FINAL REPORT

Runswick Bay artificial rock pool monitoring: 2020 results

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EXECUTIVE SUMMARY

The purpose of this project is to assess the success of artificial rock pools as ecological enhancement interventions, which were incorporated into a new coastal defence scheme at Runswick Bay, North Yorkshire in summer 2018.

During construction of the new rock armour defence at Runswick Bay, 70 saw-cut artificial rock pools were installed on the granite boulders. This report details the findings from the third and final field survey conducted during July 2020 and is compared with the first survey carried out 2 months post-construction (July 2018) and second survey 14 months post construction (July 2019). The survey compared the species richness, total abundance and species diversity of fauna and flora found both inside the artificial rock pools and on the adjacent granite rock faces. In addition, water parameters including water temperature, pH and salinity were collected to ascertain any variation between the water in the pools compared to the sea.

The survey found that the majority of artificial rock pools were retaining water effectively. Pools which were not retaining water were either smothered in sand due to high beach levels near the slipway or full of algal wreck. The water temperature, pH and salinity did not differ significantly between the rock pools and the sea.

This study has shown that the construction of artificial rock pools on the granite rock armour has increased the species richness compared to the un-manipulated areas of the boulders. Over the entire study period, twenty-four species were observed in the rock pools which were absent from the adjacent rock surfaces, showing that the provision of water-retaining features and increased surface heterogeneity has enabled species to survive on the rock armour when the tide goes out. The majority of these new species were mobile fauna, including crabs and fish, and a high proportion of them were juveniles. The height at which the rock pools were installed was shown to have an impact on the assemblages found within the rock pools, highlighting the importance of suitable positioning. It is important to remember that ecological enhancement will not be successful in all environments and that site-specific advice and planning is needed.

CONTENTS

1. INTRODUCTION

The Runswick Bay Coastal Protection Scheme was constructed in 2018 and included repairs to the existing concrete seawall and the placement of 9,500 tonnes of granite rock armour to protect 250 m of seawall frontage. Runswick Bay was designated a Marine Conservation Zone (MCZ) (Marine and Coastal Access Act 2009) in 2016 for low energy intertidal rock, moderate energy intertidal rock, high energy intertidal rock and intertidal sand and muddy sand biotopes. To limit the damage potentially caused to the protected features of the MCZ by the construction of the new sea defence, various measures were put in place, including designated access routes for machinery, protection of existing colonised boulders and ecological enhancement techniques. The ecological enhancement techniques which were incorporated into the new coastal defence scheme at Runswick Bay included the construction of 70 artificial rock pools which were saw-cut into the boulders.

Artificial structures typically lack optimal habitats for intertidal species due to the absence of habitat heterogeneity and water retaining features. On natural rocky shores, rock pools provide intertidal organisms with a refuge from biotic and abiotic stresses such as predation and desiccation (Little et al. 2009, Firth, Schofield, et al. 2014, White et al. 2014).

Ecological enhancement integrates ecology and engineering to create multifunctional structures which provide both protection from coastal erosion and also a suitable habitat for intertidal organisms (ITRC 2004, Hall et al. 2018). Previous ecological enhancement studies have shown that water retaining features and habitat heterogeneity are important to promote biodiversity on artificial structures (Firth *et al*. 2013, Browne and Chapman 2014, Evans *et al*. 2015). Existing trials at Runswick Bay have shown how increased habitat heterogeneity can lead to increased species richness and diversity on granite boulders (Hall et al. 2018).

The aim of this current survey was to determine if the artificial rock pools have increased species richness, total abundance and species diversity compared to the control rock faces since installation in 2018 (2 years and 2 months). The previous surveys conducted at 2-month and 14-month post installation showed initial success, however the current survey determines the longer term success of the interventions.

2. METHODS

2.1 Site description

Runswick Bay is a moderately exposed sandy shore with large shale bedrock platforms. It has an easterly prevailing wind direction and the mean tidal height is 5.6 m during spring tides and 4.2 m during neap tides. The new rock armour was placed on top of the shale bedrock at the foot of the seawall (Figure 2.1). Existing boulders were moved during construction and replaced in front of the granite rock armour to test if "seeding" would increase colonisation rates.

Figure 2.1. Location of new granite rock armour at the foot of the seawall, note the (colonised) natural boulders which have been placed in front of the granite rock (July 2020).

2.2 Installation of artificial rock pools

The 70 artificial rock pools were created using a circular saw and breaker. The circular saw was used to make two sets of parallel cuts which were perpendicular to each other to form a cross shape. A breaker was then used to break up the cuts and form pools of approximately 300 mm diameter and 150 mm depth (Figure 2.2).

Figure 2.2. Examples of saw cut artificial rock pools roughly 300 mm diameter x 150 mm deep.

2.3 Survey protocol

Surveys were conducted between 7th and 9th July 2020 by Dr Sue Hull and Dr Alice Hall and followed the same protocol as previous surveys to allow direct comparisons to be made.

The abundance of fauna and flora were recorded in-situ inside the rock pools and compared to the adjacent rock face to determine if the artificial rock pools had a positive effect on increasing biodiversity on the rock armour.

The percentage cover of algae and count data for barnacles and mobile species such as fish and crabs were recorded to measure species abundance. All organisms were identified to the lowest taxonomic resolution possible. Photographs of all rock pool and control areas were taken to illustrate changes in assemblages over time. Water parameters, including temperature, pH and salinity were recorded inside the rock pools and compared to a sample of seawater.

In order to estimate the approximate tidal height of the rock pools, a standard theodolite and line of sight method was used to determine the relative height of each pool above the low water mark (Little et al., 2009). Tide tables provide an approximate calculated water depth (m) above a fixed UK chart datum (CD) point at both high and low water. The low water estimate can be used as a reference point to determine how much higher the rock pools are above the low water mark compared to the chart datum. A theodolite was placed in the mid shore and the measuring staff placed at the edge of the tide at low water and readings taken by line of sight from the measuring staff to enable calculation of distance to theodolite and also the change in height between the fixed theodolite point and low water. This was then repeated for each rock pool enabling the distance from the level and an estimate of the height above chart datum of each pool to be determined. Whilst inaccuracies may occur in determining the actual low water height due to wave action, the method provided a mechanism of grouping pools by approximate tidal height in metres above low water mark.

3. RESULTS

3.1 Community assemblages

In July 2020, a total of twenty-nine species were record within the artificial rock pools and only twelve species were recorded on the adjacent control rock faces. The additional species recorded in the rock pools included eight algal species, two annelids, one anemone, three crustaceans, one insect and four molluscan species. Examples of species recorded are shown in Figure 3.1. Results indicate that the artificial rock pools supported significantly greater species richness, species diversity and total abundance than the adjacent rock face controls (Figure 3.2, Table 3.1).

The results also show that there was a significant increase in species richness, species diversity, % cover of algae and total abundance of animals between 2018 and 2020 (Figure 3.2, Table 3.1). The results for rock pools in 2019 and 2020 show similar mean species richness, a slight decrease in algal diversity and no significant difference in animal diversity. The abundance of both algae and animals increased from 2019 to 2020 but only showed a significance increase for algae (Figure 3.2).

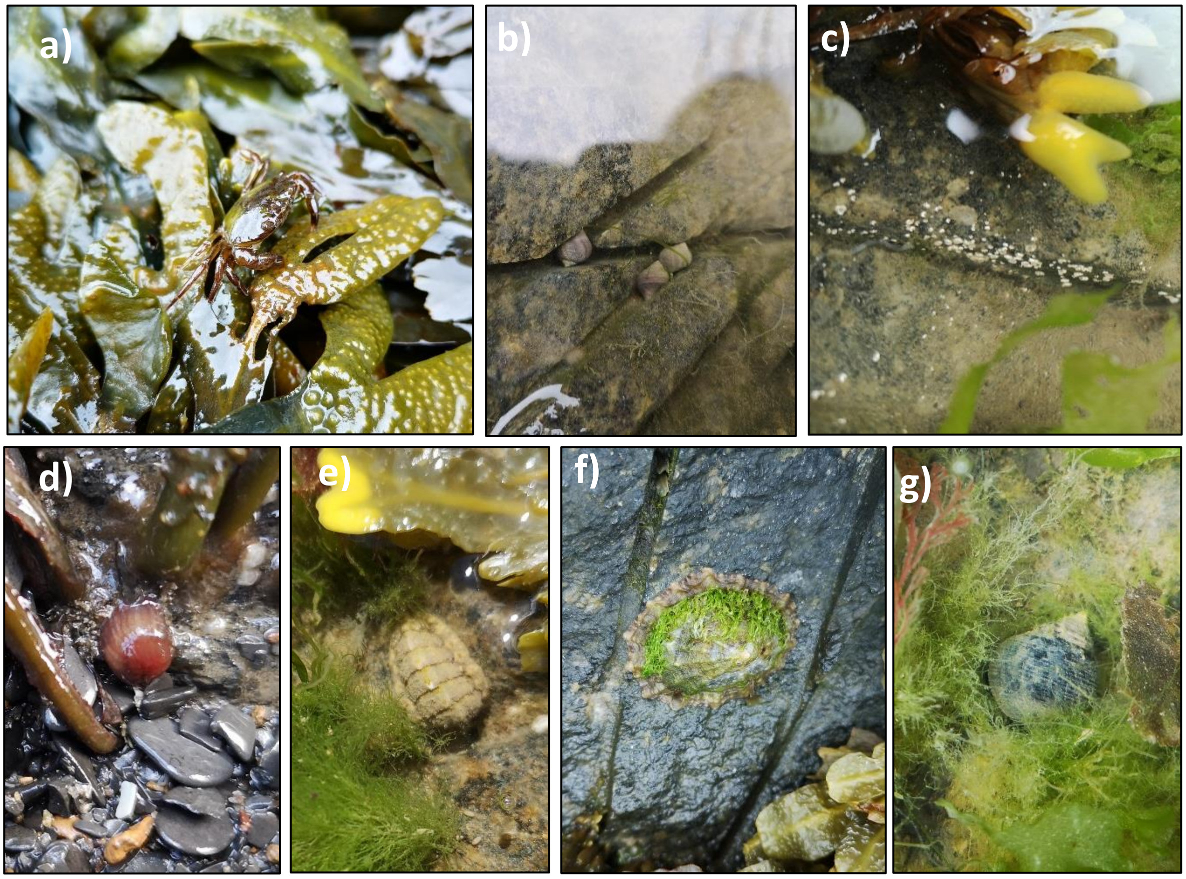

Figure 3.1. a) Green shore crab (*Carcinus maenas*), b) Rough periwinkle (*Littorina saxatilis*), c) Spiral tube worms (*Spirobis* sp), d) Beadlet anemone (*Actinia equina*), e) Chiton (*Lepidochitona cinerea*), f) Common limpet (*Patella vulgata*) and g) Edible periwinkle (*Littorina littorea*). Images from July 2020.

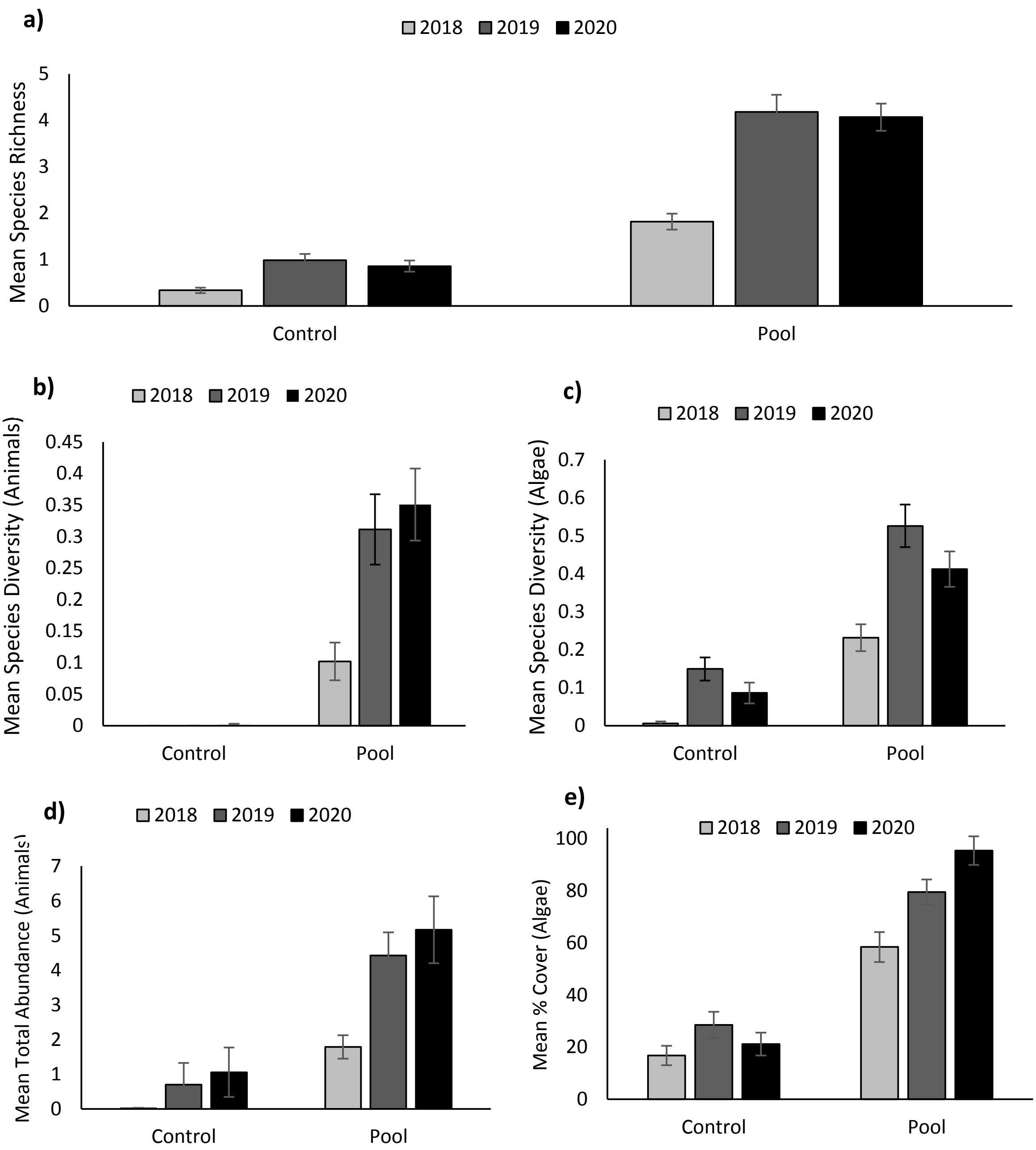

Figure 3.2. a) Mean species richness, b) mean species diversity (Shannon Wiener) of animals, c) mean species diversity (Shannon Wiener) of algae d) mean total abundance of animals and e) mean total abundance of algae recorded in controls and rock pools in August 2018 (light grey bars), July 2019 (dark grey bars) and July 2020 (black bars) (+/- SE).

Table 3.1. Analysis of variance (ANOVA) results for comparison of species richness (algae & animals) , species diversity richness (algae & animals) and % cover of algae and total abundance of animals between pools (artificial rock pools) and control (adjacent rock face) and Year (2018/2019/2020) NS= Not significant *= low significance **=medium significance * = highly significant.**

	Species Richness			Species Diversity						Total Abundance					
				Algae			Animals			% Cover algae			Total abundance of animals		
	df	*f*	*p*	*df*	*f*	*p*	*df*	*f*	*p*	*df*	*f*	*p*	*df*	*f*	*p*
Pool/Control	1	141.94	< 0.001 ***	1	102.04	<0.001 ***	1	54.97	<0.001 ***	2	159.68	< 0.001 ***	1	32.33	0.001 **
Year	2	57.58	< 0.001 ***	2	17.16	<0.001 ***	2	9.25	<0.001 ***	1	10.85	<0.001 ***	2	7.04	<0.001 ***
Pool/Control * Year	1	25.15	< 0.001 ***	2	2.07	0.12 NS	2	9.10	<0.001 ***	2	6.35	0.002 **	2	2.07	0.13 NS

The multidimensional scaling plot (MDS) in Figure 3.3 illustrates the separation in algal communities between artificial rock pools and the control rock face. Each individual triangular symbol represents a sample rock pool, the closer together the points the more similar the communities are.

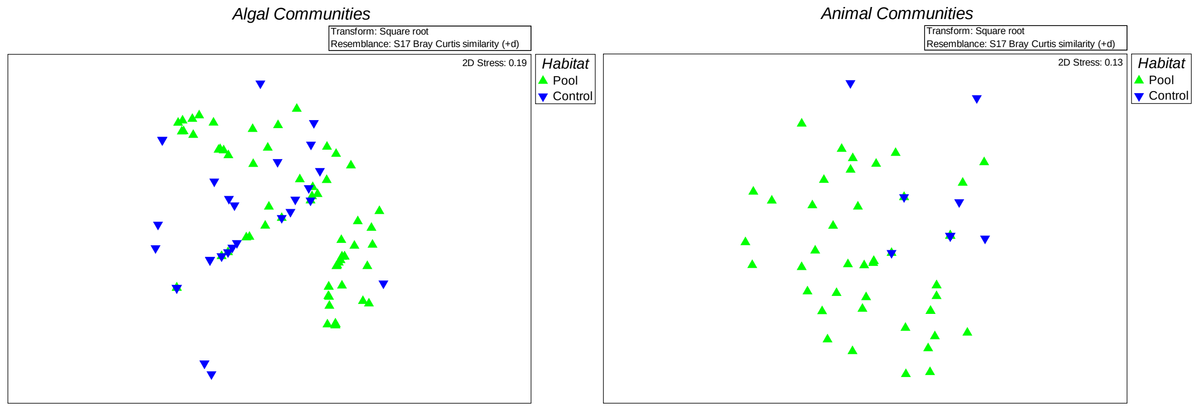

Figure 3.3. Multidimensional scaling plot of the a) algal and b) animal communities in the rock pools and control areas on the rock armour (July 2020). This figure illustrates the separation in communities between artificial rock pools and the control rock face. Each individual triangular symbol represents a sample rock pool, the closer together the points the more similar the communities are.

The similarity percentage analysis (SIMPER) found that 91.01 % of the overall 92.39 % dissimilarity between algal communities found between pools and controls was attributed to five taxa; Diatom film, *Ulva* sp., *Fucus vesiculosus, Ulva lactuca* and *Fucus spiralis*. The SIMPER also found that 92.34 % of the overall 99.33 % dissimilarity between animal communities found between pools and controls was attributed to nine taxa; *Carcinus maenas, Littorina saxatilis, Patella vulgata, Littorina littorea, Semibalanus balanoides, Littorina obtusata,* Amphipoda, *Ligia oceanica, Lepidochitona cinerea* (Table 3.2).

Table 3.2. SIMPER analysis on a) algal and b) animal community similarity between artificial rock pools and adjacent control rock faces on the granite rock armour in July 2020.

a) Algae	Pool Average Abundance	Control Average Abundance	Average. Dissimilarity	Dissimilarity /SD	Contribution %
Diatom film	41.20	1.41	30.16	0.87	32.64
Ulva sp.	23.11	5.15	25.74	0.91	27.86
Fucus vesiculosus	14.37	7.87	14.41	0.59	15.60
Ulva lactuca	6.54		7.56	0.52	8.19
Fucus spiralis	5.14	2.82	6.22	0.46	6.73
b) Animals	**Pool Average Abundance**	**Control Average Abundance**	**Average. Dissimilarity**	**Dissimilarity /SD**	**Contribution %**

Carcinus maenas	0.70	0.01	20.93	0.66	21.07
Littorina saxatilis	0.96		20.82	0.62	20.96
Patella vulgata	1.08	0.01	15.91	0.61	16.02
Littorina littorea	0.65		9.52	0.46	9.58
Semibalanus balanoides	0.62	0.56	6.90	0.45	6.95
Littorina obtusata	0.10	0.45	6.30	0.31	6.35
Amphipoda	0.18		4.69	0.32	4.72
Ligia oceanica	0.21		4.31	0.32	4.34
Lepidochitona cinerea	0.11		2.33	0.28	2.35

Table 3.3 illustrates the average species abundance in the artificial rock pools compared to the control rock face and gives a full species list of all species recorded.

Table 3.3. Species list and average abundance (*SD*) for fauna and flora recorded in the artificial rock pools and on the control rock face in August 2018, July 2019 and July 2020 (%= %cover, c= counts, SD in brackets).

Taxon	Species	Rock pool Average Abundance			Control Average Abundance		
		2018	2019	2020	2018	2019	2020
Algae	Brown filamentous *(%)*	22.97 *(33.19)*	14.60 *(26.22)*			2.32 *(9.16)*	
	Ceramium sp. *(%)*		0.03 *(0.17)*				
	Cladophora sericea (%)		0.45 *(2.46)*	1.41 *(8.50)*			
	Cladophora vagabonda (%)			2.66 *(12.78)*			
	Diatom film (%)			41.20 *(43.46)*			1.41 *(11.87)*
	Ectocarpus sp. (%)			0.04 *(0.36)*			
	*Fucus (*Hybrid)						1.20 *(10.09)*
	Fucus serratus (%)			0.42 *(1.84)*			
	Fucus spiralis (%)			5.14 *(14.71)*			2.82 *(11.76)*
	Fucus vesiculosus (%)		3.08 *(6.85)*	14.37 *(29.71)*		1.92 *(4.32)*	7.87 *(25.84)*
	Green filamentous *(%)*	14.10 *(29.05)*	0.31 *(2.39)*	0.07 *(0.59)*	1.30 *(4.58)*	5.46 *(11.81)*	1.55 *(7.68)*
	Mastocarpus stellatus (%)			0.06 *(0.47)*			
	Osmundea hybrida (%)			0.01 *(0.12)*			
	Pilayella sp. *(%)*		0.02 *(0.12)*				

Taxon	Species	Rock pool Average Abundance			Control Average Abundance		
		2018	2019	2020	2018	2019	2020
	Porphyra sp. *(%)*		1.2 *(2.55)*	0.21 *(1.22)*		6.03 *(8.77)*	1.14 *(4.51)*
	Scytosiphon lomentaria (%)		0.06 *(0.23)*	0.11 *(0.49)*			
	Ulva intestinalis (%)		41.2 *(39.32)*			6.16 *(16.43)*	
	Ulva lactuca (%)		2.6 *(6.62)*	6.54 *(17.76)*			
	Ulva linza (%)		13.4 *(23.37)*			29.65 *(31.42)*	
	Ulva sp. *(%)*	22.07 *(30.69)*	8.69 *(19.64)*	23.11 *(31.85)*	47.70 *(36.49)*	2.43 *(7.71)*	5.15 *(14.84)*
Annelida	Annelid	0.01 *(0.12)*					
	Spirobranchus lamarcki (c)			0.04 *(0.26)*			
	Spriobis spirobis (c)			0.35 *(2.97)*			
Cnidaria	Actinia equina (c)			0.01 *(0.12)*			
Crustacea	Amphipoda (c)	0.01 *(0.12)*	0.23 *(0.54)*	0.18 *(0.80)*			
	Carcinus maenas (c)	1.41 *(2.47)*	2.28 *(2.91)*	0.70 *(1.43)*			0.01 *(0.12)*
	Idotea granulosa (c)			0.04 *(0.26)*			
	Ligia oceanica (c)		0.31 *(0.64)*	0.21 *(0.92)*	0.01 *(0.21)*	0.05 *(0.24)*	
	Necora puber (c)	0.03 *(0.17)*					
	Palaemon sp. *(c)*	0.04 *(0.27)*					
	Semibalanus balanoides(c)		0.92 *(3.54)*	0.62 *(2.71)*		1.19 *(5.34)*	0.56 *(4.75)*
Insecta	*Anurida maritima (c)*			0.03 *(0.17)*			
	Neomolgus littoralis (c)						0.01 *(0.12)*
Mollusca	*Lepidochitona cinerea (c)*			0.11 *(0.43)*			
	Littorina littorea (c)	0.03 *(0.17)*	0.32 *(0.87)*	0.65 *(2.00)*			
	Littorina obtusata (c)	0.01 *(0.12)*	0.06 *(0.23)*	0.10 *(0.45)*		0.03 *(0.12)*	0.45 *(3.56)*
	Littorina saxatilis (c)		0.15 *(0.97)*	0.96 *(3.24)*			
	Melarhaphe neritoides (c)		0.02 *(0.12)*	0.07 *(0.59)*			
	Patella vulgata (c)		0.52 *(1.07)*	1.08 *(4.21)*		0.03 *(0.12)*	0.01 *(0.12)*

Taxon	Species	Rock pool Average Abundance			Control Average Abundance		
		2018	2019	2020	2018	2019	2020
Pisces	*Lipophrys pholis* (c)	0.26 *(0.77)*	0.02 *(0.12)*				
	Total Number of Species	**11**	**22**	**29**	**3**	**11**	**12**

3.2 Water parameters

The average temperature recorded in artificial rock pools (19.5◦C) was slightly higher than that recorded in the seawater (18.6◦C). The salinity and pH recorded in the rock pools were on average higher than the seawater (Figure 3.4).

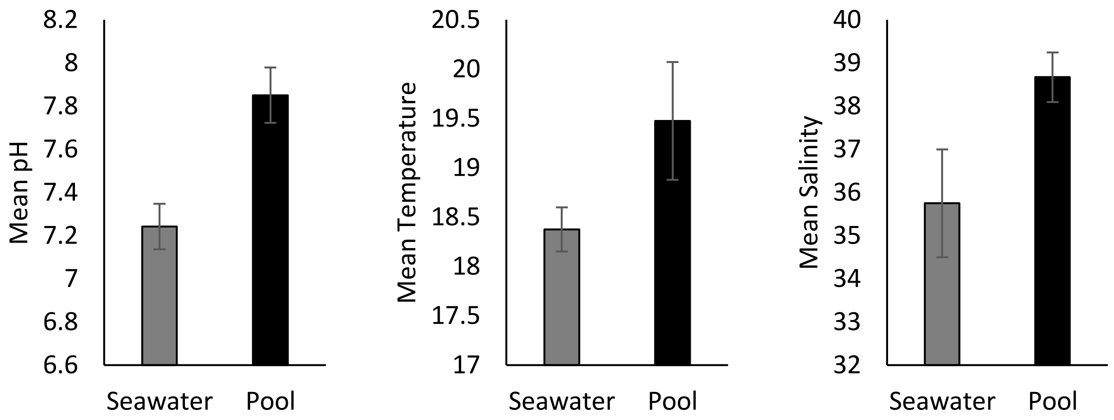

Figure 3.4. Comparison of water pH, temperature and salinity between artificial rock pools and seawater in July 2020 (+/- S.E).

3.3 Rock pool tidal height

Out of the 71 artificial rock pools, 27 were installed beyond the Splash zone (5.50m above CD) 15 were installed above the Splash zone (5-5.5m above CD), 17 in the Upper zone (4.5-5m above CD) and 12 in the Upper Mid zone (4-4.5m above CD). Only four pools were empty in July 2020 and this was due to a build-up of sediment filling the pools. Pools which are located above the Splash zone and within the Splash zone are more prone to algal bleaching due to more extreme environmental conditions such as higher temperatures. The most diverse rock pools with the highest number of species were found in the Upper and Upper Mid tidal zone as they are regularly replenished with seawater and exposed to the air for shorter periods of time at low tide (Figure 3.5 and Figure 3.6).

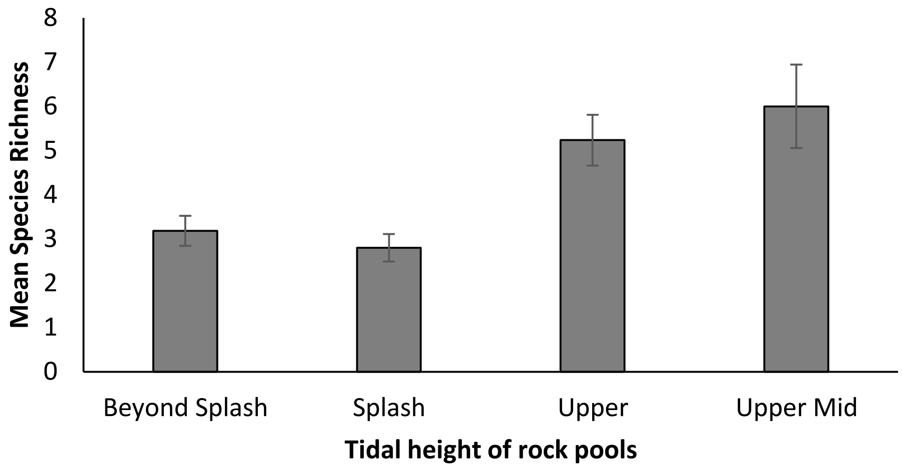

Figure 3.5 Mean Species Richness of rock pools located a varying tidal heights, surveyed in July 2020 (Beyond Splash zone (5-5.5m above CD), Splash zone (5.50m above CD) Upper zone (4.5-5m above CD) and Upper Mid zone (4-4.5m above CD)).

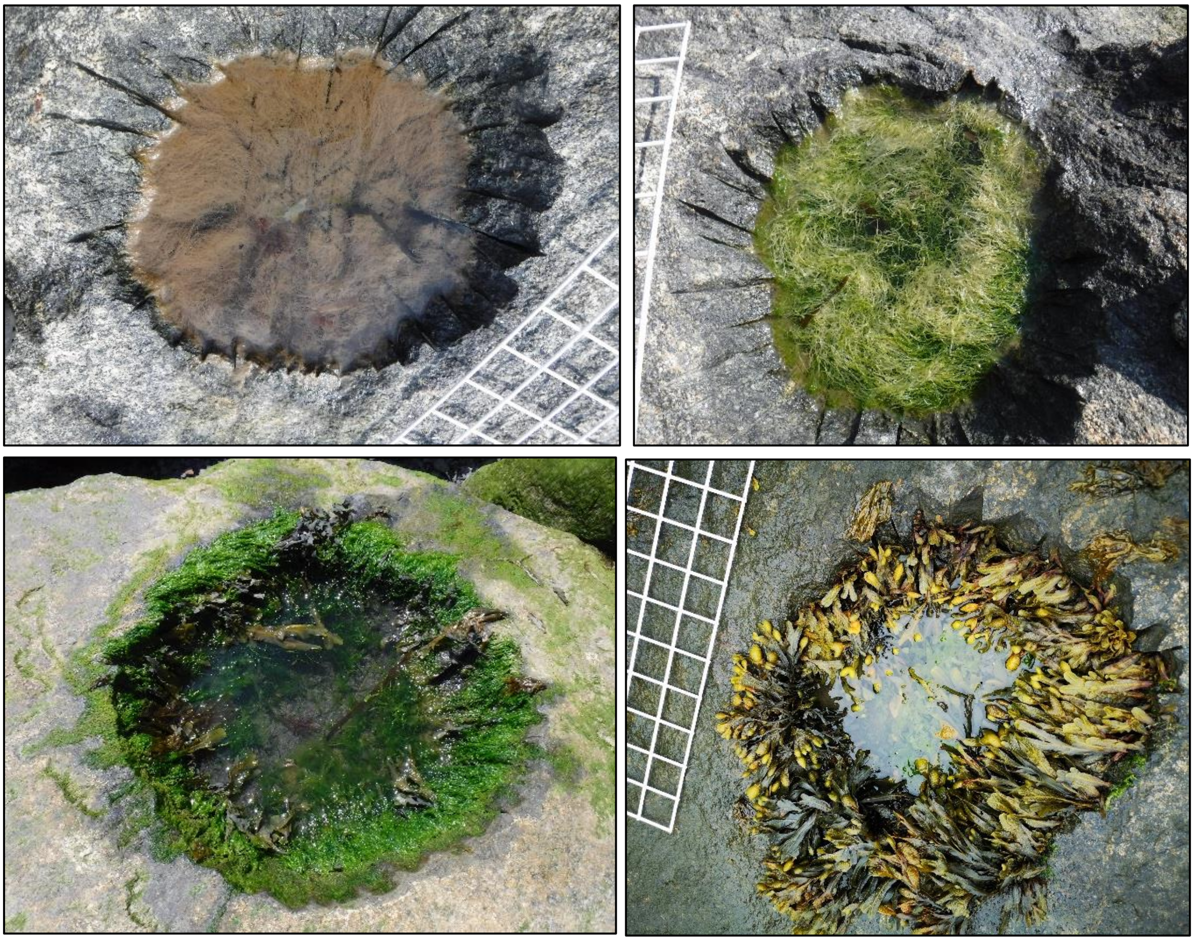

Figure 3.6 Variation in rock pool colonisation at different tidal heights in July 2020: a) Beyond Splash, b) Splash, c) Upper d) Upper Mid

4. DISCUSSION

Incorporating ecological enhancement into the new coastal defence scheme at Runswick Bay has resulted in an increased number of species and a greater abundance of marine organisms living on the granite rock armour. To date there are 29 species living on the enhancement rock armour compared to 12 species living on the un-manipulated control rock faces. The installation of saw-cut artificial rock pools into the top faces of the granite rock armour has provided both an area of water retention and a habitat with increased surface texture. The abundance of seaweed and animals have increased year on year as would be expected with succession in the intertidal environment.

Intertidal community succession has been studied in detail on natural rocky shores (Sousa 1979, Benedetti-Cecchi and Cinelli 1996); however, research is lacking on the succession of communities on new coastal defence structures. Existing ecological enhancement studies have mainly focused on retrofitted options rather enhancement built into schemes (Firth, Thompson, et al. 2014, Hall et al. 2019). This research has shown how both the enhanced and control areas have colonised and developed over a 2-year period. The communities on both the control and enhanced areas have changed year on year but the enhanced areas have always supported a greater diversity of marine life, particularly animals. There is a distinct lack of animals on the control rock faces and this is due to the lack of suitable habitat. The rock faces do not provide a wet refuge when the tides goes out which means most intertidal animals would struggle to survive. The creation of artificial rock pools has reinforced the importance of water retention on artificial structures (Firth et al. 2013).

Since installation in 2018 the diversity of animals has increased year on year; however, the diversity of seaweed only increased between 2018 and 2019. This reduction in algal diversity in 2020 can be explained by the dominance of canopy algae, specifically Spiral wrack *Fucus spiralis* and Bladder wrack *Fucus vesiculosus.* Canopy algae can dominate rock pools and prevent settlement by other algal species, it can smother existing species and prevent sunlight from penetrating to the under canopy, inhibiting survival and photosynthesis (Clark et al. 2004, Jenkins et al. 2004).

The number of species recorded in the artificial rock pools increased rapidly between 2018 and 2019, after which it appeared to stabilise. This trend was observed on both the artificial rock pools and the control rock faces. The number of species present within a habitat can be limited by space availability; therefore, if the rock pools have a large abundance of seaweed and/or animals there may not be any space available for additional species to utilise. As with natural rocky shore environments, disturbance events may occur which will remove existing species, allowing space for new species to recolonise. This highlights the importance of long term monitoring in order to see changes in communities over time. The speed at which the artificial rock pools have colonised has been very surprising, especially compared to previous artificial rock pool experiments (Hall et al. 2019), including previous experiments conducted at Runswick Bay (Hall et al. 2018). This rapid colonisation is most likely explained by the availability of larval supply provided by the adjacent natural rocky shore and the existing limestone boulders which were used to "seed" the new defence structure. Further investigation into the effectiveness of "seeding" is being conducted.

The community composition was found to be more varied in the artificial rock pools than in the control areas; this could be attributed to the variety of different habitats created in the rock pools. As well as water retention there are also deep score marks on the edges of the pools which make suitable habitat for marine snails, chitons, juvenile crabs and fish. As each rock pool is unique due to the techniques used to install them, there will be variability between rock pool depth, volume, and orientation, just as there would be on natural rocky shores (Metaxas and Scheibling 1993).

The height at which ecological enhancements are created was very important in determining their efficacy. If enhancements are implemented too far up the tidal zone above the mean high water mark, the ecological benefit will be diminished. This study has shown that the rock pools installed in the lower tidal zone were the most successful and supported the greatest amount of diversity. The pools located above the Splash zone were not very successful and experienced high levels of algal bleaching, despite initial colonisation. This indicates that whilst colonisation can occur during favourable environmental conditions, diversity is then subsequently lost as conditions become more extreme (especially high temperatures in summer). Tidal height is a well-known factor which influences the distribution of marine organisms (Schonbeck and Norton 1978, Suchanek 1978, Underwood and Jernakoff 1984) and natural rock pools have shown to extend the distribution of some species (Metaxas and Scheibling 1993). The creation of artificial rock pools at Runswick Bay has also helped to extend the height at which some species can survive; however, there will always be a limit. Rock pools above the Splash zone do not get replenished with seawater regularly enough for marine organisms to survive. The height at which saw-cut rock pools are installed on future projects should be planned carefully and we suggest they should be installed below the Splash zone, ideally between the Upper and Mid tidal zone. Sea level rise will also need to be considered in the position of rock pools, especially on structures with a long term life expectancy.

The installation of artificial rock pools on the granite rock armour at Runswick Bay has shown very promising results in a relatively short space of time. There are significantly higher numbers of species living in the rock pools compared to the control areas and the number of species increased rapidly between year 1 and 2. It is important to continue monitoring the changes in communities over time in order to evaluate the long term success of these ecological enhancements. It is important to note that although the artificial rock pools have been very successful at Runswick Bay, they may not be suitable for all locations. It is very important to get input from ecologists to determine site suitability, especially in terms of tidal height and availability of larval supply from existing populations. This innovative award winning research has shown that artificial rock pools in granite rock armour can be very successful at enhancing marine infrastructure in a suitable location.

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