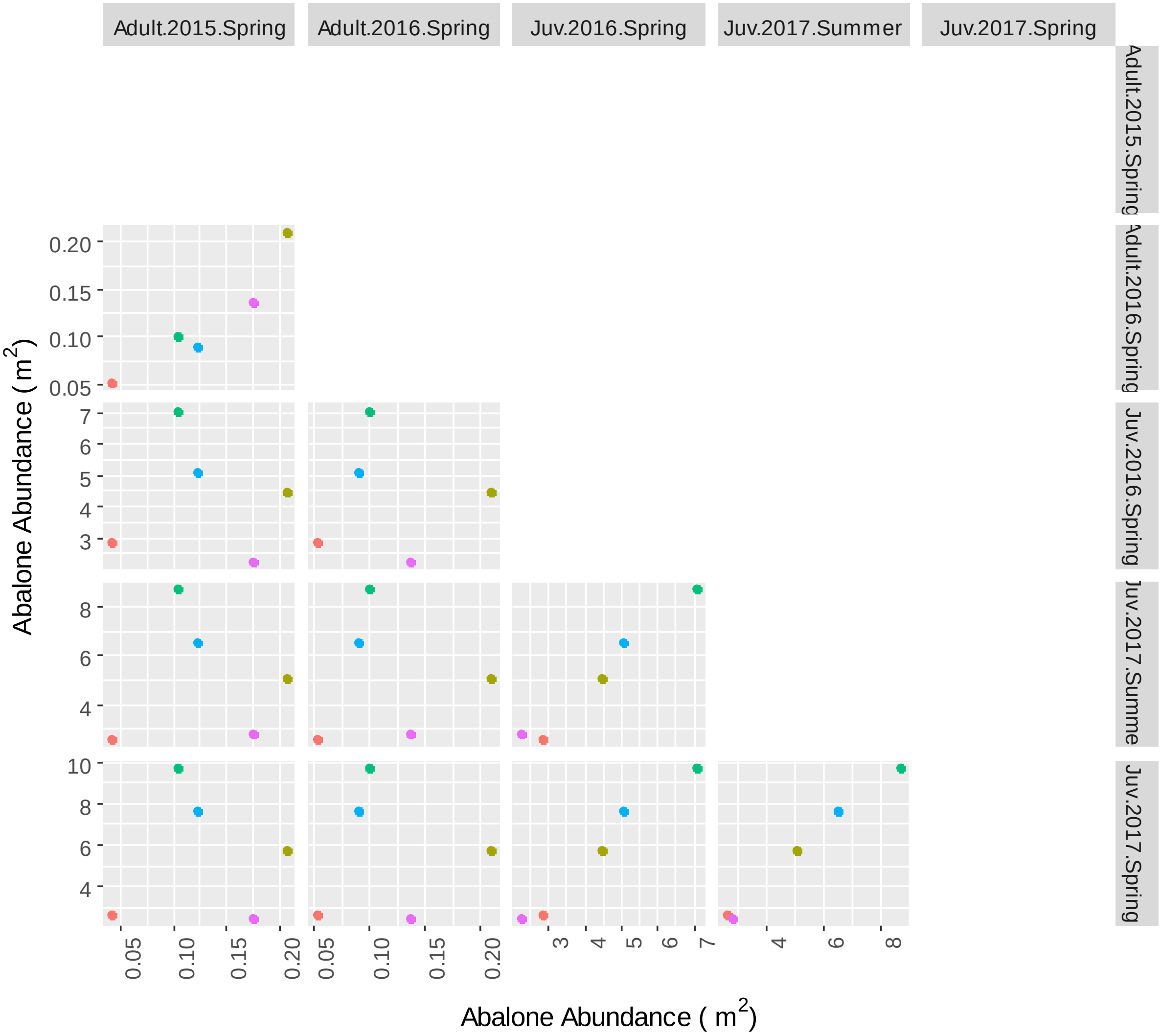

Figure 20. Lagged association between abundance of legal sized (> = 138 mm SL) animals (2015 Spring, 2016 Spring) and abundance of juveniles <= 40 mm SL (2016 Spring, 2017 Summer, 2017 Spring). Sites are colour coded. A positive association is evident between years for adult abalone and between years for juveniles, but not between adults and juveniles.

6.5 Different patterns observed in time-series of juvenile, sub-adult and adult abalone

A severe marine heat wave (MHW) affected the East coast of Tasmania over the summer of 2015/2016 (Oliver et al. 2017), with low-levels of mortality observed primarily in the south-east. Several months after the MHW ended (April 2016), a severe storm hit Tasmania’s eastern coastline, with peak swells arriving from the north-east. If the MHW or the storm contributed to increased abalone mortality we may expect to see a decline in abalone abundance in the time-series from Winter 2016 onwards. An obvious decline in abundance of legal sized abalone (>= 138 mm SL) in transect surveys was recorded in Winter 2016 (Figure 21), whereas no such decline was evident in the sub-adult size classes (Figure 22) or the juvenile size classes observed on the ARMs (Figure 8). At George III Rock and Black Reef Slab density of juveniles on ARMs increased over the same period that larger adults declined (Figure 8, Figure 21). These contrasting patterns in time-series suggest key environmental factors may impact differentially on cryptic and emergent abalone. An alternate explanation for the drop in density of legal sized abalone in Winter 2016 coincident with the MHW and the severe storm, is that the environmental impacts were not responsible for that decline and the observed trend represents a decline in density associated with fishing pressure and/or recruitment failure drive by events 6 – 8 year earlier. However, as the same downturn was observed in the George III Rock no-take abalone research reserve as the adjacent fished sites at Black Reef, impacts from acute environmental events may be more likely assuming local recruitment dynamics (Miller et al. 2009).

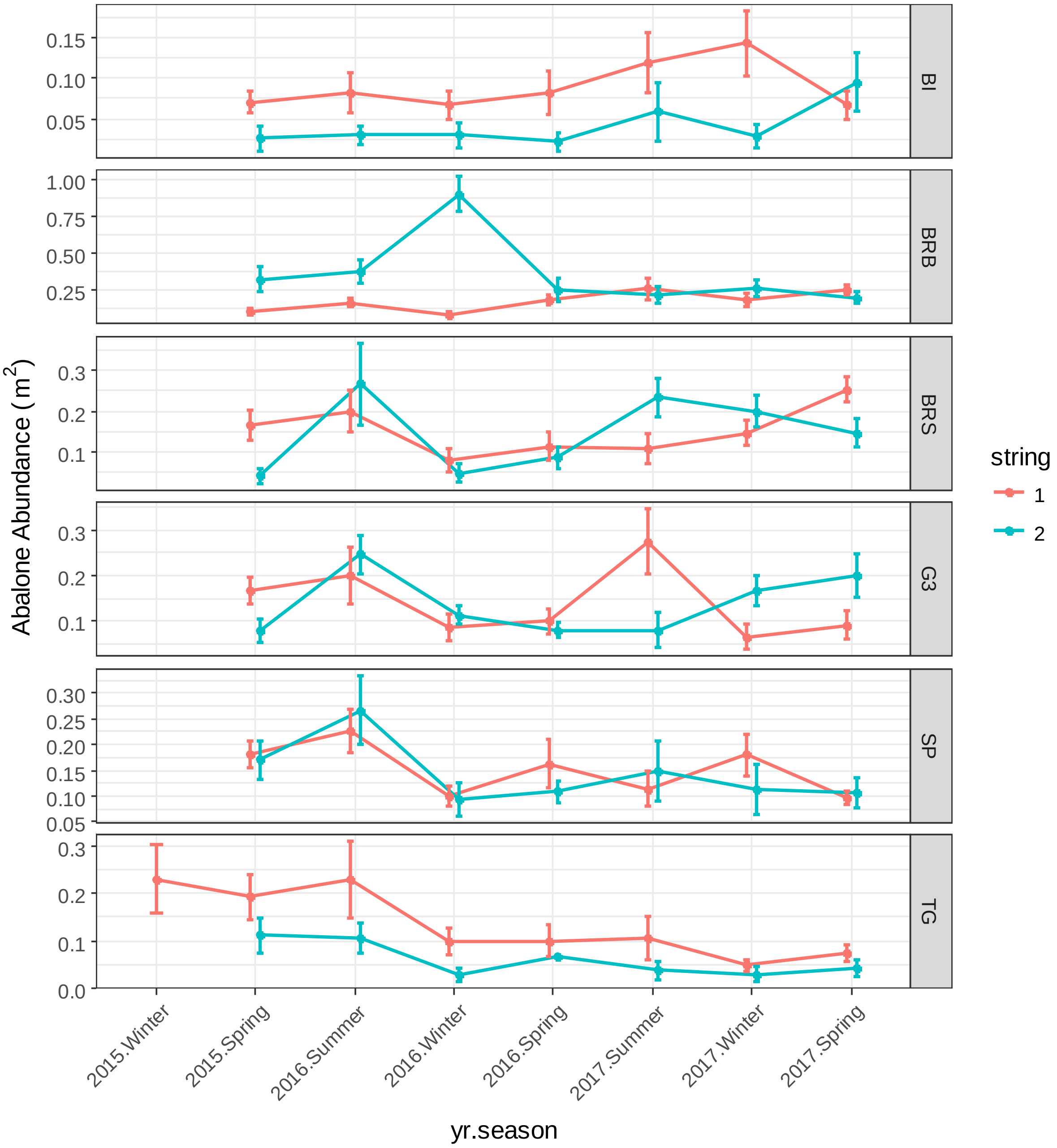

Figure 21. Mean density (m^2) (+- SE) of legal sized abalone (>= 138 mm SL) from fishery-independent surveys across eight sampling periods and six sites (BI = Betsy Island, BRB = Black Reef Boulder, BRS = Black Reef Slab, G3 = George III, SP = Seymour Point, TG = The Gardens).

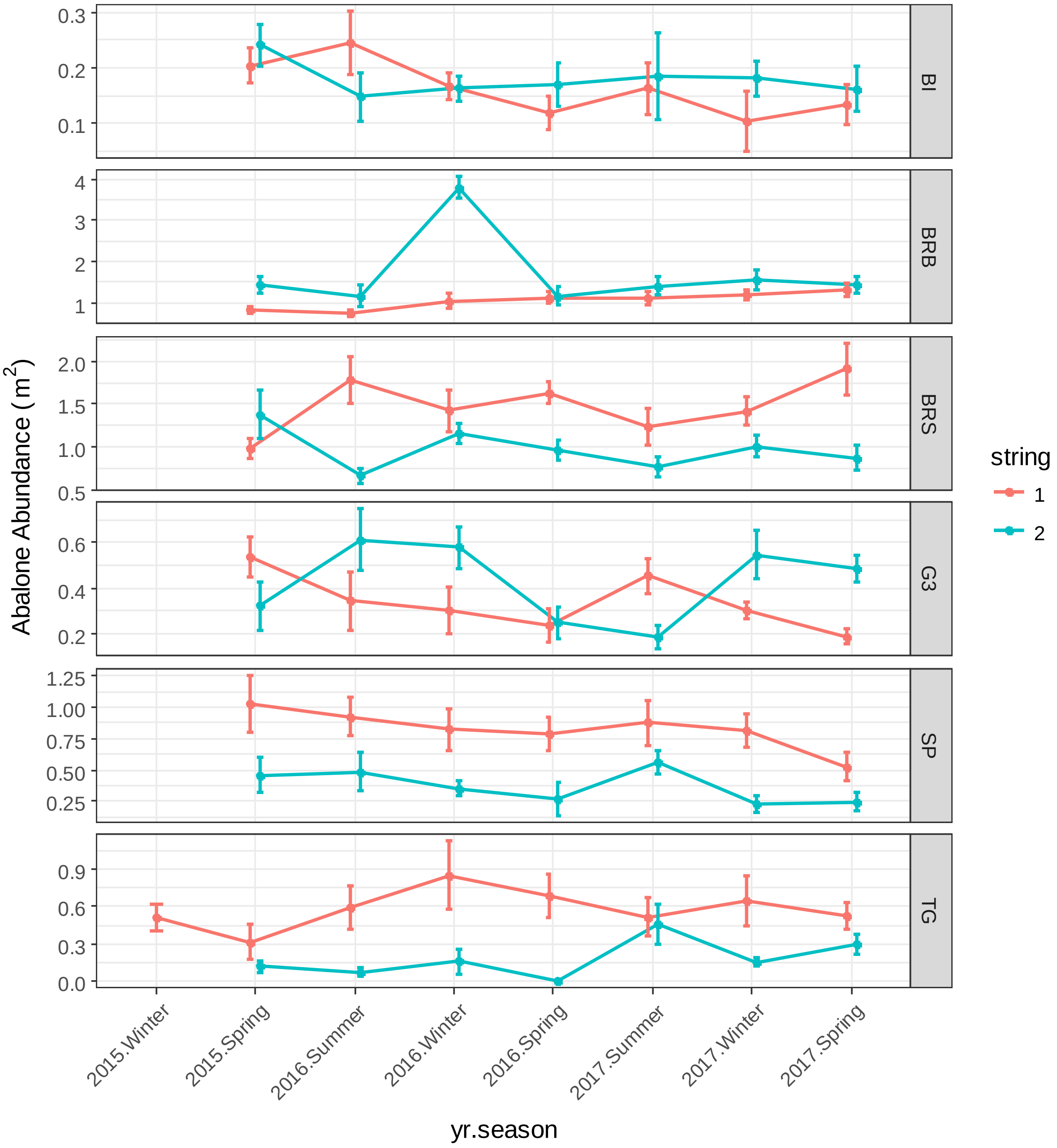

Figure 22. Mean density (m^2) (+- SE) of sub-legal sized abalone (< 138mm SL) from fishery-independent surveys across eight sampling periods and six sites (BI = Betsy Island, BRB = Black Reef Boulder, BRS = Black Reef Slab, G3 = George III, SP = Seymour Point, TG = The Gardens).

6.6 Experimental design and ability to detect change

Cohen’s D obtained from the a pilot dataset consisting of the 2016 and 2017 summer ARM data ranged from 0.53 to 1.14, with 95 % confidence intervals around D at all locations being relatively large (Table 1). Black Reef Slab appears to be unique in that it was the only location where a significant increase in mean abalone/m^2 was observed between 2016 and 2017. When translated to a Minimum Detectable Difference (MDD) at a sample size of n = 20 at each location, a 100 % increase/decrease in density would be required to determine a significant change in density of juvenile abalone at all locations, regardless of the magnitude of the mean recruit density observed in the sample dataset used here. A MDD by sample size curve (Figure

23) suggests that the current level of replication is only able to detect substantial changes in recruit density on the ARM's, and that any reduction in replication would diminish the capacity to detect changes, to the extent that only very large changes could be detected with confidence.

Table 1. Sample means and effect size (Cohen's D) by location. Sample size was set at n=20. MDD = Minimum detectable Difference between sample means.

Location	**Mean abalone m^2 (2016, 2017)**	**Pooled st.dev**	**Cohen's D 95% CI (Upper, Lower)**	**MDD**	**Prob of Sig T**
The Gardens	0.9, 2.49	1.96	0.80 (0.18, 1.41)	2.29	0.01
Seymour Point	0.47, 1.51	1.98	0.53 (-0.11, 1.16)	2.3	0.1
Betsey Island	0.43, 1.59	1.50	0.87 (0.33, 1.40)	1.71	0.012
George III	2.29, 6.86	4.72	1.07 (0.49, 1.65)	4.5	0.01
Black Reef Boulder	1.36, 4.97	3.12	1.14 (0.44, 1.84)	3.66	0.001
Black Reef Slab	9.67, 9.13	8.06	0.67 (-0.54, 0.68)	9.42	0.82

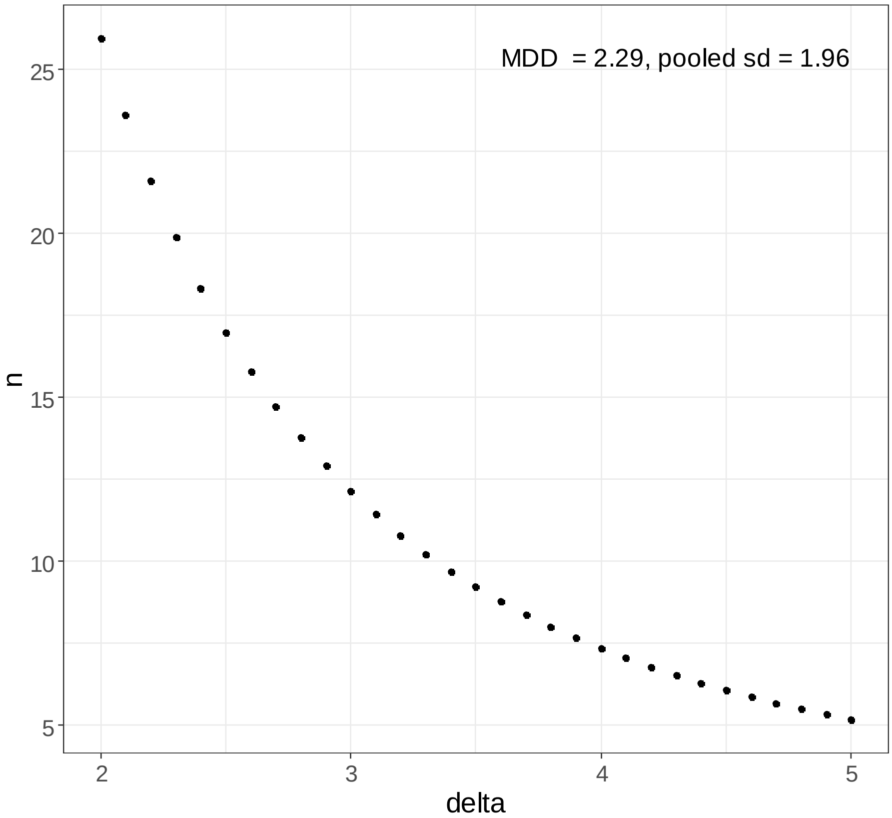

Figure 23. Effect size curve for The Gardens, based on data from Summer 2016 and 2017. Y axis indicates sample size (*n*) required to achieved delta (x axis), where delta is the difference between two sample means (abalone/m^2). MDD indicates the Minimum Detectable Difference (abalone/m^2) based on the typical sample size of N = 20, and the pooled standard deviation of the sample dataset.

7 Discussion

The primary objectives of this project were to test and improve the simple flat plate type Abalone Recruitment Module (ARM), develop a simple, effective and efficient method for examining the juvenile abalone occupying the ARMs and to test deployment across a range of habitat types. The new ARM design and attachment system performed far better than expected, was robust to significant storm systems, and could be installed in diverse habitat types. Whereas the search time of the North American ARM design was approximately 45 mins for each ARM (DeFreitas 2003, Bouma et al. 2012), we were able to assess 20 replicate arms in 60 mins and achieve higher densities of juvenile abalone. Establishment time is relatively quick at between 2 hrs – 3 hrs to install 20 ARMs with an experienced team. This enables ARMs to be installed at up to two sites per day. The size range of abalone observed under the ARMs during this study (~ < 100 mm SL) provides a perfect complement to the size range (~ > 100 mm SL) of blacklip abalone observed on fishery independent surveys (FIS) in Tasmania.

It has become clear from the start of this project that pre-recruitment abundances of abalone under the ARMs are related to habitat complexity. The habitat types selected for this project range from simple slab habitat (Black Reef Slab) to highly complex large boulder habitats (Black Reef Boulder, Seymour Point and The Gardens). The mixed low profile reefs (George III Rock, Betsey Island) are considered moderately complex. The three locations of Black Reef slab, Black Reef boulder and George III Rock were selected based on their contrasting habitat type but close proximity, to minimise potential broad scale geographic variation in environmental conditions or population dynamics (Figure 5). Within these three locations mean abundance (Black Reef slab > George III Rock > Black Reef boulder) was clearly the inverse of habitat complexity (Black Reef boulder > George III Rock > Black Reef slab) with ARMs at the least complex slab habitat supporting significantly greater abundances (Figure 11) than the more complex habitats. This result contrasts with the emergent abalone density information gathered from these locations where both Black Reef locations have abalone densities and significantly higher average densities than George III Rock (Figure 18). The elevated juvenile abundance at the low complexity site is potentially a consequence of lack of natural cryptic habitat in slab habitat and the predatory risks associated with emergence from cryptic habitat by immature abalone. The lack of suitable natural cryptic space at the slab habitat and the presence of existing refuges in the more complex habitats is a plausible contributor to the patterns of pre-recruitment numbers observed. It is likely that the proximity of the slab habitat to adjacent high quality natural juvenile habitat underpins the high densities on ARMs within the low complexity slab site at Black Reef. Furthermore, the quality of the surrounding habitat and the distance from the ARM to the nearest natural juvenile habitat were expected to influence the rate and abundance of pre-recruits under the ARMs.

Abalone have a reputation for high levels of variation in abundance across a range of spatial scales. The level of variability among ARMs in this study supports that pre-conception, but also provided some insight into the underlying drivers of local-scale variability. At all sites, several individual ARMs consistently supported either high or low densities of juvenile abalone across all time periods. This pattern has implications both for choices made when installing ARMs, but also for understanding the potential drivers of local scale variation.

Sampling to validate the density of abalone obtained from the ARM method by rolling boulders to access abalone inhabiting the cryptic space highlighted inadequacies of the boulder rolling method. These inadequacies include the difficulty in quantifying suitable cryptic space for abalone, destructive sampling methodology and limitations on size of boulders which can be rolled. The boulder rolling exercise in this study was a clear demonstration of why an alternative method such as the ARMs is required in order to monitor abundance of abalone in the cryptic space. While the boulder rolling method has been utilised in several previous studies(Prince et al. 1987, 1988), it was clearly a destructive process, involving considerable disturbance to the site and would render a short time-series of cryptic habitat data useless as a consequence, with considerable time required to allow the cryptic population to re-establish. Data from the boulder rolling exercise also introduced a level of bias as at some sites all boulders could be moved and examined, whereas at some of the sites large boulders could not be moved resulting in an incomplete assessment of the cryptic space. As a validation method, we do not believe the boulder sampling provides a reliable estimate of juvenile abundance.

The recruitment data obtained from the ARMs thus far continues to challenge ideas around the broader use of fishery-independent data in fishery assessments. In many abalone fisheries there is a tendency to extrapolate fishery-independent indices of abundance to absolute estimates of abundance or biomass. While the benefits of such an extrapolation of point based datasets are obvious, the assumption that spatial heterogeneity can be quantified and accounted for in conversion of data to absolute measures is rarely tested, and unlikely to stand up to rigorous examination. The local scale variation in juvenile density between strings (sub-sites) and, the clear effect of habitat complexity and quality of naturally available cryptic habitat on juvenile density found in this study reaffirm our long-held view that measures of fishery-independent abalone density of adults or juveniles are best utilised as measures of relative abundance.

This project was able to collect a small time-series of data on juvenile density at a small number of sites selected to contrast stock density and habit type. As with all fishery-independent relative measures of abundance, a longer time series is required to be useful in informing fishery assessments. Ultimately, data from an ARM program has value as a leading indicator of stock levels, highlighting years of high or low biological recruitment, given sufficient coverage and appropriate site choice.

7.1 Conclusions

Installation of ARMs add substantial value to any abalone fishery independent survey program by providing data on a previously intangible question – density of juveniles in the cryptic life history phase. In addition to being a valuable asset as a leading indicator in fishery assessments, they can provide critical data on abundance of early life history stages for population dynamic model validation.

The ARM design tested in this study was highly successful and was practical to use across a range of habitat types, and was relatively robust to significant wave energy conditions. Interpretation of the data should be limited to relative measures of change at each site, and should not be used in a scaled up calculation of absolute recruit density or biomass within spatial management areas. Consequently, choice of locations as indicators of broader fishing grounds requires careful consideration.

Evaluation of Minimum Detectable Differences achieved even with a large sample size (n = 20) suggests that ARMs are best placed to identify large inter-annual changes in recruitment success, and how recruitment high's and low's influence population structure through time. Due to high levels of local variation, installation and monitoring of ARMS should not attempt to achieve small-magnitude differences in recruit density through time.

8 Recommendations and further development

1. *Soft rock anchoring system*

The anchoring system used in this study was highly effective in very hard rock (granite, dolerite), but was problematic in softer rock (mudstone). An alternate expansion bolt system for securing ARMs to the substrate is required for softer rock where surface cracking and bruising of the rock surface increases the risk of the plate detaching or moving.

2. *Juvenile abalone density validation*

Objectives 2 and 3 listed in the proposal centred on ideas of how to validate the data on juvenile density obtained from the ARMs. Neither of those ideas were feasible, and thus understanding the effectiveness of ARMs in terms of overall abundance of juvenile abalone at local sites remains a challenge. This reinforces the recommendation that data collected from ARMs be used as a relative measure of recruit density, and that it should not be used to scale up to measures of absolute abundance or biomass of abalone in the cryptic phase.

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10 Extension and Adoption

Achievements and progress with improvements in the design and installation methods of ARMs were communicated to colleagues active in abalone fishery research, and to Industry members across a range of forums. An extension project has been proposed and approved to trial the Tasmanian ARM design in Eastern Victoria, and to train Victorian Fisheries Authority and Eastern Zone Abalone Industry Association staff to enable Victoria to extend use of the ARMs and operate independently of Tasmania.

Within Tasmania, ARMs have also been installed adjacent to salmon pens as part of a broader monitoring program on the long-term effects of salmon farms on adjacent rocky reef habitats. Installation of ARMs at a range of sites on the Tasman Peninsular and in the Actaeons region, with further plans to establish ARMs at locations along the Tasmanian south coast.

11 Project materials developed

A Standard Operating Procedures Document (SOPS) has been developed and is available on request from the Principal Investigator. The SOPS provides details of the ARM design, the materials and equipment used, and the process of installing ARMs on abalone reef.

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