

# Long-term colonization of a subarctic pre-planned artificial reef system in Whittier, Alaska

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**ABSTRACT:** In 2006 Alaska's first artificial reef (AR) was deployed as mitigation for habitat lost due to coastal development. Surveys conducted the following year suggested AR assemblages resembled those of adjacent natural reefs (NR). However, there is little known about the ecological succession of AR's long-term in high latitude locations. Therefore, long-term surveying of community composition is necessary to know if AR's will display ecological succession similar to natural reefs over longer temporal scales. Dive based surveys were conducted June-December 2016 to document the community composition of demersal fish, macroalgal and invertebrate assemblages. Assemblages were pairwise tested for differences in year, reef type and season, and between two methods commonly applied in quadrat sampling. *Sebastes spp.* Was the dominant family present, There was a shift in dominant macroalgae from *Laminaria saccharina* to *Agarum clathratum*, and richness increased significantly from 2 species in 2007 to 12 species in 2016 indicating macroalgae in Alaska are particularly sensitive to ecological succession. Although fish and invertebrate densities were higher at fish havens, there were few other discernable differences between reef type and seasonality was not significant. The AR in Whittier appeared to follow a successional pattern characteristic of Alaska rocky reefs, and has surpassed the AR in 2007 in terms of diversity for fish and macroalgae.

**KEYWORDS:** Succession, temporal, high latitude, kelp

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## INTRODUCTION

The majority of Alaska's economic activity occurs along the coast, and contributes to over 50% of the U.S. coastline (USFWS 2012). Coastal development in Alaska is increasing at a rate four times that of other parts of the country (NMFS 2003) and poses a potential threat to coastal habitats (USFWS 2012). Increased development can have deleterious impacts on local nearshore habitats due to activities involved such as dredging, sheet-pile dock construction, tidal filling and overall increased usage in the area (Hanson et al. 2003, Johnson et al. 2008, Reynolds 2009). A lack of proper mitigation for coastal habitats could damage these important populations of these fishes, with potential repercussions for the economy and local subsistence (USFWS 2012).

A potential solution for fish habitat loss is the installation of an Artificial Reef (AR) system (Bohnsack and Sutherland 1985). AR systems were designed to emulate natural reef sites with the intent of increasing reef-associated species production (Carr and Hixon 1997), but can also address mitigation of habitat loss and natural reef relief (Leeworthy, Mayer and Stone 2006). AR systems have been successfully deployed for similar fish habitat restoration and enhancement projects in tropical and subtropical regions (Baine 2001), and for mitigation in temperate waters of California (Grannemen and Steele 2014) and Washington (Cheney et al. 1994). However, few AR systems

have been documented in high latitude marine environments (Hunter and Sayer 2009, Reynolds 2009). Sargent et al. (2011) observed density increases of fishes and invertebrates on a small spatial scale at a subarctic AR system off Newfoundland, Canada, however there was no indication of long-term temporal effects. An AR system was installed in Juneau, Alaska (Eckert 2010) for mitigation with follow-up surveys conducted for two subsequent years. There was an immediate recruitment of fishes and some invertebrates. However, bare rock was the primary cover for both years, and the AR did not see a significant increase in *Agarum clathratum*, which is one of the dominant foundational macroalgae species in Alaska. Eckert (2010) concluded that long-term monitoring was needed due to the extended time often required for reef maturation.

Studies in low latitude marine environments may not be applicable to high latitude marine environments, and AR systems are heavily influenced by ecological factors specific to their environment (Baine 2001). Lower latitude nearshore habitats tend to favor low-relief coral habitat as opposed to higher latitude nearshore habitats of Alaska, which are often characterized by high-relief rocky substratum and macroalgae (Bodkin 1986, Reynolds 2009) and extreme seasonality in respect to temperature and light availability, whereas temperate habitats do not experience such pronounced seasonality (ADFG 2015). Macroalgae is a foundational component of increased habitat complexity, which in turn promotes fish and invertebrate recruitment (Markis and Konar 2007) as well as survival and growth in some temperate environments (Holbrook et al. 1994). The long-term success of some fishes may depend directly on the continuity associated macroalgae communities (Efird and Konar 2014). However, macroalgae cover can show significant variation long-term; a macroalgal assemblage can thrive for several years before rapidly changing state (Holbrook et al. 1994). Macroalgae are clearly a key component of reef communities, providing essential canopy structure, and need long-term monitoring to understand how assemblages change over time (Perkol-Finkel et al. 2006).

A collaborative effort between Alaska Marine Lines (AML), Prince William Sound Science Center (PWSSC) and National Marine Fisheries Service (NMFS) deployed Alaska's first AR system in 2006 as part of a mitigation settlement for AML's facility expansion in Whittier Harbor (USACE 2005). Two types of reef structures were deployed: Reef Balls® (RB) and Fish Havens® (FH). The site was surveyed post-deployment in 2006 and 2007 to assess initial colonization (Reynolds 2009) of demersal fish and macrophyte communities, and then compared to community structure at nearby natural reef (NR) and natural hard bottom (NHB) control sites (Reynolds 2009). Surveys in 2006 found minimal macroalgae colonization (<2%) for both reef types. By 2007, the FH remained predominantly uncolonized, however, *Laminaria saccharina* cover had increased on the balls (>50%) compared to the NR sites, which were predominantly covered by *Agarum clathratum* (Figure 1). This suggested that the RB were a better substrate for colonization compared to the FH. Reynolds (2009) concluded that AR fish utilization resembled nearby NR control sites and surpassed the NHB control site in both species richness and abundance.

Despite early similarity between the AR and NR in Whittier (Reynolds 2009), successional surveying is still necessary to identify shifts in community composition, and to understand temporal effects on colonization (Hueckel et al. 1989, Perkol-Finkel and Benayahu 2005, Cartel and Prekel 2008, Eckert 2010). Fish utilization is one measure of successful colonization; understanding the colonization of the forage base including macroalgae and invertebrate species is equally important (Baine 2001), since colonization success of fishes often depends on the complexity and heterogeneity of reef structure (Perkol-Finkel et al. 2006). Successional

colonization of foundational macroalgae is critical to fish assemblage structure (Anderson 1994, Efirid and Konar 2014) and can also be variable over long-term (Holbrook et al. 1994).

AR systems often experience rapid recruitment of initial colonizers that increase habitat complexity, followed by secondary colonization and increased species richness (Bohnsack et al. 1991, Underwood and Chapman 2006). Some marine communities reach equilibrium after several years, while others continually change dominant species (Bohnsack and Sutherland 1985). Furthermore, the similarity in structure and complexity of an AR to adjacent NR can be more important than age of an AR for successful fish colonization (Perkol-Finkel et al. 2006). It is crucial to AR success that long-term quantitative monitoring occurs to assess successes and failures in the AR process, and to continue contributing to baseline data in a given environment (Bohnsack and Sutherland 1985). With the deployment of AR in both Whittier (Reynolds 2009) and Juneau (Eckert 2010), management knowledge of artificial reef effectiveness in Alaska's sub-Arctic waters is growing. However, to date there is minimal data available on the long-term effects or efficacy of AR systems in sub-Arctic waters.

This study conducted surveying of the AR system in Whittier, Alaska, in order to provide managers with quantitative insight into the long-term colonization of demersal fishes, invertebrates and macroalgae in a high latitude location. The following research questions were addressed: (1) how does the length of artificial reef establishment affect community composition, (2) are there any differences in community composition due to reef type or seasonality, and (3) how much do macroalgal and invertebrate assemblages differ between observations from 1 m above versus *in situ* abundance counts.

## **METHODS**

### **Site Location**

The study site is located at the northeastern end of Whittier Harbor, in Smitty's Cove, which is towards the western end of Passage Canal off Prince William Sound. There are 2 reef types: FH and RB with  $n = 3$  plots for each reef type. The FH were deployed along a depth gradient between 46-60 ft.; RB were deployed along a depth gradient between 38-43 ft (Figure 2). Within each plot there are  $n = 30$  structures, for a total of  $n = 180$  across the entire AR ( $n = 90/\text{reef type}$ ). Both reef types are constructed with marine grade concrete to promote colonization, and engineered for optimal water flow, light penetration and stability. Each structure has between 9-12 portal holes that allow entrance into the interior reef space (Reynolds 2009).

### **Dive Surveys**

SCUBA surveys were conducted each month from June-December, 2016. Demersal fishes at the AR were documented *in situ* using diver observations by swimming a 30 m<sup>2</sup> circular transect around each plot. All quadrats were assigned using randomly generated compass headings and fin kicks. Macroalgal and sessile invertebrate assemblages were sampled using 0.25 m<sup>2</sup> quadrats employing two different methods: (1) 1 m above observations to emulate the use of percent cover quadrats (as in the the 2007 study) and (2) *in situ* observations documenting both understory and overstory richness and abundance.

## Statistical Analysis

Shannon's H' index was used for a more robust method of accounting for both richness and evenness using the following equation:

$$H = -\sum_{i=1}^s p_i \ln p_i$$

Diversity was not calculated within each subsample, but across whole communities specific to each objective (by the AR as a whole or by reef types). Density was calculated as abundance (N) per m<sup>2</sup> for each species observed (N/30 m<sup>2</sup> for fishes and N/0.25 m<sup>2</sup> for macroalgae and invertebrates). Macroalgal percent cover was estimated from 1 m above; and both macroalgal and invertebrate abundance was calculated using *in situ* counts with 0.25 m<sup>2</sup> quadrats (n ≥ 6 per plot). Species richness was calculated as the number of species (n) normalized per unit area. Means and standard errors were averaged across n = 6 and n = 3 reef-types in 2016 and compared to 2007 data.

Unpaired t-tests were performed for comparisons between 2007 and 2016 communities, between RB and FH, and between summer and fall periods. Further analysis was conducted using linear regression for seasonality as a time series. Zero-adjusted Bray-Curtis community matrices were used to create nMDS (non-metric multidimensional scaling) ordination plots for visual analysis of dissimilarity. Paired t-test were performed for methods comparison between quadrats sampled from 1 m above and *in situ*. Mixed-model nested ANOVA was used to assess within and between trip variability.

## RESULTS AND DISCUSSION

### Length of establishment

Macroalgal communities displayed greater sensitivity to ecological succession than demersal fish. Macroalgae was significantly higher in 2016 for both diversity (p = 0.0001; Figure 3a) and species richness (p = 0.0004), however density was not significant (Figure 3b). A total of 12 macroalgal species were observed at the AR in 2016. There was a large shift in the dominant species present from *Laminaria saccharina*, a common pioneer colonizer, to *Agarum clathratum* which is characteristic of kelp communities in Alaska. Richness at the AR increased from two overstory species in 2007 to 4 overstory species with the addition of 6 new understory species and 2 encrusting species (Figure 4). The shift in dominant species and increase in diversity of understory and overstory indicates that artificial reefs in Alaska follow a similar pattern of succession to natural reefs.

A total of 12 demersal fish species were observed during the study. Diversity increased significantly in 2016 (p = 0.0107; Figure 3a) and species richness (p = 0.0004), however density was not significant (Figure 3b). The rockfish genus *Sebastes* spp. appear to be the dominant family of fishes at the AR, particularly *S. caurinus* (Figure 5). There was an increase in *Sebastes* spp. present, from 2 species in 2007 (*S. maliger* and *S. caurinus*) to 5 species in 2016 (*S. maliger*, *S. caurinus*, *S. flavidus*, *S. chrysomelas* and *S. melanops*), with the loss of Pacific tomcod (*Microgadus proximus*), crescent gunnel (*Pholis latea*) and whitespotted greenling (*Hexagrammos*

*stelleri*). There were also 3 new species in addition to *Sebastes* spp., the Arctic shanny (*Stichaeus punctatus*), starry flounder (*Platichthys stellatus*) and genus *Cottidae* sp for a net gain of 3 species.

### **Reef type and seasonality**

Macroalgae appeared to be more densely and diversely colonized at the RB (Figure 6), however pairwise testing did not detect any significant differences for any of the variables. There were no detectable differences in diversity and species richness for fish or invertebrates. Densities were significantly higher at FH for demersal fish ( $p = 0.0308$ ; Figure 7) and invertebrates ( $p = 0.0201$ ; Figure 7), despite RB appearing to more densely colonized with greater vertical structural habitat. However, when looking closer at how overstory macroalgae species are contributing to the two different reef types, abundance of dominant *A. clathratum* is clearly higher at RB sites than FH (Figure 8). *In situ* abundance counts used to calculate density do not account for differences in species size or cover, so the lack of significance in macroalgal density between reef types may not adequately explain the visual differences in cover observed between reef types. Therefore, it is possible that statistical differences in fish and invertebrates density may be due to conspicuousness of reef type rather than true differences in density. The study in 2007 concluded that rapid initial colonization of the RB may be due to its pH balanced concrete material. A lack of significant difference between macroalgal communities in 2016 would indicate that pH basic materials (as used for FH) are still capable of being adequately colonized, but may be more conducive to the colonization of understory species than canopy species.

Pairwise tests were conducted to understand if local seasonality may have different effects on a more established community, primarily the decreasing light availability and temperature. However, testing between summer and fall periods were not significant for any of the variables, which was surprising considering the extreme seasonality that macroalgal communities experience in Alaska. Further analysis was done using regression with sampling trips as a time series. Regression was also not significant, but did provide some insight into the annual cycle of macroalgal senescence in Whittier. Invertebrate assemblages appeared to following changes in macroalgal assemblages closely, which was anticipated given invertebrate need for refuge (Jordan et al. 2005). Diversity for both was lowest in early June, with a large increase occurring in late June and staying relatively constant the remainder of the study period. This suggests the effects of seasonality are likely occurring outside of the time frame used in this study, with rapid macroalgal in early summer and senescence occurring post-study.

### **Ecological distance between communities**

The nMDS plot for both macroalgae and fish display the ecological distance between each reef plot and the AR reef as a whole for both 2007 and 2016, as well as the 2 NR communities as a whole for 2007 (Figure 9). Ordination supported that macroalgae were more similar within each reef type than between reef types, and there was greater distance between 2007 and 2016 AR communities as a whole, similar to the results from pairwise tests. Patterns were less discernible for fish communities as there was more variability between reef types, and there was less distance in AR communities between 2007 and 2016. This result was also supported by pairwise testing, as there was a greater increase in macroalgal species richness than in fish (although both were significant).

### **Methods comparison between 1 m above and *in situ***

Paired t-tests confirmed species richness was significantly higher ( $p = 0.0303$ ) when using *in situ* observations instead of percent cover from 1 m above (Figure 10). However, diversity was not significant presumably because Shannon's  $H'$  is calculated using relative abundance. Therefore, two disparate communities may produce a similar  $H'$  index depending on species richness and evenness. Density was not tested as abundance counts and percent cover are not comparable.

When measuring large overstory canopy species, large fronds often cover the quadrat overshadowing other species or appearing to have higher density (Figure 11). This was noted in the initial study in 2007, but may not be as much of a concern during initial colonization surveys as there are much fewer species present to account for. However, this study supports that more mature reefs require *in situ* observations in order to accurately observe all macroalgal species present. These results would indicate that natural reefs should be recharacterized using *in situ* observations. For this reason, we did not do statistical testing between the 2007 NR sites and AR in 2016, since the data may not be comparable.

### **CONCLUSIONS**

This study supports that the artificial reef in Whittier has followed a normal colonization pattern over long temporal scales, and has been successfully colonized by demersal fish, macroalgae and invertebrate assemblages relative to 2007 artificial and natural reef communities. Only 2 of the 9 tests were statistically different between reef types, indicating there may not be meaningful ecological differences between the two structure types. From a management perspective, both RB and FH were successfully colonized so both might serve as viable materials for AR construction. Also, when surveying macroalgal communities in Alaska on longer temporal scales, it may be more effective to conduct *in situ* observations especially if canopy species are present or there is high turbidity.

Future research should include recharacterizing the natural reefs to (1) observe if communities have changed significantly since 2007 (indicating continuous turnover in species) or are similar to 2007 (indicating a climax community) and, (2) employ *in situ* observations to document any discrepancies in species present. It may also be useful to calibrate inter and intra observer bias throughout the study when using a large dive team or a rotation of divers, to identify any potential discrepancies in sampling. Additionally, we qualitatively observed dense microhabitats throughout the FH sites. Environmental variables such as depth, turbidity and current should be further quantified, which may explain microhabitat occurrence and the lack of significance difference between reef types.

### **ACKNOWLEDGEMENTS**

Thank you to Eloise Brown, my advisor at Alaska Pacific University (APU) who oversaw this project and Erika Ammann at NOAA who originally presented this project to me and provided professional guidance. A special thank to Nathan Wolf and Scott Smeltz at APU for statistical support, and my dive team Kaili Martin, Ben Jevons, Eloise and Erika. Funding for this project was provided by the E.R. Jackman Internship Support Program, Izma Bailey Conser Fund, and At-Sea Processors Association (APA)/Pollock Conservation Cooperative (PCC). Conference travel support was awarded from the AAUS Kevin Flanagan Award.

## FIGURES

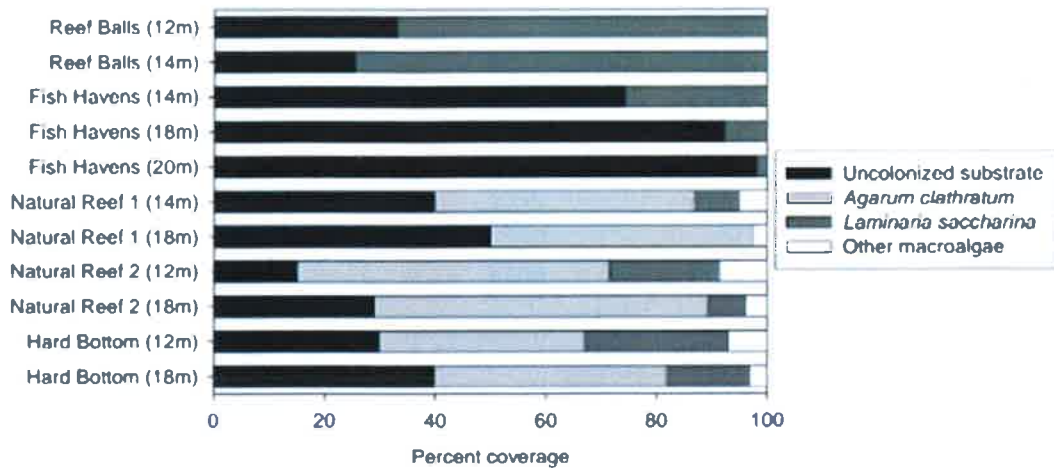


Figure 1. Percent coverage of Reef Balls, Fish Havens, Natural Reefs and Hard Bottom Control sites from the 2007 study (Reynolds 2009).

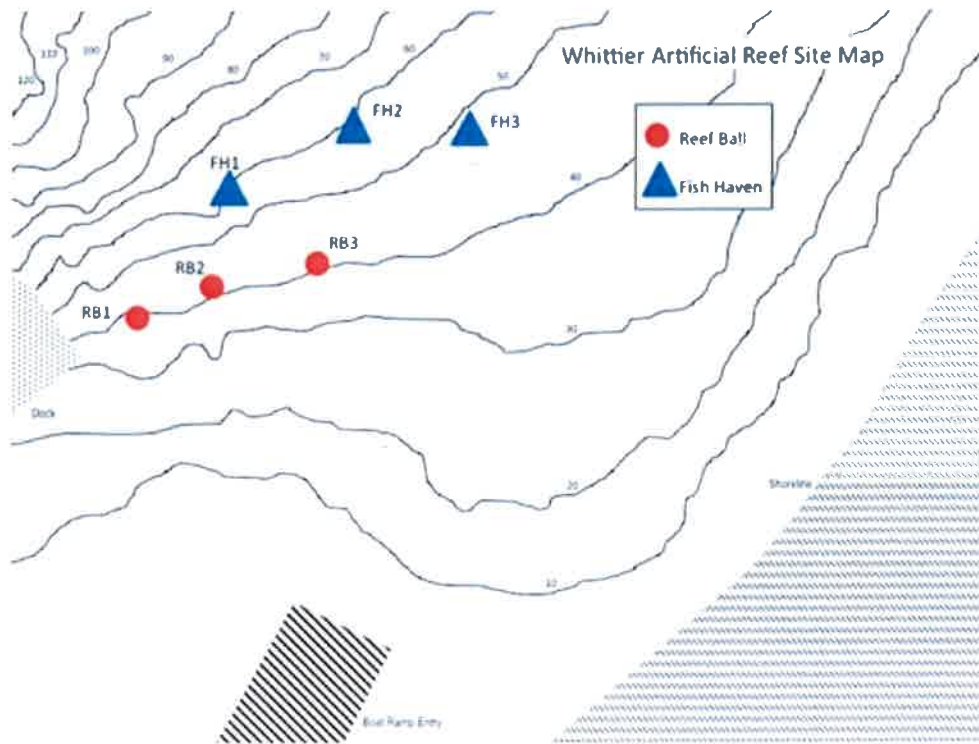


Figure 2. Site map of the 6 artificial reefs plots in Smitty's Cove, Whittier.

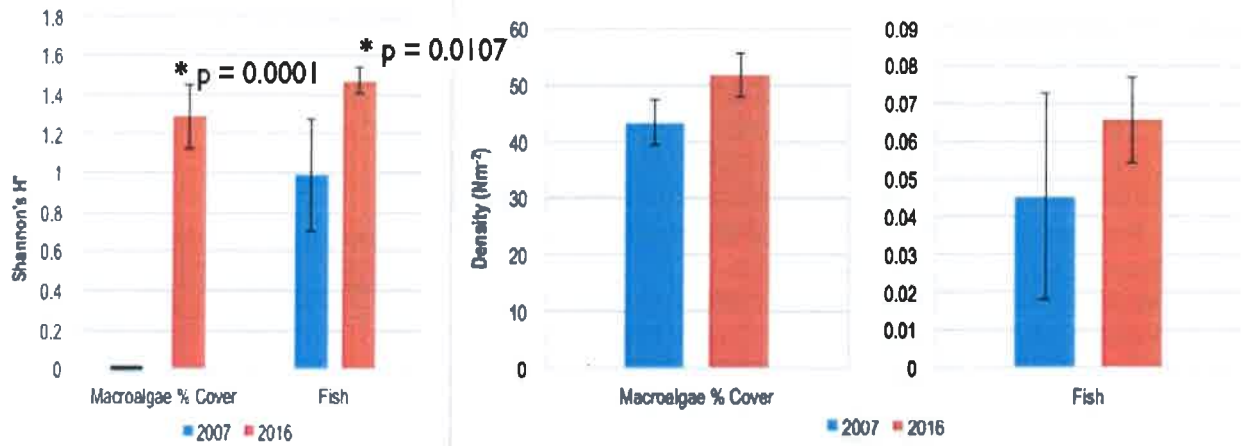


Figure 3a. Both fish and macroalgal communities were significantly more diverse in 2016.  
 Figure 3b. Density was not statistically different between years for fish or macroalgae.

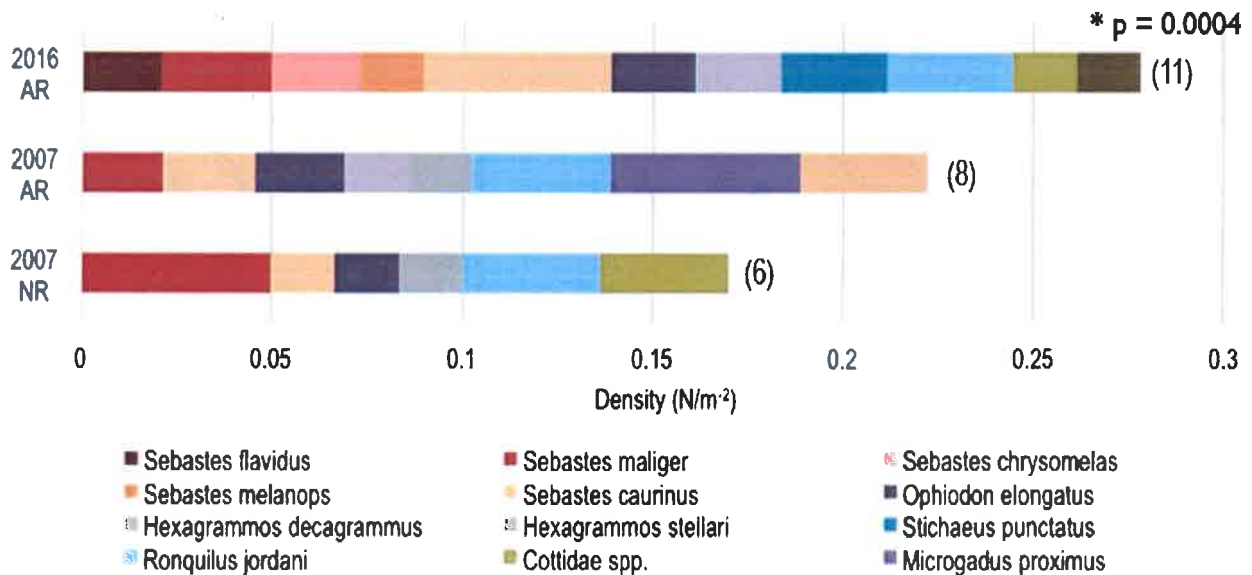


Figure 4. Species richness was significantly higher in 2016 for fish communities, with an increase in *Sebastes* spp. present. There was an addition of 6 new species and loss of 3 species for net gain of 3 species.



	Common Name	Species Name	2007	2016	2007 NR
Overstory	Twisted Shotgun Kelp	<i>Thalasssiophylum clathrus</i>		X	
	Shotgun Kelp	<i>Agarum clathratum</i>	X	X	X
	Split Kelp	<i>Saccharina groenlandica</i>		X	
	Sugar Kelp	<i>Saccharina latissima</i>	X	X	X
Understory	Small Branched Red	<i>Callophyllis</i> spp.		X	
	Hidden Rib	<i>Cryptopleura ruprechtiana</i>		X	
	Fan Shaped Red	<i>Palmaria</i> spp.		X	
	Filamentous Red	<i>Ceramiales</i> spp.		X	
	Soda Straws	<i>Scytosiphon lomentaria</i>		X	
	Witch's Hair	<i>Desmarestia aculeata</i>		X	
	Sea Lettuce	<i>Ulva</i> spp.			X
Encr.	Turf Brown Algae	Class Bacillariophyceae spp.		X	
	Pink Encrusting Algae	Coralline spp.		X	X

Figure 5. Macroalgal communities displayed a shift in dominant species present from *L. saccharina* in 2007 to *A. clathratum* in 2016. There was an increase from 2 species in 2007 to 12 species in 2016, with the addition of 6 understory, 2 canopy and 2 encrusting species.



Figure 6. Comparison of the RB on the left and FH on the right show the RB sites visually appear to be more densely colonized by macroalgae than the FH plots on the right.

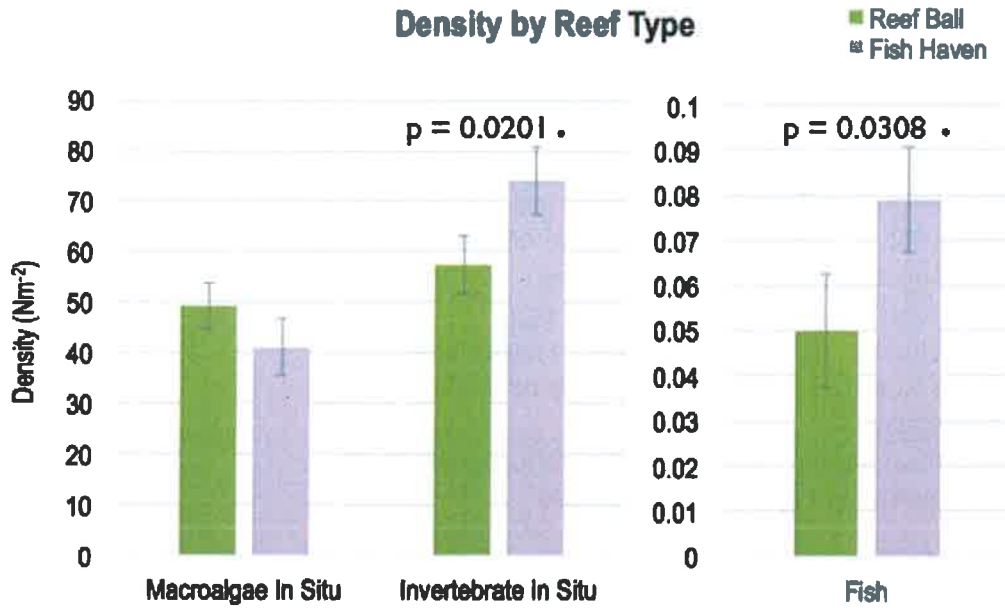


Figure 7. Density was significantly higher at FH for both invertebrates and fish assemblages.

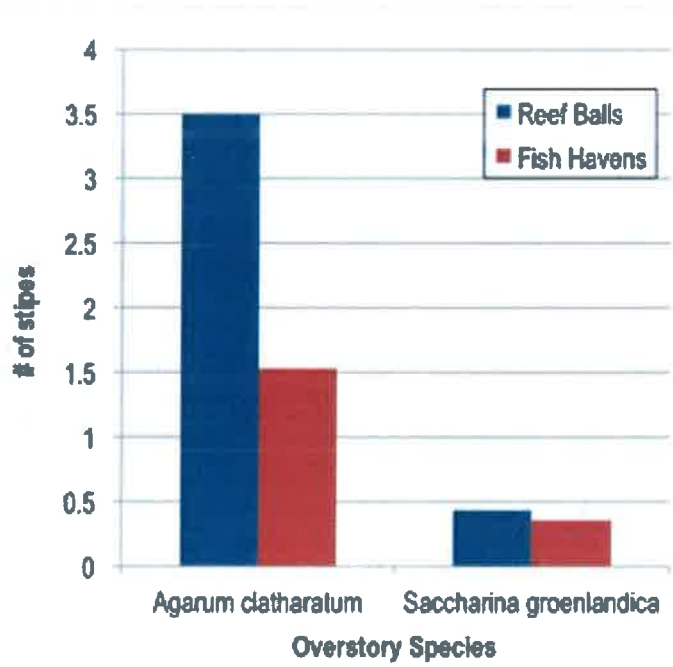


Figure 8. Raw abundance counts of the two primary canopy species contributing to both reef types (averaged across all RB and FH observations) show abundance of overstory species is higher at RB.

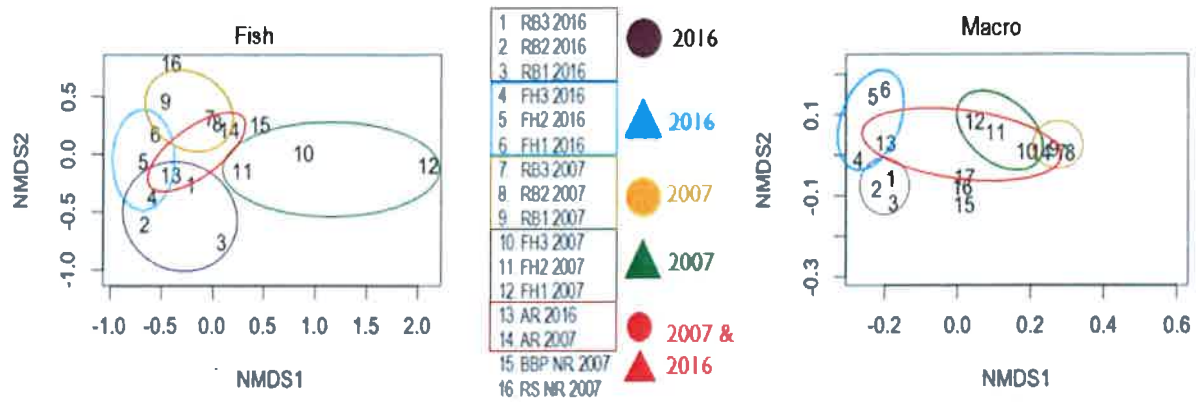


Figure 9. Macroalgal communities display high similarity within reef types, and more distance in overall AR communities between 2007 and 2016. Fish communities display higher variability and more dispersal among reef types, and less distance in overall AR communities between 2007 and 2016.

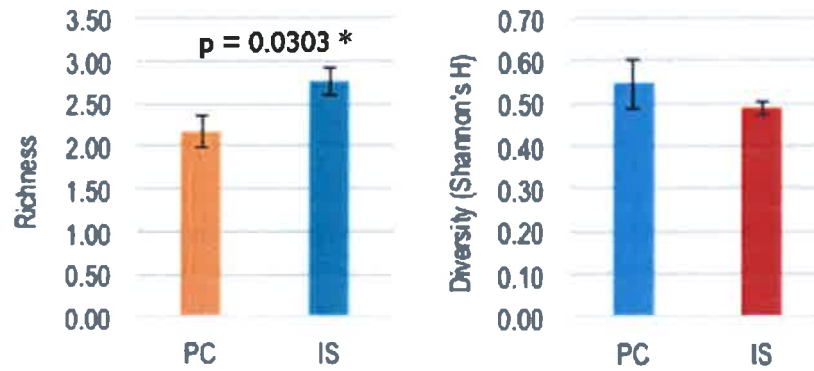


Figure 10. Species richness was significantly higher using *in situ* observations, however there was no significant difference in diversity.



Figure 11. Comparison between the quadrat employing percent cover on the left at the RB and the quadrat employing *in situ* observations on right at the FH.

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