Monitoring abalone juvenile abundance following removal of *Centrostephanus* and translocation

Jaime McAllister, Sarah Pyke and Craig Mundy

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Abbreviations

AFCOL	Abalone Fishermen’s Co-operative Limited
ARM	Abalone Recruitment Module
ANOVA	Analysis of Variance
EZAIA	Eastern Zone Abalone Industry Association
FIS	Fishery Independent Survey
IMAS	Institute for Marine and Antarctic Studies
IPB	Island Point urchin barren
IPCT	Island Point, urchin cull, abalone translocation
PPC	Petrel Point control
PPCNT	Petrel Point, urchin cull, no abalone translocation
SL	Shell length (mm)
SOP	Standard Operating Procedures
VFA	Victorian Fisheries Authority

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Executive Summary

Abalone populations throughout south east Australia continue to come under increasing environmental pressures particularly the loss of productive habitat resulting from the range expansion and destructive grazing of algae by *Centrostephanus rodgersii*. Subsequent, attempts to rehabilitate reefs through urchin culling have proven successful in restoring algae communities yet have not translated to a detectable recovery in the abalone population. Therefore, translocation of abalone to reefs affected by *Centrostephanus* has been trialled as a supplement in the recovery process in Eastern Victoria. A key limitation in assessing recovery is that abalone remain cryptic for the first 5 to 7 years of life. Consequently, in the past the increased rate of recovery by translocation over natural recovery processes could only be quantified in the medium to long term once abalone become emergent and visible to researchers. To assess the effectiveness of translocation over the short term, a method to monitor juvenile abalone abundance was required.

A new system of Abalone recruitment modules (ARMs) have proven to be successful in collecting juvenile abalone in Tasmanian waters. This design was subsequently transferred to the Eastern Zone, Victoria, where IMAS staff and Eastern Zone Abalone Industry Association (EZIZA) members installed ARMs at four sites with contrasting abalone populations: 1) healthy abalone reef subject to commercial abalone fishing, 2) previously healthy abalone reef that no longer supports abalone populations as it has been denuded by urchins, 3) a site that has been subject to urchin culls to improve abalone habitat but has not had any abalone translocated from elsewhere, and 4) a site that has been subject to urchin culls to improve abalone habitat and has had abalone translocated from elsewhere.

After a 6-month deployment the ARMs incurred no major damage and had attracted juvenile abalone across a broad size range (9-91 mm SL) at all four sites. Overall there was a significant difference in abalone density between sites with the highest density recorded at the Petrel Point control site attributed mostly to the higher density of larger individuals (>25 mm SL). In contrast, remaining sites had lower but similar densities except for the Barren site which recorded no individuals larger than 45 mm SL. Small abalone (<25 mm SL) abundances were generally consistent and not significantly different across all four sites. These results demonstrate that both recent and historical spawning events have contributed to maintaining some level of recruitment in these areas, however, suggests there may be some disparity in the survival of recruits between sites.

This project supports the application of ARMs for collecting information on juvenile abalone. Although these results provide evidence of abalone recruitment, evaluating the benefits of urchin culling vs abalone translocation vs natural recruitment will require a better understanding of the spatial and temporal patterns of recruitment across all sites before the benefits of the various recovery efforts can be made. Ongoing monitoring of the ARMs is also expected to provide a greater understanding of the stock recruitment relationships and the suitability of this as a technique in more broadly forecasting recruitment.

Introduction

Environmental factors are thought to be affecting abalone recruitment and populations in south east Australia (Stewardson *et al.* 2016). The range expansion of native sea urchins *Centrostephanus rodgersii* and the loss of healthy algae communities resulting from their destructive grazing has been suggested as a significant contributor to the decline of the eastern Victoria abalone stock (Gorfine *et al.* 2012). In response, the Eastern Zone Abalone Industry Association (EZAIA) in collaboration with the Victoria Fisheries Authority (VFA) have been conducting urchin culling trials funded by FRDC (refer to FRDC projects 2012-058 and 2014-224) to rehabilitate reefs with greatly reduced productivity.

Despite good success with local eradication of urchins and recovery of affected kelp communities there has been no detectable recovery of abalone populations at sites where urchins have been removed (Gorfine *et al.* 2012). Subsequently, translocation of mature abalone has been trialled as an option to rebuild reefs that had been affected by urchins. However, abalone remain cryptic for the first 5 to 7 years of life, consequently, determining the increased rate of recovery by translocation over natural recovery processes using traditional underwater visual assessments can only be quantified in the medium to long term once abalone become emergent and visible to researchers. Therefore, in order to gauge the effectiveness of urchin culling and translocation as a direct intervention strategy, implementing a method of determining juvenile abalone abundance was required.

Previous attempts to monitor juvenile and sub-adult abalone populations have been met with mixed results and have typically involved labour intensive and sometimes destructive methodologies (Mundy and Miller 2012; Nash *et al.* 1995; Prince *et al.* 1987). Artificial structures referred to as 'Abalone Recruitment Modules' (ARM) have also been used with some success for monitoring changes in the abundance of abalone (Bouma *et al.* 2012; Davis 1995; DeFreitas 2003; Rogers-Bennett *et al.* 2004). More recently, in Tasmania a simple, cost effective ARM has been developed and successfully deployed in different habitat types, and is currently being used to assess the abundance and size structure of juvenile abalone (Mundy *et al.* 2018).

Understanding stock-recruitment is highly desirable in fisheries management yet is rarely demonstrated given the time frames needed to determine the relationship between spawning biomass and recruitment (Szuwalski *et al.* 2015). This is further compounded in particularly long-lived species and those exposed to fluctuating environmental conditions (Munch *et al.* 2018; Szuwalski *et al.* 2015). Similarly, the stock-recruitment relationship for abalone also remains poorly understood largely due to the difficulties of gathering information during their cryptic (i.e. early) life stages. Testing methodologies that can improve our understanding of abalone during cryptic life stages is also required to assess their appropriateness as a tool for forecasting stock-recruitment.

In this study we adopt the ARM design used in Tasmania to assess the effectiveness of this tool for monitoring juvenile recruitment and to measure the direct effect of reef restoration for abalone populations in Victoria, and more broadly in monitoring the cryptic phases of abalone.

Objectives

1. Test Tasmanian designed juvenile abalone collectors on Victorian Eastern Zone reef systems.
2. Use juvenile collector methods to assess effect of translocation on population recovery.
3. Consider broader application of juvenile collectors as a recruitment monitoring tool.

Methods

Site selection

The main study location was located between Island Point and Petrel Point, approximately 60 kilometres southwest of Mallacoota Inlet, Victoria (Figure 1). Sites were chosen to represent four contrasting abalone populations in Eastern Victoria and overlap with those of a previous experimental study aimed at determining the effect of reducing sea urchin densities on restoring habitat for abalone (FRDC project no. 2014-224):

1. Control site with fishing (PPC): healthy abalone reef subject to commercial abalone fishing.

2. Urchin barren site (IPB): previously healthy abalone reef that no longer supports abalone populations as it has been denuded by urchins.

3. Urchin cull site not subject to translocation (PPCNT): a site that has been subject to urchin culls to improve abalone habitat but has not had any abalone translocated from elsewhere. Approximately 65,000 urchins were removed between 2011 and 2016.

4. Urchin cull site subject to translocation (IPCT): a site that has been subject to urchin culls to improve abalone habitat and has had abalone translocated from elsewhere. Approximately 350,000 urchins were removed between 2011 and 2014, and 3,000 abalone translocated in 2016.

Island Point and Petrel Point sites were approximately 5 km apart, and sites within separated by approximately 500 and 800 m, respectively.

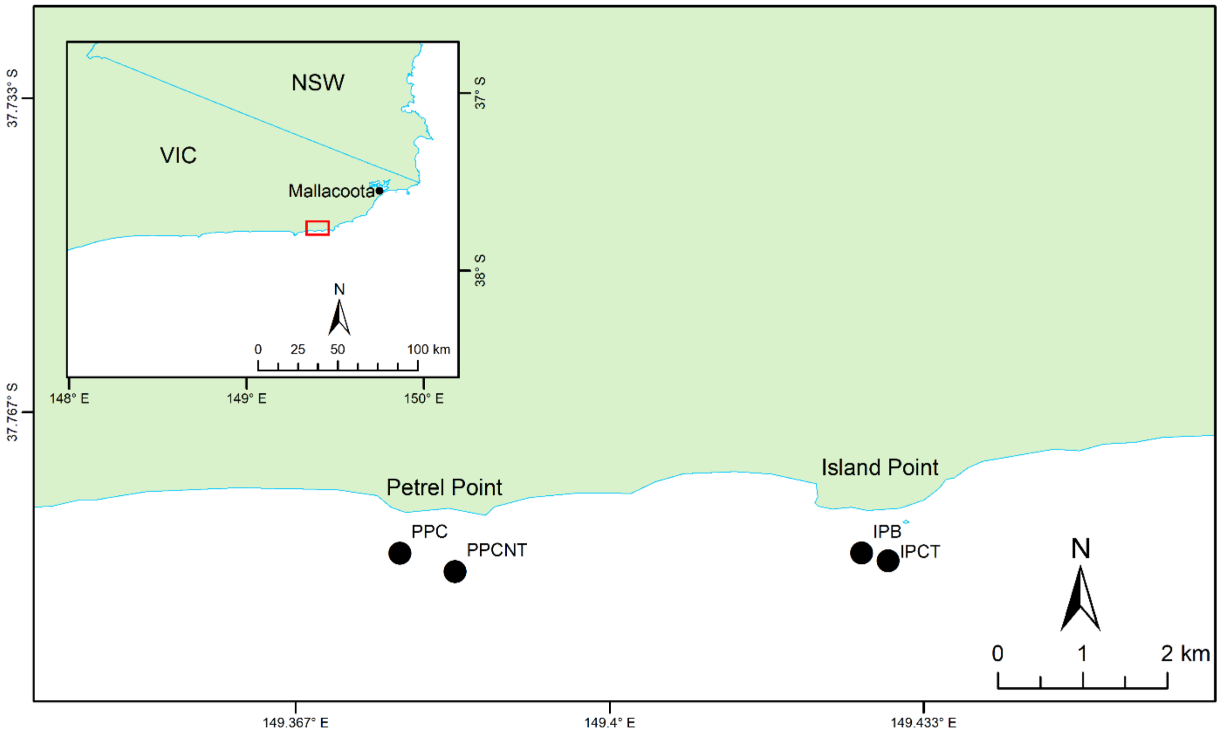

Figure 1. Map of study area between Island and Petrel Point in eastern Victoria showing sites (circles) where ARMs were installed. IPB = Island Point barren, PPCNT = Petrel Point cull and no translocation, IPCT = Island Point urchin cull and abalone translocation, and PPC = Petrel Point control (no cull or translocation). Each site consists of one string of 20 replicate ARMs.

ARM installation

The installation of the ARMs was performed following standard operating procedures (SOPs) developed as part of FRDC project 2014-010. The SOPs provide a detailed description of the ARM design, equipment, and installation procedures (Pyke et al. 2017) (see appendix 2). The installation of ARMs also involved the training of several EZAIA members by IMAS staff so that future installations could be performed independently of IMAS.

ARM resurvey

The first resurvey of deployed ARMs occurred on the 16th March 2019, approximately 6-months post-installation. The resurvey consisted of three divers working either individually or in buddy pairs to measure all abalone to the nearest mm using plastic callipers present underneath the ARMs. The re-survey also involved the training of an EZAZIA member in procedures outlined in the SOP so that future re-surveys could be performed independently of IMAS.

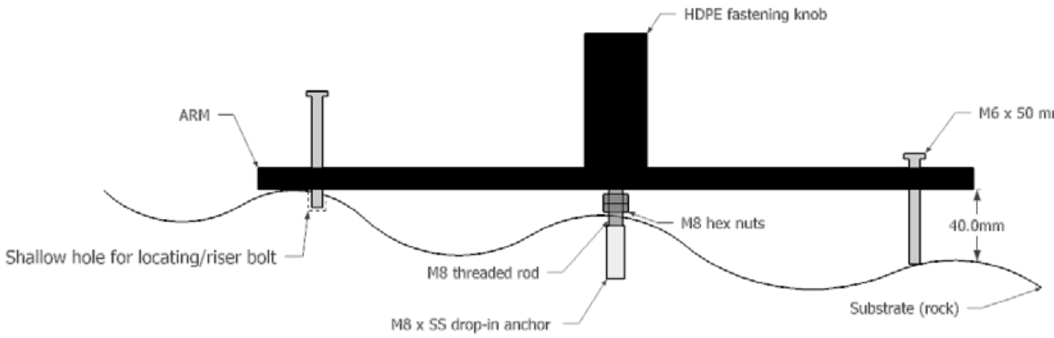

Figure 2. Cross-section view of ARM configuration and installation.

Data analysis

Size frequency distributions were used to examine the size structure of abalone found on the ARMs at the different sites. Abundance of juvenile abalone found underneath ARMs were converted to density (abalone/m^2) to determine differences in mean abundance between sites. Differences in size structure between sites were compared using the Anderson-Darling test and the ratio of small (<25 mm SL) to large (>25 mm SL) juvenile abalone between sites were compared using a G-Test of Independence. Overall differences in density between sites were compared using one-way ANOVA. All data analyses were conducted using R (R-Core-Team 2017), and data summaries and figures prepared using dplyr (Wickham and Francois 2016) and ggplot2 (Wickham 2009) packages.

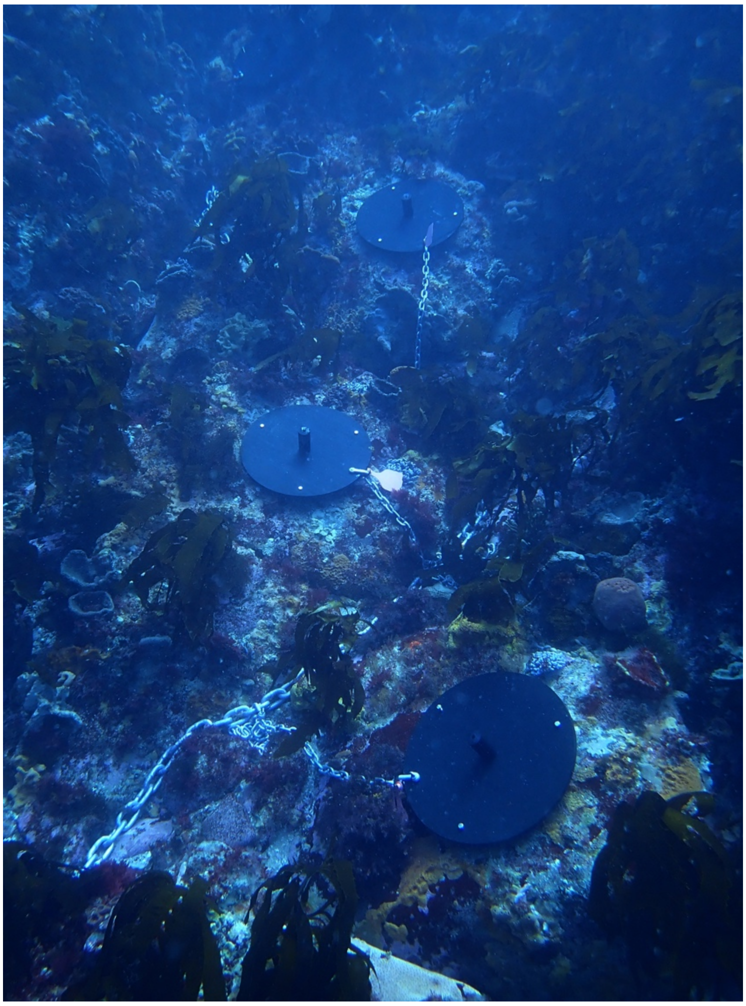

Figure 3. Abalone recruitment modules (ARMs) attached to baseline chain via chain tethers soon after deployment at the Petrel Point Cull, No Translocation (PPCNT) site.

Results

ARM Performance

Overall, there was no major damage or loss of ARMs with 95% (76 of 80 ARMs) effectively sampling for the entire 6-month deployment. At PPC one ARM had dislodged from the substrate and was determined to be the result of the thread stripping in the fastener knob, and three ARMs at PPCNT were subject to sand inundation of the rock gutter in which they were deployed. Subsequently, these ARMs at PPCNT, plus five additional ARMs, were re-positioned on higher substrate in the string to minimise the potential for further sand inundation. Minor repairs were needed at some sites and mostly involved general maintenance items such as the replacement or tightening of centre bolts.

ARMs appeared to withstand varying conditions for much of the initial deployment, with persistent wave energy from the southwest and several periods where the significant wave heights for the area appeared larger than normal (e.g. late November) (Figure 4).

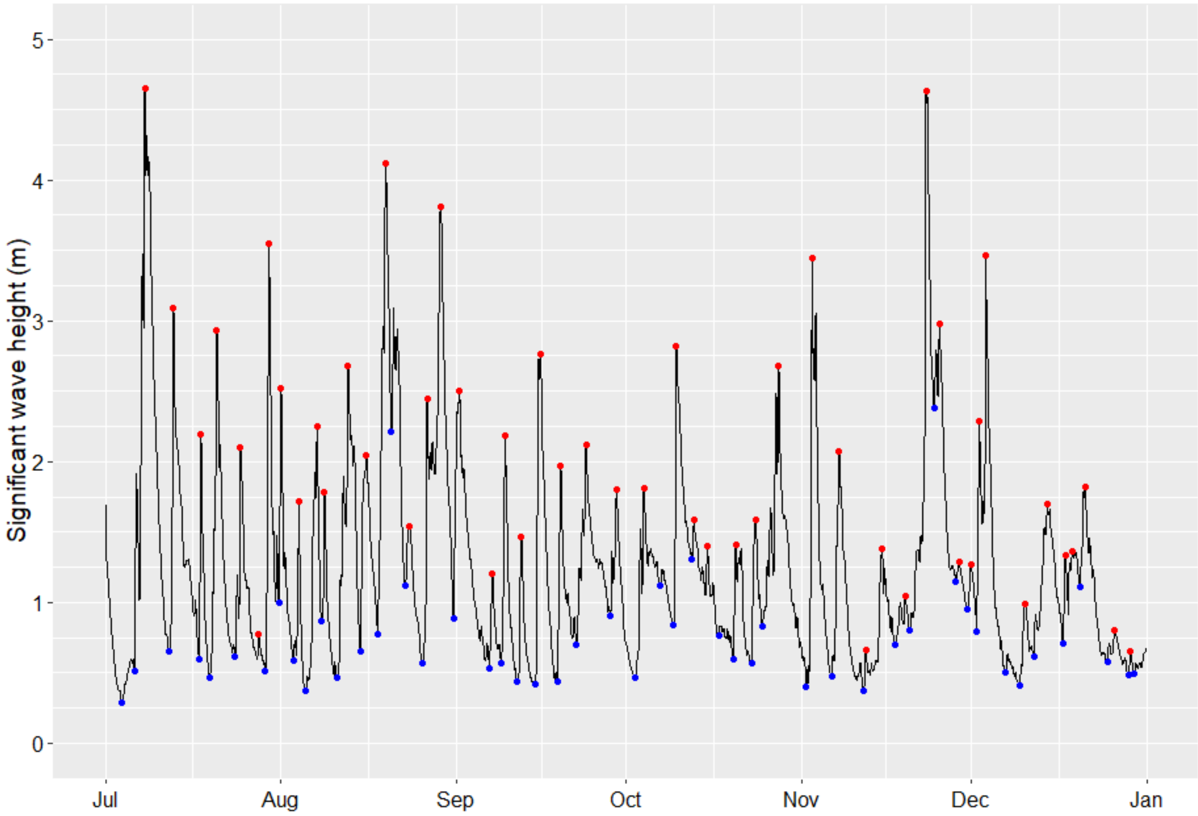

Figure 4. Significant wave height (hs) from Point Hicks, Victoria, July 2018 to December 2018 extracted from the hindcast reanalysis dataset produced by the Bureau of Meteorology (Durrant and Greenslade 2011).

Abalone size structure and density

Juvenile abalone were recorded on more than 50% of ARMs at each site (Figure 5) and found attached to either the ARM itself or the substrate below (Table 1; Figure 6). There were no abalone larger than 91 mm shell length (SL) recorded under the ARMs, and the smallest abalone observed was 9 mm SL (Figure 7). Abalone found underneath the ARMs at the Petrel Point control site were typically 30 to 60 mm SL whereas at the remaining sites they were significantly smaller at around 20 to 30 mm SL (AD = 19.82, $p < 0.05$) (Figure 8; Figure 9). Very small abalone (less than 20 mm SL) were also observed, particularly at IPB and PPCNT sites (Figure 7). There was no clear evidence of a pattern in the size structure from size frequency histograms, however, with the exception of the IPB site where no abalone larger than 42 mm SL were recorded, the presence of abalone larger than 60 mm SL suggests at least two modal size classes may be present at remaining sites (Figure 7).

Table 1. Summary statistics for abalone recorded underneath ARMs in March 2019 (Autumn) at each site. IPB = Island Point barren, PPCNT = Petrel Point cull and no translocation, IPCT = Island Point urchin cull and abalone translocation, and PPC = Petrel Point control (no cull or translocation). % ARM and % Rock = percentage of abalone recorded attached to the ARM or substrate, respectively. Each ARM has a planar surface area of 0.126 m^2.

Site	*Abalone m^2 (± s.e.)*	*Abalone ARM^{-1} (± s.e.)*	*Mean SL (mm) (± s.e.)*	*Min SL (mm)*	*Max SL (mm)*	*% ARM*	*% Rock*
IPB	5.2 (1.8)	0.7 (0.3)	26.3 (2.5)	14	42	54	46
PPCNT	6.4 (2.3)	0.8 (0.3)	27.6 (4.6)	9	66	94	6
IPCT	9.5 (2.4)	1.2 (0.3)	32 (2.8)	18	72	75	25
PPC	24.7 (2.3)	3.1 (0.3)	48.8 (2.2)	18	91	55	45

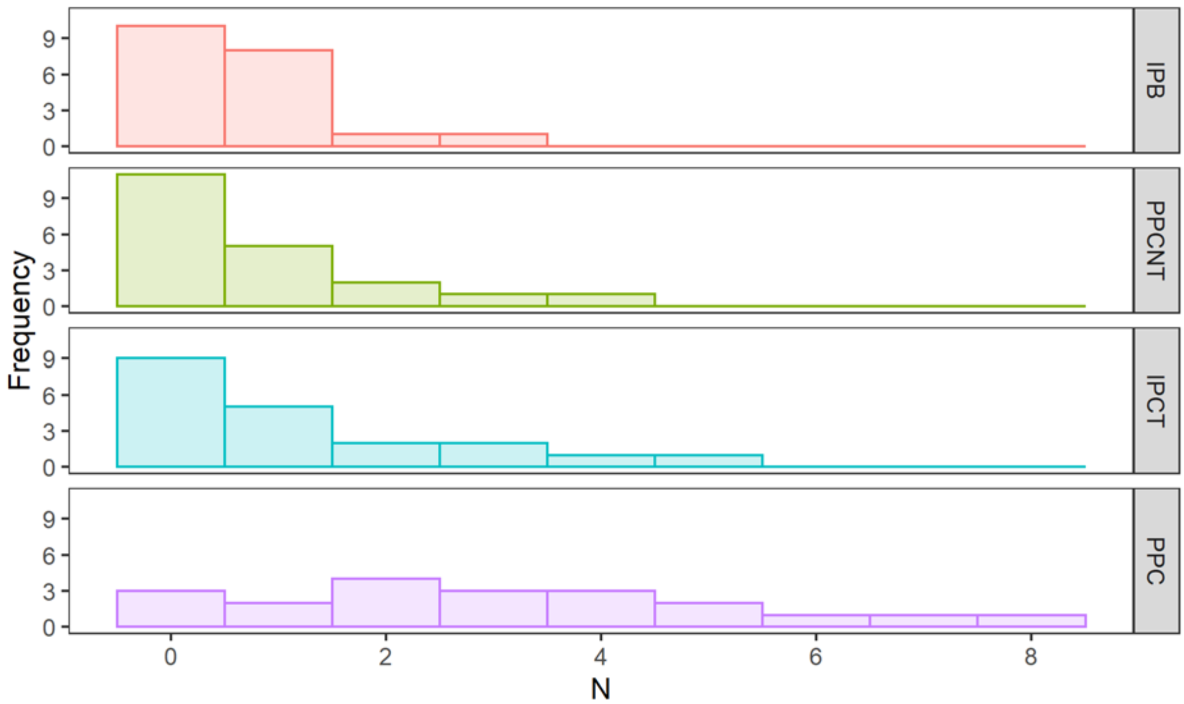

Figure 5. Frequency distribution of individual abalone (N) recorded underneath each ARM at four sites. IPB = Island Point barren, PPCNT = Petrel Point cull and no translocation, IPCT = Island Point urchin cull and abalone translocation, and PPC = Petrel Point control (no cull or translocation).

Figure 6. Juvenile abalone found attached to the underside of an ARM at the Petrel Point Control site. Note the formation of bryozoans and sponges, and presence of the feather star (*Cenolia trichopteran*).

There was a significant difference in overall abalone density between sites ($F_{3, 76} = 10.78$, $p < 0.05$) with the highest density recorded at the Petrel Point control site (25 abalone m^{-1}) and lower but similar densities recorded among the three remaining sites (Figure 10). Densities at the PPC site were of a magnitude four times greater than those recorded at the IPB site and were attributed mostly to a significantly higher proportion of larger juveniles (>25 mm SL) ($G = 19.91$, $df = 3$, $p < 0.05$) (Figure 9). In contrast, densities of small abalone (<25 mm SL) were consistent (~3-4 abalone m^{-1}) and not substantially different across sites.

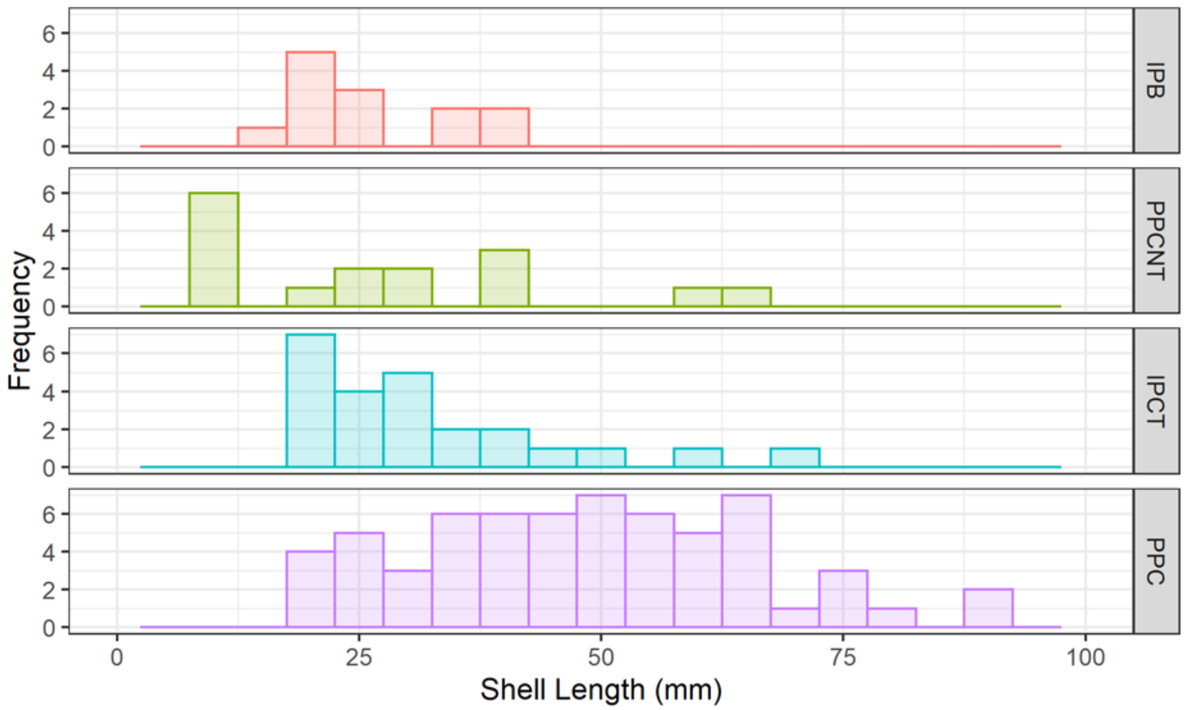

Figure 7. Size frequency of abalone recorded underneath ARMs across four sites. IPB = Island Point barren, PPCNT = Petrel Point cull and no translocation, IPCT = Island Point urchin cull and abalone translocation, and PPC = Petrel Point control (no cull or translocation).

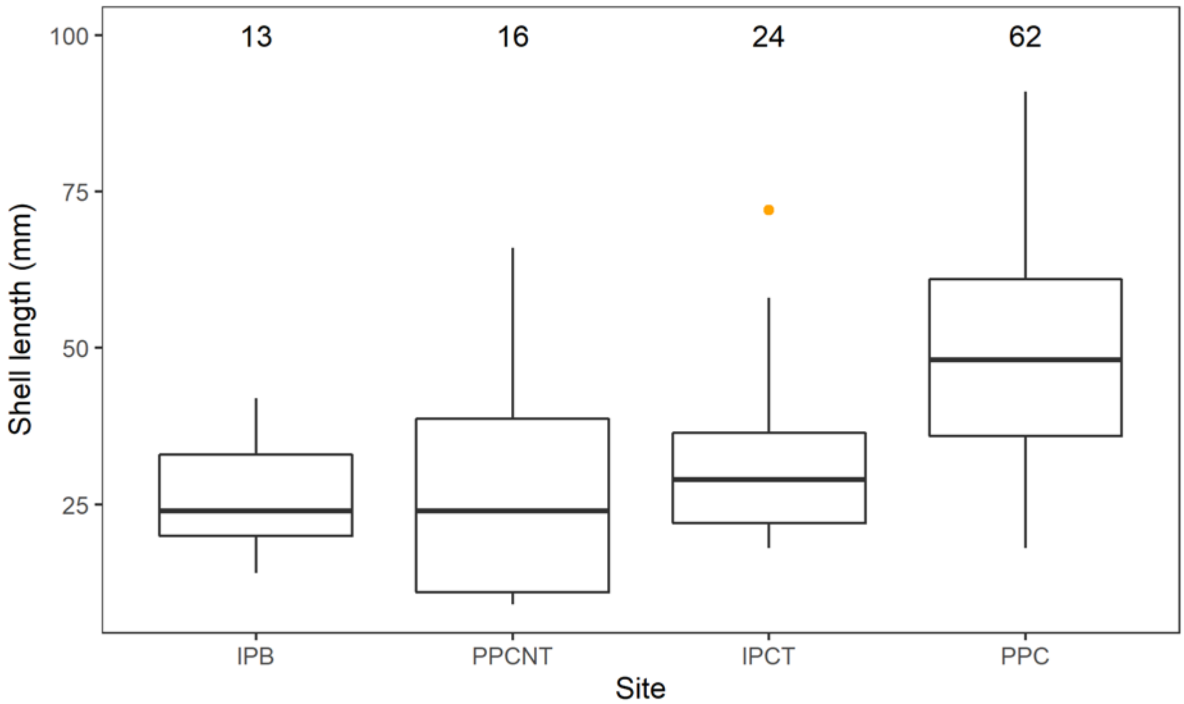

Figure 8. Size structure boxplot of abalone on ARMs recorded in March 2019 (Autumn) at four sites. IPB = Island Point barren, PPCNT = Petrel Point cull and no translocation, IPCT = Island Point urchin cull and abalone translocation, and PPC = Petrel Point control (no cull or translocation). Total count of abalone per ARM site given above each boxplot.

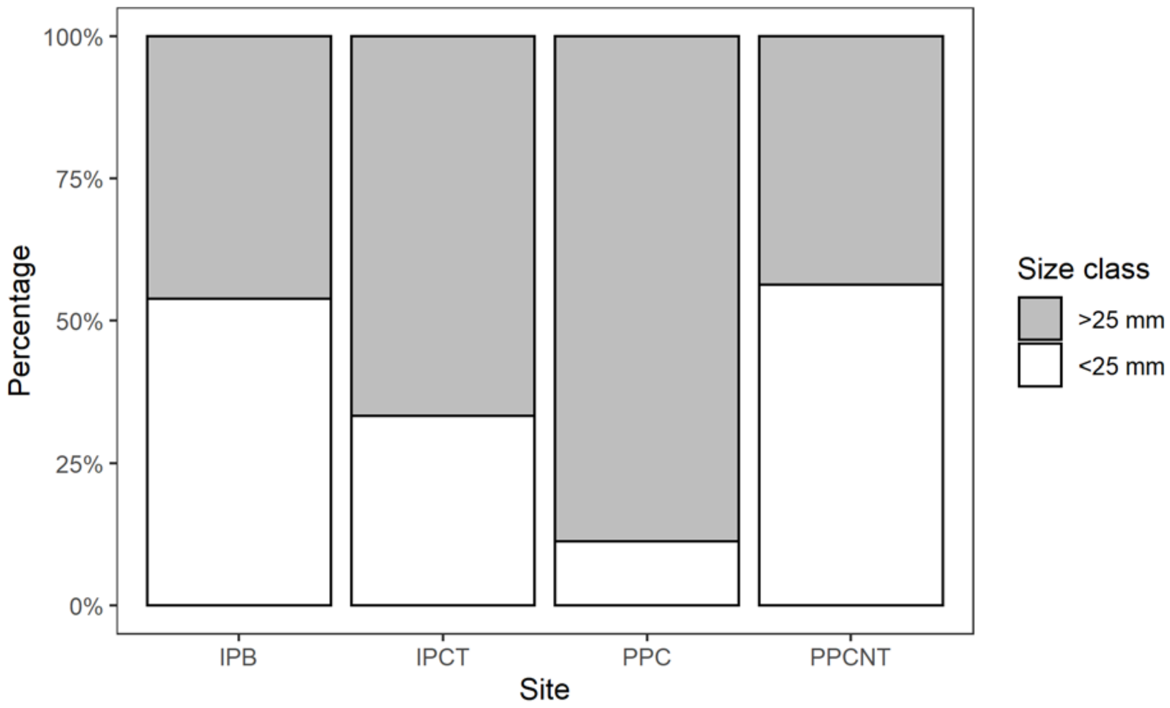

Figure 9. Overall ratio of small (<25 mm SL) to large (>25 mm SL) juvenile abalone recorded under ARMs at each site. IPB = Island Point barren, PPCNT = Petrel Point cull and no translocation, IPCT = Island Point urchin cull and abalone translocation, and PPC = Petrel Point control (no cull or translocation).

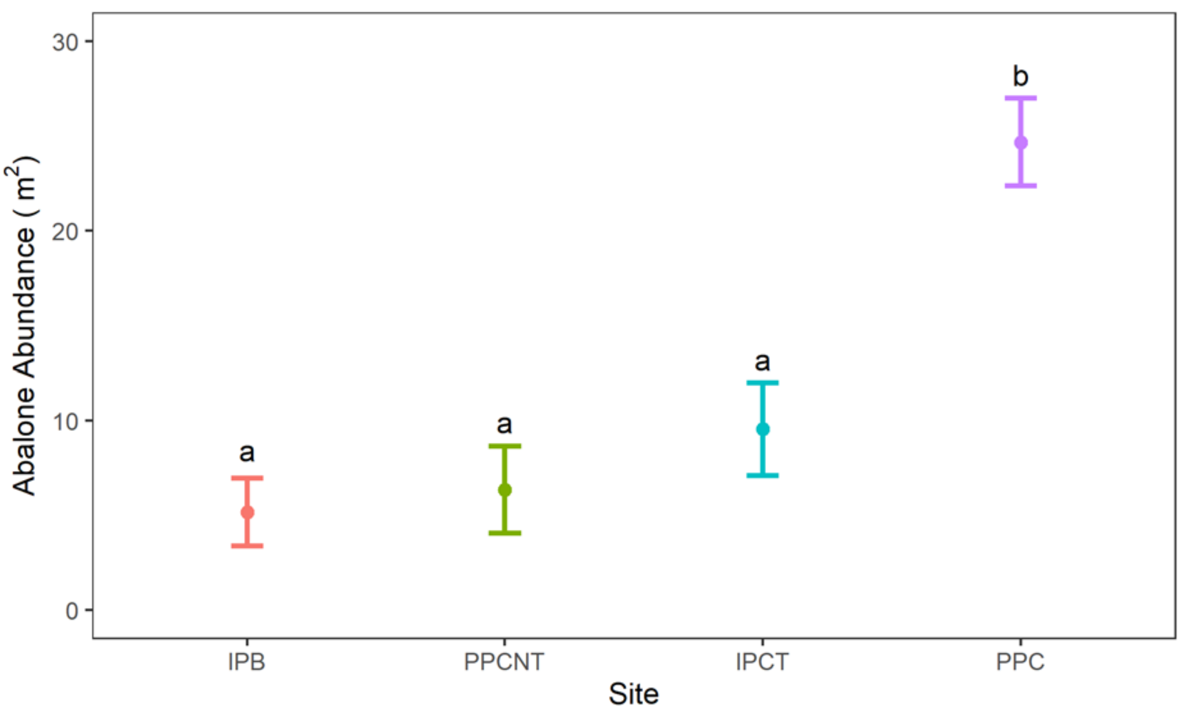

Figure 10. Mean overall density (m^2) of abalone (+- SE) on ARMs across each site. Each ARM has a planar surface area of 0.126 m^2. IPB = Island Point barren, PPCNT = Petrel Point cull and no translocation, IPCT = Island Point urchin cull and abalone translocation, and PPC = Petrel Point control (no cull or translocation). Different letters represent significant differences in abalone abundance between sites ($p < 0.05$).

Discussion

This study demonstrated that abalone recruitment modules (ARMs) can be deployed successfully in Eastern Victoria waters. After a 6-month deployment there were no major equipment losses and juvenile abalone were recorded at four sites with contrasting abalone populations. The site with the healthiest population of mature abalone also had a significantly higher density of juvenile abalone, further demonstrating the effectiveness of ARMs to monitor juvenile abalone which are normally misrepresented in traditional fishery independent surveys (FIS).

Developing an ARM system that is robust enough to withstand the challenging sea conditions experienced in typical abalone habitats has been an area of continual refinement by IMAS staff. The negligible damage observed to ARMs deployed in this study is in part due revisions to the methods resulting from failures experienced with early deployments in Tasmania (e.g. the recent use of threaded plastic knobs vs previous use of tubing and bolts to fasten ARMs to the substrate). Furthermore, the deployment of ARMs on consistently harder rock at the Victorian study sites with greater holding capacity for fasteners (i.e. granite) and in marginally deeper water (14 m vs 9 m) where sea turbulence is likely to be less, may have also contributed to the minimal rate of ARM loss. These results provide a basis for future ARM installations and for maximising their longevity in collecting uninterrupted information on juvenile abalone populations.

The size range of abalone observed underneath the ARMs indicates that several year classes/spawning events have contributed to recruitment across the four sites examined in the study. Recent recruitment events within the study period (i.e. 6-months) were also evident given the presence of very small abalone (i.e. <15 mm SL) at all sites. However, the lower abundances of large juveniles (25-100 mm SL) at the non-control sites suggests that there is a disparity in the survival, or emigration rate of of juvenile abalone post 25 mm among sites. This was particularly evident at the Island Point urchin barren site where there were no abalone larger than 45 mm SL and very few at the two remaining sites impacted by *Centrostephanus* (IPCT and PPCNT) suggesting that there are limited safe refuge sites for smaller abalone beyond a certain size which may be contributing to higher mortality or emigration.

The presence of particularly small abalone <15 mm on the barren site was somewhat surprising based on observations made by divers during the ARM installation and resurvey indicated there were no obvious adult abalone in the near vicinity (i.e. 15-20 m). Blacklip abalone populations are largely self-seeding with larval dispersal generally restricted to quite discrete spatial scales (i.e. hundreds of meters) (Miller *et al.* 2009). However, broader larval dispersal (i.e. tens of kilometres) has been suggested when abalone larvae can more freely access the water column in areas where the kelp canopy is more open (McShane *et al.* 1988). Therefore, given the size of these abalone suggests they were from a recent spawning event (i.e. within 6-months) and the paucity of adults in the area, it is plausible that remanent or fringing populations of adult abalone are providing an important source of recruitment to these barren sites. Regardless of the reason for low survival once reaching around 25 mm SL, this observation provides some confidence that successful recruitment of abalone in these sites is possible but at present appears compromised.

It is difficult to determine if the differences in recruitment between the control and impacted reefs is a direct consequence of the habitat damage caused by *Centrostephanus* or simply because the impacted reefs have historically supported low abalone recruitment and survival. Blacklip abalone populations are well known for their patchiness in abundance and size structure across quite small spatial scales (e.g. Brown 1991; Miller *et al.* 2009; Worthington and Andrew 1998). Indeed, in

Tasmania there can be a significant disparity in abalone abundance between ARM strings separated by relatively short distances (e.g. <50 m) (Mundy *et al.* 2018). Although this study supports the effectiveness of ARMs for capturing juvenile abalone, a much greater time-series is required to assess the benefit of the various rehabilitation efforts. Strong conclusions would be inappropriate without further understanding some of the spatial and temporal variations in abalone recruitment in these areas.

Understanding the long-term spatial and temporal variability in ARM performance also has implications for adopting ARMs more broadly as a forecasting tool for stock abundance. One of the challenges with any fishery independent survey is a pragmatic consideration of whether the data are representative of the overall fishery and suitable for estimating absolute abundance, or, applicable to each site individually. However, failure to recognise temporal and spatial variations in recruit abundance may lead to under or over representation of trends in the fishery. The level of variation in juvenile abundance across a relatively small spatial range (i.e. <500 m) observed in this study clearly demonstrates the need to better understand these dynamics before ARMs can be used to make generalisations about the overall consequences of year class strength for a fishery. More broadly, continuing to assess the long-term survival of cryptic juvenile abalone captured by ARMs and how they transition into adults (i.e. 5-7 years) will be required to validate the suitability of ARMs as a forecasting tool of stock abundance.

Conclusion

The successful deployment of ARMs and their ability to capture juvenile abalone demonstrates we now have a method for evaluating habitat restoration efforts such as translocation and urchin culling over the short-medium term. Our results provide strong evidence in support of the ability of ARMs to provide critical data on abalone at life stages which are normally challenging collect (i.e. cryptic juveniles). Whilst this study provides evidence of recruitment and disparity in juvenile abalone density across sites with contrasting abalone populations, ongoing monitoring of the ARMs will be required to understand inter-annual variability in recruit density, and site -specific trends in recovery from restoration activity.

Recommendations

Although there is currently insufficient evidence to disentangle the benefits of the translocation vs urchin culling, it is likely that a combination of each strategy has contributed to the maintenance of abalone recruitment observed across sites. As a precaution, maintaining *Centrostephanus* numbers at low densities may be warranted to ensure habitats do not deteriorate further and thus maximise the outlook for survival of abalone recruits and successful stock re-building. Fishing pressure applied to these reefs is likely to impact on abalone recruitment and catch levels should be carefully considered if a higher level of recruitment is desired.

Implementing a fishery independent survey (FIS) program to monitor emergent abalone density should be established at the current ARM sites to assess the long-term survival of recruits and their transition into surrounding habitats as adults. Understanding patterns in recruitment will not only help determine the long-term benefits of urchin culling and abalone translocation verse natural recruitment but more broadly in understanding the abalone stock-recruitment relationship and in assessing the usefulness of ARMs as an indicator of stock abundance. Where abalone densities were low (e.g. PPCNT, IPCT and IPB), it is important to understand whether recruits are produced internally, or from adjacent healthy habitat (larval dispersal, juvenile immigration).

Engagement with industry during the installation and resurvey were fundamental to the successful outcomes observed so far. Continuing to engage with industry through their assistance with any ongoing monitoring programme using ARMs or FIS is likely to facilitate a better understanding by stakeholders of the importance of collecting these data in managing abalone fisheries. Subsequently, this is likely to further improve the already demonstrated high level of stewardship of the resource by providing stakeholders the opportunity to contribute to management of their fishery.

Extension and Adoption

The installation of ARMs in Victoria is an extension to the success of the Tasmanian ARM project (FRDC project 2014-10). The installation and re-survey of the ARMs was done by IMAS staff, in the presence of EZAIA divers to ensure that further work of this nature could proceed independently of IMAS.

A commitment to an ongoing monitoring programme of the ARMs has been facilitated by EZAZIA and VFA. Trained EZAZIA members were due to undertake the second re-survey in September/October 2019 with the results being analysed by the VFA in consultation with IMAS.

The outcomes of this project contribute to our knowledge of ARM performance in differing habitats and provide several refinements which can be adopted in future ARM installations to improve their longevity (e.g. deploy at greater depth and on harder substrate).

These results also increase our understanding of using ARMs to monitor juvenile abalone populations and subsequently their suitability as a fishery independent indicator of recruitment and potential to be adopted as a performance measure in harvest strategies.

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Appendix 1

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Appendix 2

ABALONE RECRUITMENT MODULES (ARMS): INSTALLATION AND SERVICING

Standard Operating Procedures including Underwater Drilling Equipment

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Introduction

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. 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.

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, 2004; Bouma, et al., 2012). In addition, a range of ARM designs have been tested by the Institute for Marine and Antarctic Studies (IMAS) 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).

The current ARM design utilises a black high-density polyethylene (HDPE) disc that is secured using a threaded stainless rod and a drop-in anchor drilled into the substrate. The following document provides the standard operating procedures for installation and servicing of these ARMs, including the use of underwater drilling equipment.

1. ARM System Components

1. Abalone Recruitment Module (ARM)

Each ARM consists of a 400 mm diameter x 12 mm thick HDPE disc (Figure 1). A 10 x 30 mm central slot provides a fastening hole for attaching the ARM to a threaded rod anchored into the substrate. Three 5 mm diameter holes are triangulated around the perimeter of the ARM and are threaded M6 x 1.25 to accept varying length M6 stainless steel bolts for raising the ARM off the substrate to create ‘cryptic space’. An additional 10 mm diameter hole is used for attaching a shackle and tether chain. The ARMs are cut using a computer numerical control (CNC) router by Xanderware (see Appendix C). See Appendix F for the CNC cut file and instructions.

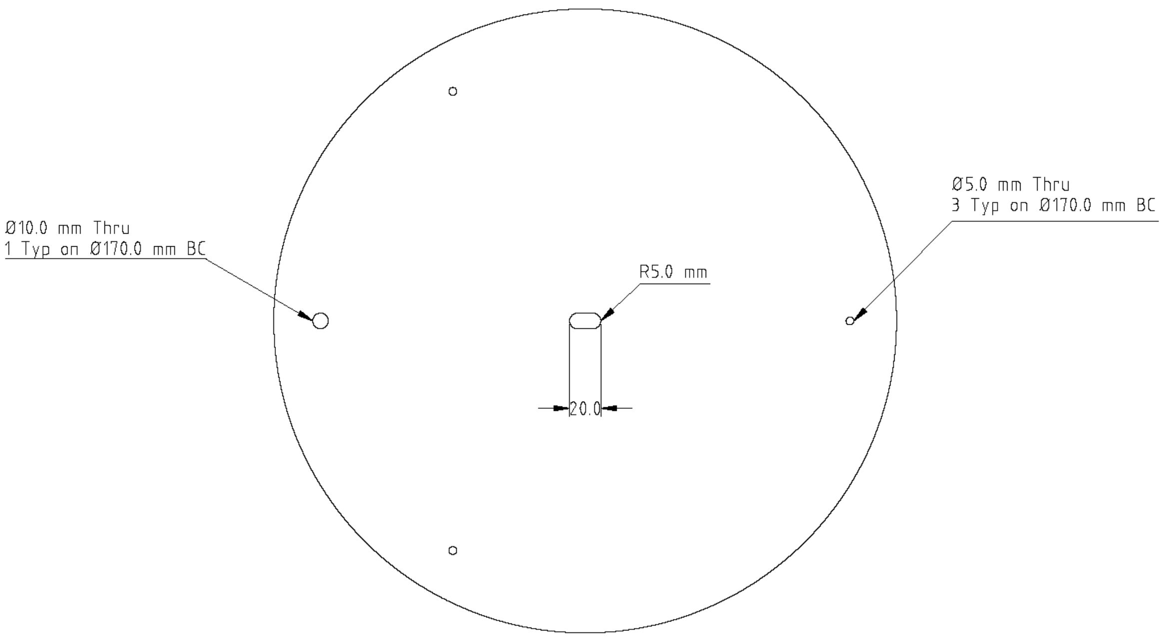

Figure 11. Abalone Recruitment Module (ARM) detailing cutting dimensions.

1.1. Chain tethers

The ARMS are tethered to the main chain with 1.5 m of 6 mm galvanised chain (Figure 2). The threads of the shackles are dipped in Lanolin grease to slow the corrosion process. Shackles are then tightened with a shifter and ’moused’ off with a cable tie to prevent un-twisting of the bolts. For ease of transport and set up, attach the tethers to the ARMs before going in the field. If using ARMs with a countersunk central hole rather than slot, ensure the shackle bolt feeds in from the top-side of the ARM so that the ARM isn’t fouled on the substrate when adjusting the height (i.e. the side opposite the countersunk centre hole). The tether chain and shackles can be sourced from Tasmanian Marine Distributors (TMD) (see Appendix C).

Figure 12. Assembled ARM and tether ready for installation.

1.2. Baseline chain

The baseline chain provides an easy way to locate and anchors the ARMs to the substrate if they become detached from their anchoring bolt. The gauge of chain used depends on the exposure of the site. In exposed sites, 13 mm PWB Regular Proof Coil Chain is preferred. Moderate to sheltered sites have been set up using 10 mm chain successfully. For a standard string of 20 ARMs, 30 m of chain is deployed. Extensions of 5 m can be added to the baseline chain with shackles to provide additional space in the event of unsuitable locations for the ARMS in the initial 30 m. Tie loops of thin cord (e.g. 5 mm trawl twine) at 5 m intervals to allow attachment of lift bags during deployment and to provide a reference for spacing ARMS/tethers (see ARM installation section). Baseline chain can be purchased from The Rope and Chain Company (see Appendix C).

1.3. Fastening bolts

ARMs are secured to a length of M8 x 1.25 316 stainless steel threaded rod and M8 x 316 DynaSet DropIn Anchors drilled into the substrate. The length of threaded rod can vary depending on the substrate type however a good compromise is around 110 mm long. Threaded rod can be purchased in 1 m lengths and cut with an angle grinder. Ensure the ends are chamfered with a linishing belt or grinder flapper wheel to remove sharp burrs and to prevent binding on fastening knob and drop-in anchor. Two (2) M8 x 1.25 Hex stainless steel nuts are also threaded onto the rod and are used for tightening the rod into the drop-in anchor. For ease of transport loosely assemble the components according to Figure 3. All fasteners can be sourced from Nuts and Bolts, Tasmania (see Appendix C).

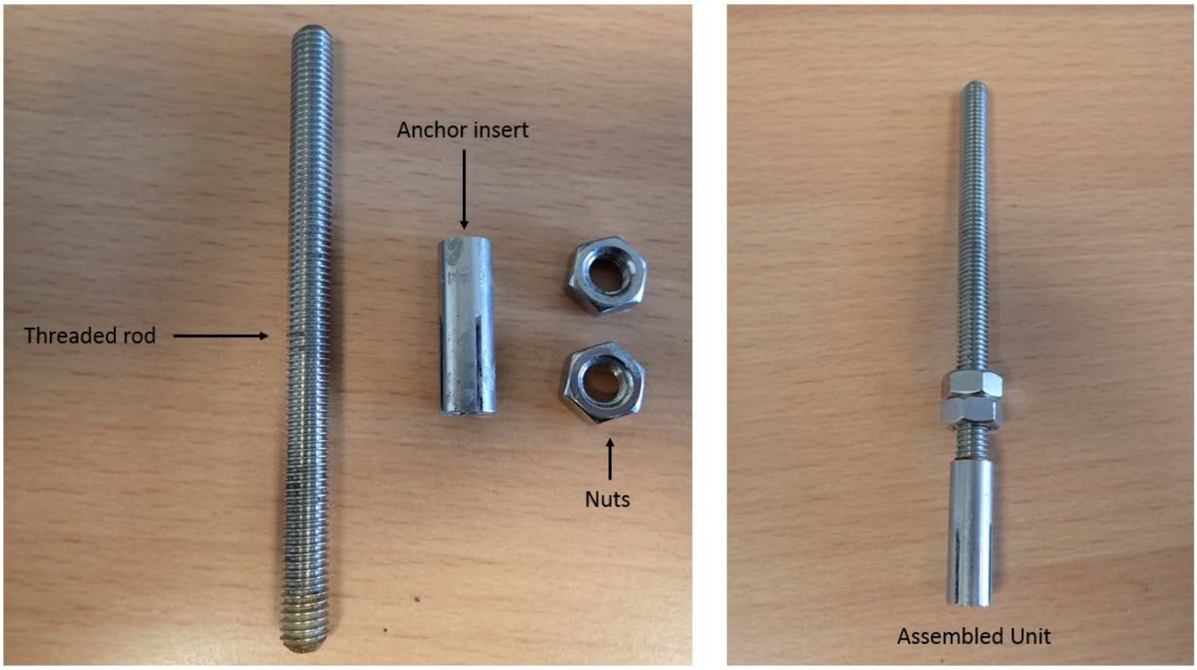

Figure 13. The drop-in anchors, threaded rod and tightening nuts (left) and assembled unit (right).

1.4. Fastening knobs

Fastening knobs are made from 35 mm, black acetyl rod, cut into 75 mm lengths. The knobs are threaded M8 x 1.25 in the centre with a 20 mm unthreaded section at one end and 40 mm at the other (Figure 4). The unthreaded section is an allowance to take up excess threaded rod and to reduce the time taken to tighten the knob on the ARM. Acetyl rod is supplied by Allplastics Engineering or Tas Bearing and Chain (Figure 5) (see Appendix C).

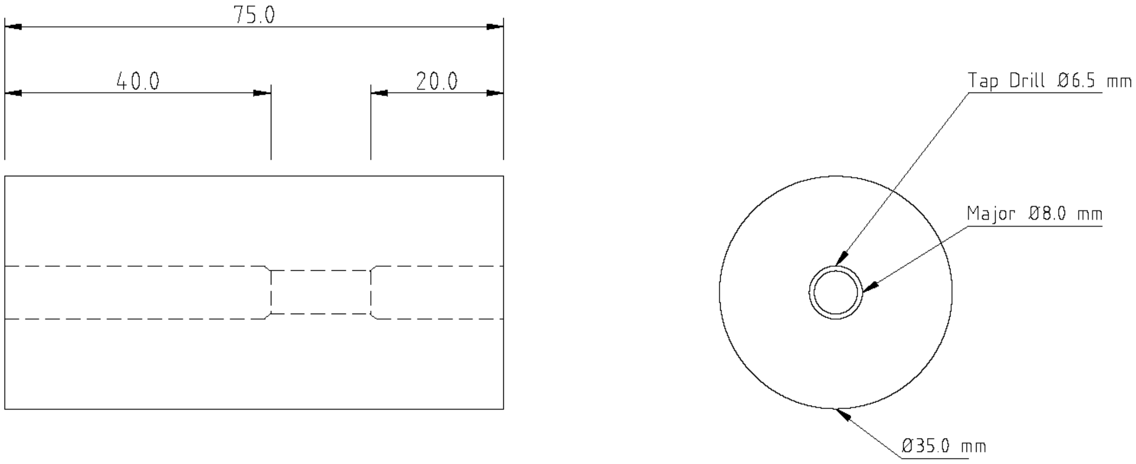

Figure 14. ARM fastening knob detailing machining dimensions.

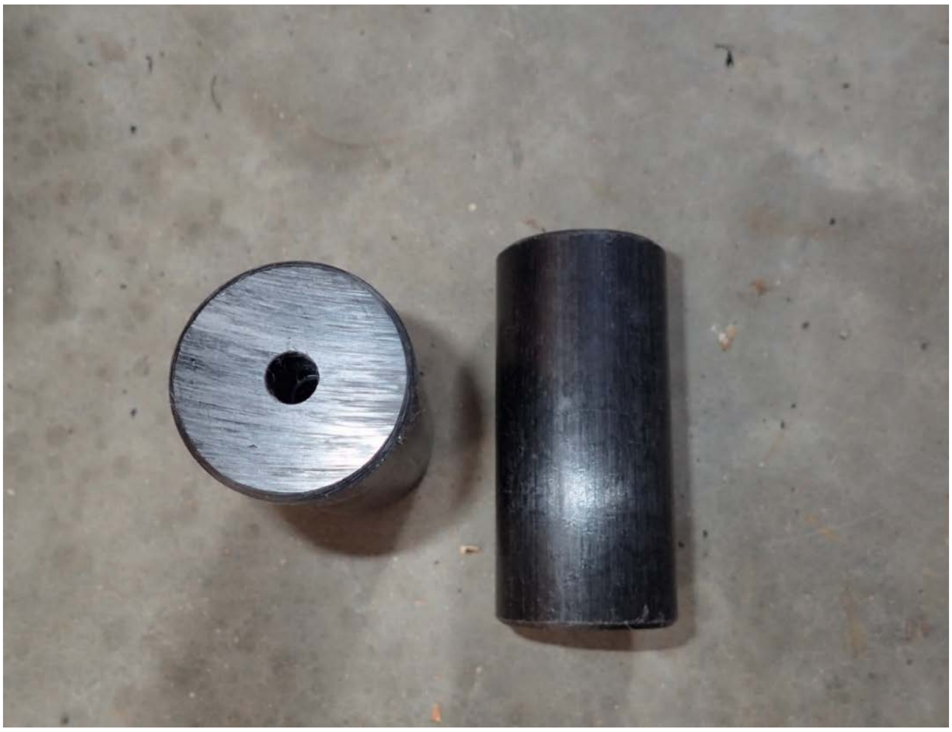

Figure 15. ARM fastening knob.

1.5. Labels

ARMs are individually labelled with cattle ear tags (1-20) attached to the ARM tether shackle with a cable tie (Photo of ARM with label). These can be printed with appropriate label e.g. IMAS 1. Printed tags can be sourced from Livestock ID Online (see Appendix C).

1.6. Sub-surface buoys (optional)

ARMs can become highly fouled and difficult to see under some conditions. To help with re-locating ARMs, each end of the baseline chain can be marked with a sub-surface buoy. Sub surface buoys consist of a small net float (Yellow SHE-6) attached to plastic coated wire, crimped with copper crimps and covered in heat shrink, and attached to the baseline chain with stainless steel shackles (Photo of float underwater). Floats can be sourced from TMD and wire/crimps from Wellsys Tackle (see Appendix C).

2. ARM Installation

2.1. Overview

The ARMs are secured to the substrate with the threaded rod assembly and fastening knob while three adjustable riser bolts are located on the perimeter to control the space between the ARM and the substrate (Figure 6). One of the riser bolts is also used to prevent the plate rotating, by locating the riser bolt within a shallow hole drilled into the substrate. This also provides increased security in adverse sea conditions, and ensures the ARM is replaced in the same orientation each time.

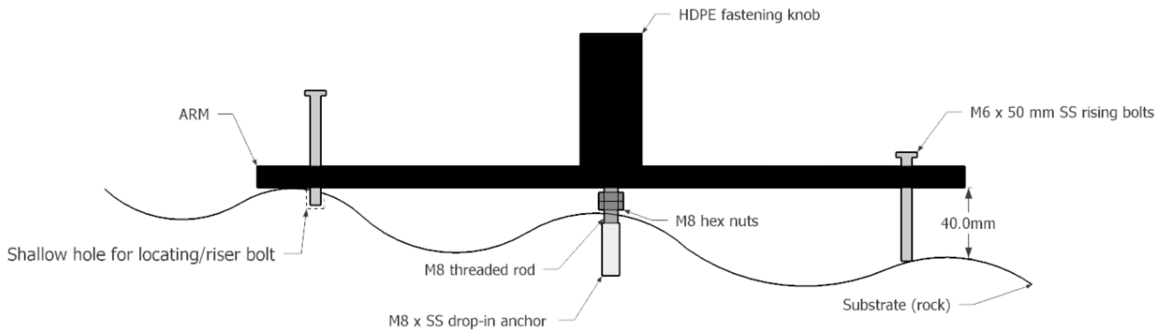

Figure 16. Cross-section view of ARM configuration and installation.

2.2. Dive team

Installation of ARMs is conducted by a team of at least four people, with one person remaining on the vessel at all times and up to three divers in the water. The makeup of the team will be dependent on the set up of the boat and the conditions of the site. The diving team normally consists of a ‘driller’, driller assistant, and a ‘fixer’. The divers complete relatively independent tasks during the installation process. The driller normally selects the ARM position on the substrate and drills the fastening holes, with the assistant handing tools and fasteners to the driller as required. The fixer follows closely behind the driller and adjusts the height of the ARM above the substrate, mouses off shackles and attaches labels. Once the team is familiar with the work a string of 20 ARMs can be installed in 2-3 hours.

2.3. Site selection

Broad site selection will largely be determined by the goals and scientific design of individual projects. The substrate should consist of suitable rocky reef for abalone of a ‘hard’ rock type such as granite or dolerite. The ARMs can be set up in ‘softer’ rock types but suffer a greater degree of damage due to the properties of the rock. The ARMs are designed to provide suitable cryptic habitat for juvenile abalone, however they will attract other fish and marine invertebrates and algae will colonise the surfaces.

In low profile reef or small boulder habitats, or sheltered sites, it is unlikely that the baseline chain will move with the swell. In higher profile habitats the chain is likely to ‘fall’ in to cracks and crevices after a large swell and should therefore be taken into consideration when laying the baseline chain. In areas of significant sand movement or gravel/cobble substrate the chain may sink and be hard to follow.

Evaluation of current ARM deployments suggests even with large sample sizes (n = 20) they are best suited to detecting larger rather than small magnitude differences in juvenile abalone density through time (Mundy et al. 2018). Therefore consideration should be given to selecting sites that have the capacity to install at least 20 ARMs.

It is recommended divers perform an assessment of potential sites before choosing to deploy ARM equipment. Once a suitable site has been chosen, used surface buoyed shot lines to mark the approximate position of where the 30 m baseline chain is likely to lay. Leaving the shot lines in place provides a reference point for deploying the baseline chain from the vessel.

2.4. Deploying the baseline chain

Deploying the baseline chain should be done with care as it is extremely heavy. Effective communication lines should be established, and care should be taken by all in the process. The exact method of deployment will be governed by the sea conditions on the day and experience of the crew but typically the chain is deployed directly from the vessel and then spread out by divers. The suggested technique is to lower one end of the baseline chain to the seabed at one of site marker shot lines. A diver then inflates lift bags attached to the corded loops at the surface as the remainder of the chain is fed out. The diver then secures the lowered end to the substrate by wedging it into a crack and ‘floats’ the trailing end of chain towards the other marker shot line. A long rope tether can be used by the vessel to help assist the diver manoeuvrer the baseline chain. The diver then deflates the lift bags and guides the chain into its final position.

2.5. Spacing the ARMs

The driller assistant and/or fixer will generally space the ARMs out along the baseline chain close to their fixing positions while the driller begins drilling and installing fasteners. Spacing the ARMs out along the baseline prevents them from becoming tangled and aids the drilling process. It is best to simply loop the tether chain around the baseline rather than fix in place with the shackle so that adjustments to the final position of the ARM can be easily made by the driller. ARMs can be fixed to either side of the baseline chain within the 1.5 m restriction of the tether chain. ARMs should be spaced so they will have minimal interaction with other ARMs or as per the project design. Using the 5 m spaced cord loops provides a good reference for spacing.

2.6. Individual ARM positions

The final position of the ARM should be as low and flat in the substrate as possible, giving sufficient room for removal by the service team. ARMs will collect in horizontal and vertical positions, but thought should be given to the sources and locations of suitable cryptic habitat surrounding the ARMs, where juvenile abalone may currently inhabit (e.g. bedrock extending out from ledges and overhangs containing abalone). Avoid placing ARMs on top of unstable rocks which may move in heavy sea conditions. Algae should be removed with a paint scraper before the ARM is installed. (This is where we could add a couple of mock photos of good and bad deployments on a rock in the yard)

2.7. Tools and equipment

2.7.1. Driller tools and equipment

Most of the installation tools are carried by the driller and/or driller assistant and should be carried in a catch bag or similar to prevent losing items (Figure 7):

- Offset 12/13 mm ring spanner
- Open end 13 mm ring spanner
- Adjustable spanner
- Club hammer
- 6 mm parallel pin punch
- Drilling template
- Heavy duty paint scrapper
- Rotary hammer drill
- 10 mm SDS masonry drill bit
- Threaded rod assemblies x 20 (plus 2-3 spares)
- Fastening knobs x 20 (plus 2-3 spares)

The drilling template is made from 12 mm acetyl or lead-weighted HDPE and is used as a guide for the drilling the shallow locating hole relative to the threaded rod (Figure 8). It is also worth attaching the pin punch to the hammer with a short tether so that it is easy to find amongst other equipment (fig. 6). See appendix G for CNC cut files and instructions.

Figure 17. Tools required by the divers to install the ARMs (left to right) 12/13 mm offset ring spanner, 13 mm open end ring spanner, adjustable spanner, 10 mm socket, and club hammer with tethered pin punch.

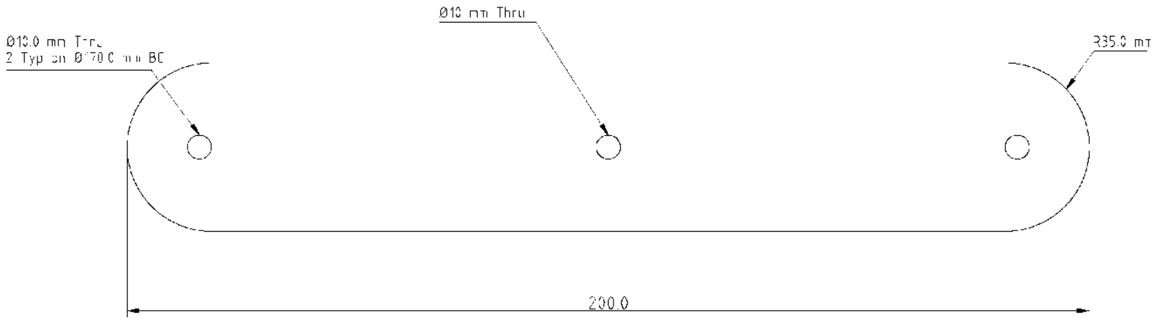

Figure 18. ARM drilling template detailing the dimensions.

2.7.2. *Fixer tools and equipment*

- 10 mm socket with custom winder handle
- Adjustable spanner
- M6 x 50 mm bolts x 60 (plus spares)

- Cattle ear tag labels x 20
- 100 and 200 mm cable ties x 20 each (plus spares)

The 10 mm socket with custom winder handle is used to wind down the riser and locator bolts when adjusting the ARMs into their final position (Figure 7). It was made by drilling a 5 mm hole into the side of a 10 mm socket and threading a M6 x 100 mm 316 stainless bolt into place. This tool speeds up the process of adjusting the riser bolts to their required heights.

2.7.3. Drilling equipment

A hydraulic hammer drill (Spitznas model. II2GcT6) with SDS-plus shank is used to drill the holes required for the drop-in anchor and locating riser bolt (Figure 9). The drill is powered by a hydraulic pump and petrol motor (9.5 hp) unit, mounted in a frame. Hydraulic hose 40 m in length supplies the drill with oil (Photo of hydraulic power unit(s) and hose).

Figure 19. Hydraulic drill fitted with FF Series Flush Face Non-spill 316 Stainless couplings to minimise corrosion.

The hydraulic drill and pump require a separate induction. Please ensure you carry an emergency spill kit, particularly absorbent pads. The surface attendant should wear appropriate hearing protection; divers may wear a secondary hood to reduce noise. Please be aware of the maintenance requirements of this equipment before use. (See Appendix A for operating and maintenance procedures when using the hydraulic drill and power unit).

A battery operated SDS underwater rotary hammer drill manufactured by Nemo Power Tools is also available to use as an alternative tool for drilling (Photo of battery drill). Initial trials with this drill are promising and provide several advantages over the hydraulic drill. Unfortunately, at the time of writing this document the drill had malfunctioned and was being assessed for repair by the manufacturer.

SDS-plus 10 mm masonry drill bits are required for drilling the drop-in anchor and locator hole, with quad head bits recommended for dolerite and granite rock types. Monitor the sharpness of the drill bits and replace as required.

2.8. Drilling the drop-in anchor and locating holes - ’Driller’

Once the final ARM position has been identified and cleared of encrusting algae, etc, the driller can proceed to drill the central hole, which will house the drop-in anchor and rod assembly. The sequence of tasks for the driller/driller assistant should follow:

1. Drill the central hole to the depth of the anchor (30 mm) or deeper in ‘soft rock’ substrates. When drilling, hold the drill as close to 90° to the substrate as possible. This will ensure the fastening rod is at right angles to the substrate which minimises the plate ‘pinching’ on the thread when it is installed and maximises the contact of the ARM with the fastening knob when it is tightened (Mock photo of good/bad hold).

2. Remove debris from the hole and place rod assembly in hole checking that the hole is deep enough for drop-in anchor. Drill deeper if required and leave rod assembly in place.

3. Slide the centre hole of the template over the rod assembly and align the locating hole on the template over the rock so it will be opposite the position of the tether chain on the ARM. Drill the locating hole through the template guide to a depth of approximately 10 mm.

4. Remove the template and unscrew the rod from the drop-in anchor and insert the anchor into the hole.

5. Using the punch and the hammer, set the anchor, by striking the central pin inside the anchor.

6. Thread the rod into the anchor and use the 13 mm offset ring spanner on the double nuts to tighten the rod and flare the anchor securely into the substrate.

7. Adjust the double nuts so the lower nut ends up no more than 5 mm from the face of the substrate and tighten. This allows the ARM height to be adjusted without fouling on the nuts.

8. Place the ARM on the tightened rod assembly and loosely secure in place with the fastening knob.

2.9. Adjusting the height of the ARM - ’Fixer’

The fixer sets the height of the ARM and fastens the ARM to the substrate. The general sequence followed is:

1. Thread the M6 x 50 mm riser bolt into the locating bolt hole (opposite the tether fastening shackle), threading it in according to the depth of the locating hole set by the driller. The ARM should touch or sit close to the substrate at the locating bolt.

2. Thread the two remaining riser bolts to adjust the height of the ARM off the substrate at the

leading edge. This is typically 30-40mm or as determined by the project design.

3. Tighten the fastening knob until all movement is removed from the ARM.

4. Tighten the tether shackle to the baseline chain and mouse off with small cable tie.

5. Gather any loose tether chain and cable tie to the baseline chain to minimise drag on the ARMs by water movement or tangling with algae.

6. Cable tie the label to the shackle attached to the ARM. Try to place the label under the front edge of the ARM as this will reduce the fouling on the label and make identification easier at re-survey.

Note: the current design uses 50 mm bolts as risers, and once threaded all the way through create a 35 mm gap. Longer bolts can be used if the substrate is uneven and causes the 50 mm bolts to bottom out before contacting the substrate.

2.10. Record site location

Accurate GPS positions should be taken of the first and last ARM in the string by a tight shot line to the surface once the installation has been completed.

3. ARM re-survey and assessment

3.1. Habitat conditioning

Depending on the ecology and diversity of the algal and sessile invertebrates of the habitat, the ARMs may take 6-12 months to condition. The species composition under the ARMs will change due to the lack of light and recruitment of coralline and other algal species (Figure 10). Abalone will attach themselves to both the under surface of the ARM and substrate below.

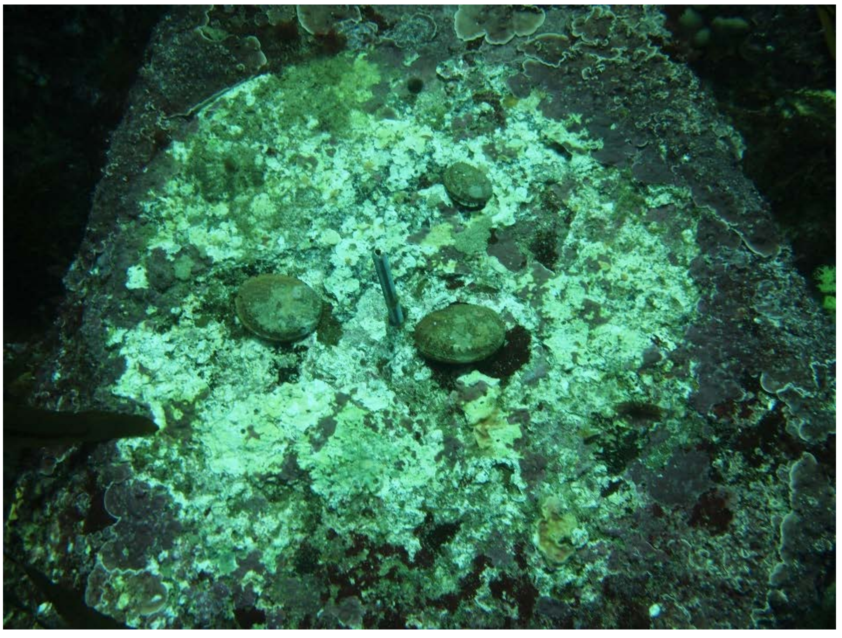

Figure 20. Juvenile abalone on rock protected by an ARM. Distinctive ring of dead coralline algae due to the lack of light under the ARM.

3.2. Re-survey procedure

Re-surveys of the ARMS are conduced periodically according to the requirements of the project. Using the GPS location marks, deploy shot lines from the boat; aim for a 2 m accuracy. Accurate GPS marks will save search time. Divers then enter the water and locate the ARMs via the sub surface buoys.

The general technique used to assess the ARM collection is to remove the fastening knob from the rod assembly, lift the ARM and count and measure the abalone attached to the plate and the substrate underneath. Abalone attached to the underside of the ARM are denoted by circling the measurement on the data sheet. Replace the ARM, ensuring the locator riser bolt is in the locator hole and fasten with the knob. Continue until all the plates have been checked. Record other data as required.

Given the diver is expected to perform several tasks during the re-survey of each ARM, the exact technique used will often come down to the individual and is sometimes dictated by the sea conditions on the day. Use the following tips as a guide for conducting ARM assessments:

- The fastening knobs are negatively buoyant, so they can be placed on the substrate or once the ARM is removed placed over the rod assembly.

- Large numbers of abalone can be tapped on the shell to initiate the foot into gripping on to the substrate and prevent the abalone from 'walking' away.

- Measure the abalone on the underside of the ARM first as they will often let go once disturbed and float away. Try to wedge the ARM under a rock while assessing abalone on the substrate.

- Measure 3-4 abalone at a time and then record on the data sheet to speed up the process.

- Look closely for very small abalone (under 20 mm SL) which have a purplish appearance and camouflage very well (Figure 11). Abalone of this size may also be hidden under brittle or feather stars. Measure these as a priority as they are more likely to move away.

- The presence of wrasse and other predatory fish will motivate the abalone to find shelter quickly. They are particularly vulnerable to predators at this size, so you may have to fend predators off.

- Using two divers to assess ARMs is recommended when sea conditions are less favourable or when predators become a nuisance. One diver can remove and hold the ARM, defend off predators if present, while the second diver can concentrate of recording the abalone both under the ARM and on the substrate.

- Align the locating bolt with the locating hole before you put the plate back down and start to tighten it up.

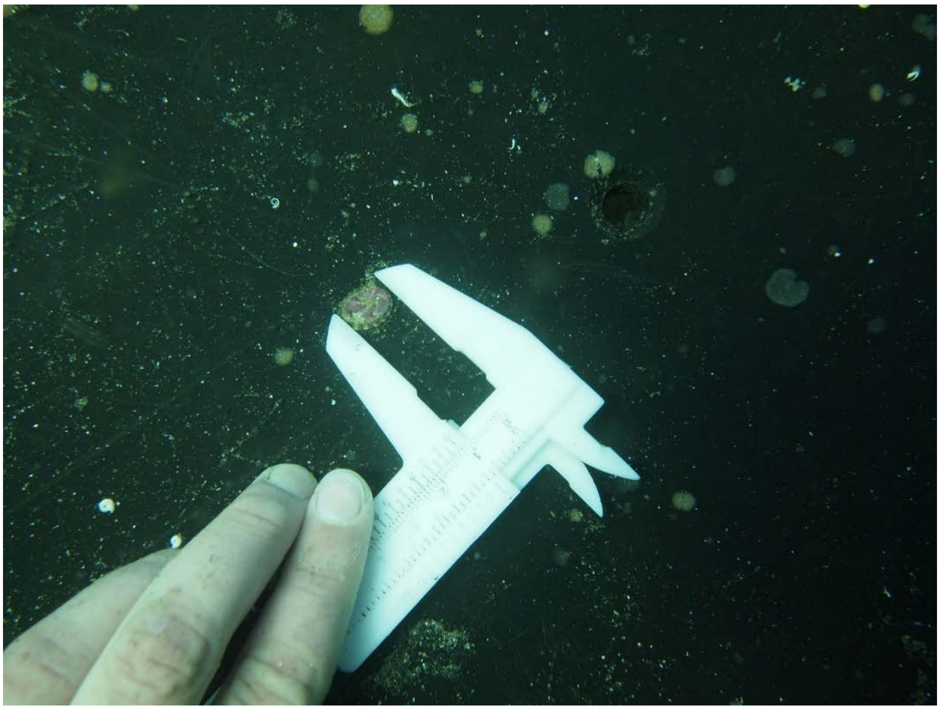

Figure 21. Measuring juvenile abalone with Vernier callipers. Small abalone can be difficult to identify from the fowling on the plates and the rock underneath.

4. Servicing and maintenance

Depending on the exposure of the site, repairs will have to be made from time to time. A repair kit in a catch bag containing, tools, replacement fasteners, and labels will enable basic repairs to be conducted during the re-survey dives.

Major repairs include re-drilling and replacing ARMs. These are normally done separate to re-surveys given the extra equipment and time required. In a bad year of poor weather expect around a 15% replacement of ARMs.

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Appendices

Appendix A Hydraulic drill and power unit

The Spitznas (model. II2GcT6) hydraulic hammer drill with SDS-plus shank can be used to drill the holes in hard substrate during underwater operations. The drill is powered by a custom made hydraulic pump and Honda GX270 petrol motor (9.0 hp) unit, mounted in a frame with a pressure bypass regulation valve. Hydraulic hose 40 m in length supplies the drill with oil. The hose is also fitted with a pressure relief safety value at the drill end. To prevent corrosion and improve longevity it is recommended all hose connections are replaced with 316 stainless steel fittings (e.g. FF Series Flush Face Non-spill 316 Stainless couplings).

A.1. Pre-trip checks

1. Depending on the hydraulic power unit check the hydraulic oil level in the reservoir tank. This can be done by viewing the sight glass or checking that oil reaches the bottom of the filler gauze. Use ISO 46 Hydraulic oil to top up if required; this seems to have the best viscosity for cooler water temperatures.

2. Check fittings on pump for corrosion and wipe clean with cloth.

3. Check hydraulic hose for nicks and check fittings are operational.

4. Connect drill to safety value on hydraulic hose first, then connect hose to hydraulic pump.

5. Open the bypass value on hydraulic pump and check the motor runs. DO NOT START MOTOR WITHOUT VALUE OPEN OR IF NO HOSES ARE CONNECTED TO PUMP.

6. Check hose and drill for leaks. Test drill operates, and the hammer function select shift is working. Depending on the hydraulic power unit, a pressure gauge can be monitored to ensure the pressure remains between 100-120 PSI during operation. DO NOT EXCEED 120 PSI as this is the maximum working pressure of the drill. Once the oil is warm the pressure will normally fluctuate between 80- 120 PSI as the drill trigger is depressed. The pressure can be regulated by adjusting the throttle of the motor and/or by opening the relief/bypass value. If using the hydraulic power unit fitted with the Prince RDRS-100 relief value, the pressure regulator value can be adjusted by removing the acorn nut, loosening the jam nut and turning the adjusting screw clockwise to increase the pressure and counter clockwise to decrease pressure.

A.2. Equipment list for field operations

It is recommended to carry the following equipment for the hydraulic drill and power pack:

- Emergency spill kit (particularly absorbent pads)

- Engine starter recoil kit (Honda part# 28400-ZE2-W022ZN)

- Engine starter pull cord

- 4 ltr Hydraulic oil (ISO 46 grade) and funnel

- Tools (Metric/AF socket set/ring spanners, screw drivers, etc)

- Spark plugs (Honda part# 98079-55846)

• INOX lubricant spray

• Rags or absorbent pads

• 10 ltr fuel can and funnel

A.3. Boat work

1. It is advisable to anchor the vessel as close to the drilling site as possible (i.e. within 20-30 m) when using the hydraulic drill. Working the vessel 'LIVE' when using the drill should only be performed in calm conditions and by an experienced team.

2. Assemble drill and hydraulic hose (OPTIONAL: fit desired drill bit).

3. If using an SSBA compressor, ensure exhaust from the pump is well away from the air intake of the SSBA.

4. Run the pump to warm up the hydraulic fluid in the hoses and reservoir before the commencement of drilling. Start with the bypass open and slowly close, whilst at the same time depressing the trigger of the drill to allow oil to circulate through the hose. Doing this allows the oil to warm up and will prevent the motor from stalling due to the increased viscosity of cold fluid.

5. Between divers and surface attendant, agree on when the pump will be switched ON and OFF and what signals will be used to dictate this. For example; for surface attendant Surface Marker Buoy (SMB) visible = drill ON, SMB not visible = drill OFF. During ARM installations the power unit will normally stay switched on until the installation is complete or divers are having a surface interval.

6. The drill can either be passed to a diver at surface who then attaches and inflates a lift bag to help carry the drill to the site, or the drill can be lowered to the diver on the bottom.

7. Feed hose out as diver moves away from the vessel.

8. Once the pump has been started based on earlier discussions with divers ensure the bypass is CLOSED so that the drill will operate.

9. Monitor pump and hose throughout dive. Pay attention to the pressure gauge (if available), and the hose near outboards and chances of entanglement with kelp.

10. In the event of a pump or noticeable hose failure during operation, the surface attendant should IMMEDIATELY shut the hydraulic power unit OFF.

A.4. Diver

1. When using the hydraulic drill, try to minimise unnecessary wear on the drill and hoses by not dragging them across the substrate.

2. Use a lift bag to help manoeuvre the drill and hose where appropriate.

3. Try to keep the hoses relatively straight and avoid using the drill at sharp angles to avoid putting extra strain on the hoses and fittings.

4. In the event of a hose failure underwater, the divers should IMMEDIATELY signal to shut the hydraulic power unit OFF with their SMB or safely ascend to notify the surface attendant.

A.5. Post-dive checks

1. Thoroughly wash all drill components and hose in freshwater.

2. Dry drill preferably with compressed air.

3. Spray and wipe down drill with suitable spray lubricant (INOX).

4. Check hydraulic oil level in reservoir and wipe down pump with WD-40.

5. Replace damaged or worn hoses and parts where necessary.

A.6. Servicing and maintenance

It is recommended the hydraulic drill be serviced every 6-12 months or after a period of constant underwater use. There are several internal components which require periodic maintenance and should only be attempted by an authorised service agent.

Hydraullic and Phneumaic Engineering supplied the most recent Spitznas drill and hydraulic power unit and are the agents for drill repairs and servicing.

Hydraulic hoses, fittings, and pumps for the original hydraulic power unit were sourced from Wellco.

The hydraulic power unit motor can be serviced by Roberts Don Mac who are service agents for Honda small engines.

Emergency repairs to hydraulic hoses in the field can be arranged with the ENZED Field Service Fleet (ph. 6273 0706). General maintenance of hoses can also be done by ENZED.

Appendix B Abalone Research Team

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Dr. Jaime McAllister

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David Faloon

Appendix C Supplier Contacts

Allplasitcs Engineering Pty Ltd

Unit 20, 380 Eastern Valley Way

Chatswood

NSW 2067

Phone: (02) 94176111

Email: sales@allplastics.com.au

Xanderwear

87 Chapel Street

Glenorchy

TAS 7010

Phone: 03 62737457

Website: www.xanderware.com.au

Rope and Chain Company PTY LTD

13 Goodman Court, Invermay

TAS 7148

Phone: (03) 63266620

Website: http://ropenchain.com.au/

Tasmanian Marine Distributors

28 Mertonvale Circuit

Kingston

TAS 7050

Phone: (03) 6229 6741

Website: http://www.tmdmarine.com.au/

Hydraullic and Phneumaic Engineering

90 Mornington Road

Mornington

TAS 7018)

Phone: (03) 6244 5755

Wellco

39 Derwent Park Road

Moonah

TAS 7009)

Email: sales@wellco.com.au

Phone: (03) 6272 3011

ENZED

37 Sunderland Street

Moonah

TAS 7009

(03) 6273 0706

Livestock ID Online

Website: https://livestockidonline.com.au/

Wellsys Tackle

Unit 8 Linkway Centre

1 Metier Linkway

Birtinya

QLD 4575

(07) 5493 5412

Website: https://www.wellsystackle.com.au/

Appendix D ARM Material list and costings

The following table provides a list of the materials, their suppliers and approximate costing required to install a complete system consisting of 20 ARMs.

Item	Material	Units	Unit price	Price
ARM	12 mm HDPE - CNC supply and cut	20	$ 15.00	$ 300.00
Centre pins	M8 316 threaded rod (110 mm)	2.5	$ 12.10	$ 30.25
Tension nuts	M8 316 hex nut	40	$ 0.22	$ 8.80
Centre knobs	36 mm Acetal rod	2	$ 34.00	$ 68.00
Anchors	M8 x 316 DunaSet DropIn Anchor	20	$ 4.51	$ 90.20
Tether shackles	6 mm galv. D-shackle	40	$ 0.80	$ 32.00
Tethers	6 mm galv. Chain (1.5 m)	30	$ 3.30	$ 99.00
Riser screws (short)	M6 x 50 mm 316 set screw	60	$ 0.44	$ 26.40
Riser screws (long)	M6 x 100 mm 316 set screw	10	$ 0.76	$ 7.60
Transect chain	PWB Regular proof 10 mm coil chain	30	$ 5.85	$ 175.50
Marker tags	Large cattle ear tags	20	$ 1.00	$ 20.00
Mousing	100 mm cable ties	40	$ 0.05	$ 2.00
Marker fasteners	200 mm cable ties	20	$ 0.10	$ 2.00
			Total	**$ 861.75**

Appendix E Juvenile ARM data sheet

Juvenile ARM data sheet (Paper size: A5).

Date: Diver:

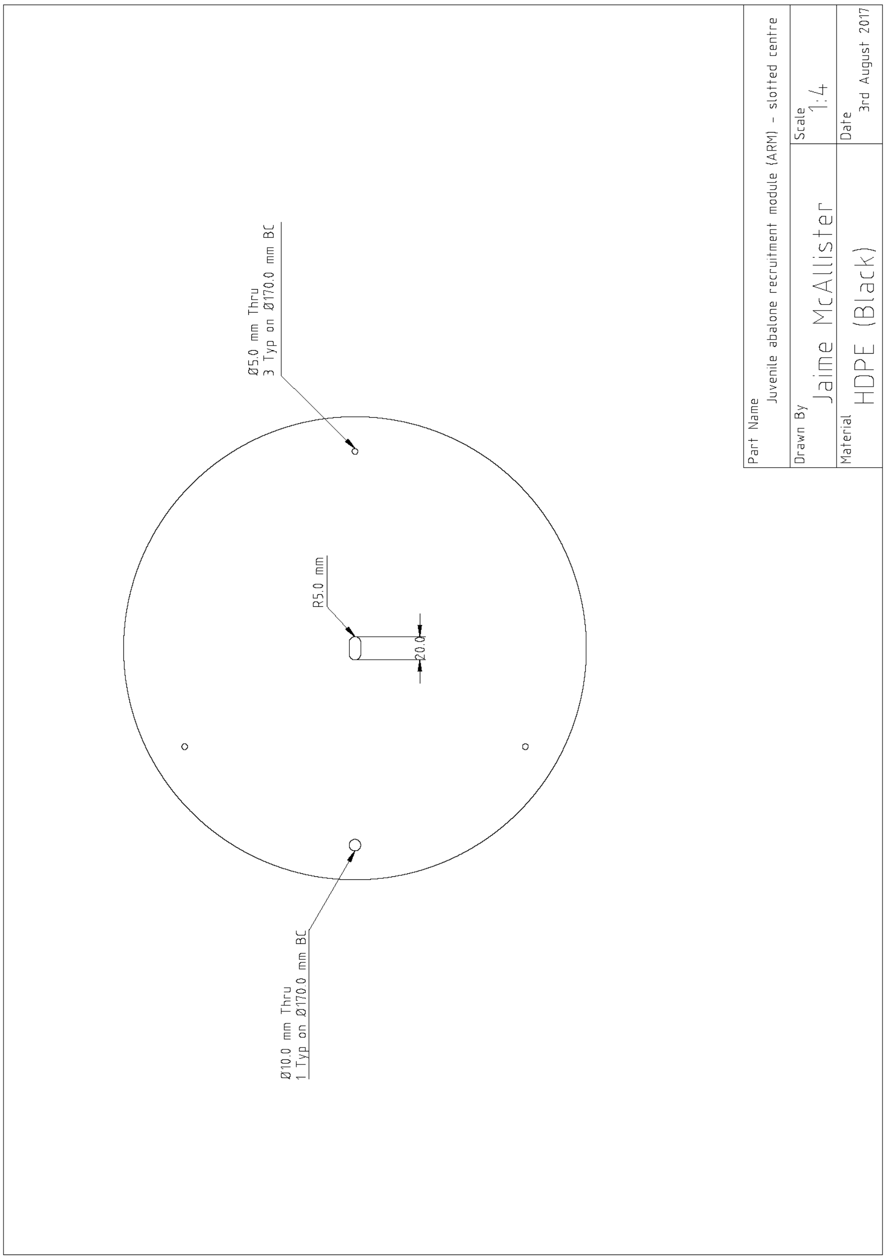
Site:

Collector #	Abalone length (mm)

Appendix F Abalone ARM CNC cut file and instructions

The ARM CNC cut file can be located at:

R:\TAFI\TAFI_MRL_Sections\Abalone\Section Shared\Field\Field SOPs\ARM SOP\Abalone_ARM_CNC file.dxf



Appendix G Abalone ARM drilling template

The ARM drilling template CNC cut file can be located at:

R:\TAFI\TAFI_MRL_Sections\Abalone\Section Shared\Field\Field SOPs\ARM SOP\Abalone_DrillTemplate_CNC file.dxf