Dredging up the Past – Tracking Recovery of Non-Target Benthos from Historic Scallop Dredging Fishing Effort in Northumberland

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Author:

James Duffy
j.duffy1@newcastle.ac.uk

Clients:

Alex Aitken (NIFCA)
alex.aitken@nifca.gov.uk

Catherine Scott (Natural England)
catherine.scott@naturalengland.org.uk

Academic Supervisors:

Ashleigh Tinlin-Mackenzie
ashleigh.tinlin@newcastle.ac.uk

Clare Fitzsimmons
clare.fitzsimmons@newcastle.ac.uk

Declaration

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1. Abstract

Scallop dredge fisheries are widely considered a destructive and invasive form of fishing due to their numerous acknowledged impacts upon seabed habitats and their inhabitants. Management in the form of Marine Protected Areas or fishery closures can provide baseline conditions to which the response of benthic organisms to the prohibition of scallop dredging can be investigated, ultimately indicating overall effectiveness of their use as a fisheries management strategy in terms of taxa recovery. Benthic sampling through SeaSpyder underwater imagery was conducted at 21 sites in and around the Berwickshire and North Northumberland Coast Special Area of Conservation in Northumberland, UK, where 1km^2 grid cells varying in degrees of dredge pressure were targeted with an equal spread (16 sites at varying current pressure, 5 historically dredged sites at moderate pressure). Recovery of non-target taxa was assessed through describing the ‘state’ of benthic communities, derived from count and cover of taxa in terms of abundance, richness and diversity parameters. The historically dredged sites, unfished since 2014, were compared with the ‘control sites’ outside the byelaw that are currently subject to dredging pressure. The threshold for cost-effective, but scientifically robust Minimum Viable Product monitoring strategies was also assessed, through investigating relationships over higher taxonomic classification levels and by reducing replicates. Full recovery of count taxa abundance was observed, while recovery had started for cover taxa abundance, richness and diversity, but would take more time to fully recover. No recovery was observed for count taxa richness and diversity. Observed differences between count and cover outputs were attributed mainly to mobile vs sessile life-history factors and thresholds of change, such as differences in dispersal ability and larval longevity. It is recommended that an established Minimum Viable Product strategy should not survey the discussed parameters above CATAMI Level 3, as Level 2 lost too much detail and patterns were either lost or weakened. Similarly, it is also recommended that monitoring should not analyse less than 100 images per dredge pressure category, as too much detail was lost, and patterns either weakened or became insignificant. It is recommended further research should factor depth and exclude dredge resilient organisms from analysis for the display of true patterns in terms of tracking recovery.

2. Introduction

2.1. Scallop Dredge Fisheries

Scallop (Pectinidae) dredge fisheries are of significant importance to local communities and global economies, with considerable increases in landings recorded throughout recent decades (Pantin et al., 2015). The King scallop is one of the most valuable species landed by UK vessels, with a reported worth of 67 million GBP in first sales value in 2016 and a five-year average of 60 million GBP (Ovchinnikova et al., 2021). However, declines in catches per unit effort have been observed in recent years, and despite this, more licenses have been approved and more vessels deployed as a result of surging scallop prices (Cappel et al., 2018). Scallop dredges are a mobile form of fishing gear, consisting of a triangular frame with a spring loaded, toothed lead bar that penetrates the seabed to scare or flip scallops up and into a collecting bag directly behind (Sewell & Hiscock, 2005). Typically, the top of the collecting bag is made up of either netting or links of chain that form a chain mesh, while the bottom of the bag consists predominantly of chain mesh with the aim of limiting damage to the seabed (Sewell & Hiscock, 2005). Numerous dredges are pulled behind a spreading bar either side of the vessel; the number of dredges used being directly determined by the regulations within the fishery’s district and the length and power of the vessel.

Restrictions on scallop dredging activity differ between local and national scales and with distance of activity from the shore. Generally, gears are restricted to 6-8 dredges per side of a vessel within six nautical miles of UK shores, leniency increasing with distance from the six nautical mile boundary offshore (Cappell et al., 2013). In addition to such general restrictions, local authorities often enact stricter regulations in specific locations around the UK. For example, some Inshore Fisheries and Conservation Authorities (IFCAs) have limited vessel sizes and even banned scallop dredging within specific areas from the shore through the implementation of byelaws within Special Areas of Conservation (SACs), amongst others (Howarth & Stewart, 2014). In addition to gear restrictions and spatial exclusions, size limitations are an important management tool. Current European Union legislation for king scallops states a 100mm shell length minimum landing size; however, this is excluding the Irish Sea and English Channel which has a limit of 110mm (Howarth & Stewart, 2014). Through limiting the intensity of dredging activity, previous investigators suggest that the restrictions discussed above directly promote sustainability of scallop stocks and indirectly benefit conservation of the wider marine environment (Bradshaw et al., 2002).

2.2. Impacts within the Marine Environment

Although significant local and global importance is attached to scallop dredge fisheries, mobile fishing gears that are towed along the seabed are also acknowledged to have considerable impacts upon marine ecosystems and associated species (Sciberras et al., 2013).

2.2.1. Impacts on Target Species

A direct impact of scallop dredging is the decrease in abundance of the target species; as firstly, high levels of scallop fishing have been reported to significantly reduce fertilisation success and recruitment through truncating age structures (Ovchinnikova et al., 2021). Despite juvenile protection through the implementation of minimum legal landing and mesh sizes, studies suggest fishing mortality is often high once legal scallop size is reached, through larger size classes being fished out rapidly and the high mortality rates among returned individuals. In turn, limited number of individuals are allowed to reach the larger sizes that are often observed in undisturbed populations (Beukerts-Stewart et al., 2005). Besides larger scallops being more economical valuable, their more developed reproductive organs are capable of producing and releasing considerably more gametes (Brand, 2006). Thus, reductions in population densities of larger scallops via dredging can lead to vast reductions in fertilisation success and recruitment (Beukerts-Stewart et al., 2005).

Target species can also be affected by physical impacts of scallop dredges. Previous investigators suggest that physical disturbances such as those caused by the close passing of dredges, as well as capture and discarding overboard can significantly reduce an individual’s ability in predator avoidance (Jenkins & Brand, 2001). Physical damage has been observed where the passing scallop dredges’ teeth has caused significant injury to the shell of the scallop, with some fatal results (Jenkins et al., 2004).

Physical damage then leads to further reduced reproductive output and growth levels, in addition to increased predator attraction and high susceptibility to predation (Beukerts-Stewart et al., 2005).

2.2.2. Impacts on Non-Target Benthos

Scallop dredges are acknowledged to be among the most damaging of fishing gears to non-target benthos and seabed habitats (Kaiser et al., 2006); particularly ‘Newhaven dredges’, which are specially designed to disrupt and penetrate surface sediments for an optimal king scallop catch rate. As a result, such dredging can cause a number of significant physical alterations to marine ecosystems, which vary with different pressure intensities, ecological communities and seabed types (Shephard et al., 2009). Previous investigators suggest scallop dredging likely disrupts benthic infauna, which could have repercussions throughout the ecosystem, such as inhibiting the important role infauna plays in linking benthic and pelagic process and reducing vital food sources for higher trophic levels (Newell et al., 1998). Benthic epifaunal organisms also provide important feeding grounds and nursery sites to the ecosystem; however, as they do not possess an avoidance ability, they are particularly susceptible to scallop dredging (Howarth & Stewart, 2014). Consequently, the removal/damage caused on such epifauna can impacts their immediate surroundings, reducing local biodiversity and the recruitment of ecologically and commercially important fish (Bradshaw et al., 2003). Mobile megafaunal by-catch is also a cause for concern, with studies reporting 20-30% of individuals suffering fatal injuries following capture (Howarth & Stewart, 2014).

2.3. Aim and Rational

The inshore area of Northumberland provides a unique opportunity to track the recovery of non-target benthic communities from previous scallop dredging activity, through the comparison of geographically close ‘historically dredged’, now closed area of Berwickshire and North Northumberland Coast SAC (BNNC SAC) with sites outside the BNNC SAC that are currently dredged at various intensities. This opportunity allows for the comparison of these two areas to determine whether scallop dredge prohibition has positively influenced benthic communities inside the SAC and whether the time period since management implementation is sufficient enough to demonstrate evidence of dredge impact prevention. Despite the impacts of dredging being widely studied around the UK, there is a significant lack of local evidence within this district to date. Local evidence is required as the Northumberland Coast is highly dynamic and has been modified by fishing over centuries. Benthic species may be adapted to strong currents and adverse weather conditions and could be more resilient to environmental pressures. Natural England and Northumberland IFCA (NIFCA) are currently consulting on changes to their scallop dredging byelaw and evidence generated by this project will feed directly into their consultation process and regional fisheries management decisions. This study also aims to advise NIFCA on possible future, cost and time effective, long-term impact monitoring strategies, through the determination of a ‘minimum viable product’ (MVP). An MVP can be defined as a developed, scientifically robust monitoring strategy with sufficient features to satisfy desired analytical goals, that is both cost and time effective through avoiding lengthy and unnecessary work (Lenarduzzi & Taibi, 2016).

2.4. Hypothesis

The study tests the hypothesis that benthos within the historically dredged sites have recovered in terms of abundance, richness and diversity since BNNC SAC implementation, by identifying whether they are most similar to sites that have a) not previously experienced scallop dredging or b) previously experienced and are currently subject to scallop dredging pressure. This study further aims to test the effectiveness of simplified monitoring strategies by reducing replication and utilising higher taxonomic levels.

3. Terms of Reference

This is a copy of the negotiated Terms of Reference (ToR) submitted to the client prior to data analysis, both the clients and academic supervisors were made aware of any changes that arose as a result of new discoveries and changes of direction.

Research Title: Dredging up the Past – Tracking Recovery of Non-Target Benthos from Historic Scallop Dredging Fishing Effort in Northumberland

3.1. Background and Purpose of Research

Scallop (Pectinidae) fisheries are of significant importance to local communities and global economies, with considerable increases in landings recorded throughout recent decades (Pantin et al., 2015). Despite the importance, mobile fishing gears can have considerable impacts upon marine ecosystems and associated species and scallop dredges are believed to be the most damaging of fishing gears to non-target benthos and seabed habitats (Kaiser et al., 2006). Previous investigators suggest scallop dredging likely disrupts benthic infauna, inhibiting the important role infauna plays in linking benthic and pelagic process, in addition to reducing vital food sources for higher trophic levels (Newell et al., 1998). Benthic epifaunal organisms also provide significant ecological functionality to marine ecosystems, in the form of representing important feeding grounds and nursery sites. However, consequent removal/damage caused on such epifauna has been linked to a series of knock-on effects to their immediate surroundings, impacting upon an area’s biodiversity and reducing the recruitment of ecologically and commercially important fish (Bradshaw et al., 2003). IFCAs have applied jurisdictions, limiting vessel sizes and have even banned scallop dredging within specific areas from the shore through the implementation of byelaws within SACs, amongst others (Howarth & Stewart, 2014).

The purpose of this research is to address critical, localised knowledge gaps for the impacts of scallop dredge fishery within Northumberland, to determine whether current NIFCA management is preventing impacts of dredging, whether the time period since management implementation is sufficient enough to demonstrate evidence of dredge impact prevention and whether benthic communities are recovering from historic dredging activity. This research will also advise NIFCA on possible future, long-term impact monitoring strategies that would be both cost and time effective.

3.2. Scope of Research and Rationale: NIFCA District

The NIFCA district is situated off the English Northeast Coast and extends from the northern Scottish-English border to the River Tyne in south, and out to six nautical miles including all estuaries up to their normal tide limit. Within this district, NIFCA is responsible for the sustainable management of fisheries such as those of scallop, NIFCA also has responsibilities regarding MPAs including the five Special Protected Areas (SPA), three Marine Conservation Zones (MCZ) and two SACs within NIFCA's district. The geography of the seabed consists of large areas of rocky reefs, sand and mud flats providing ideal grounds for Pectinidae, crustacea and Nephrops. Scallop dredging, predominantly targeting the king scallop currently occurs relatively sporadically throughout the NIFCA district as management within the region has been implemented through the BNNC SAC, restricting dredging in this area since 2014. However, scallop dredging is still permitted in the area and is continuing around the BNNC SAC's boundaries, with five holders of dredge permits reportedly registered to dredge in 2018 (NIFCA, 2020).

Considering this, the inshore area of Northumberland provides a unique opportunity to investigate impacts of scallop dredging on benthic communities within geographically close 'historically fished' now closed area (BNNC SAC) and currently fished sites. This opportunity allows for the comparison of these two areas to determine whether scallop dredge prohibition has positively impacted benthic communities inside the SAC, ultimately indicating the effectiveness of current MPA management. Despite the impacts of dredging being widely studied around the UK, there is a significant lack of local evidence within this district to date. Local evidence would be invaluable, as the Northumberland Coast is regarded as quite a dynamic area with numerous benthic species being well adapted to strong currents and adverse weather conditions, and thus it can be assumed that such species would be typically more resilient to environmental pressures. Moreover, NIFCA are currently consulting on changes to their scallop dredging byelaw and the results of this local evidence could feed directly into their consultation process and regional fisheries management decisions.

3.3. Project Aims and Objectives

This research will aim to investigate whether scallop dredge prohibition has positively influenced benthic communities inside the SAC through the recovery of abundance, richness and diversity parameters, and whether the time period since management implementation is sufficient enough to demonstrate evidence of dredge impact prevention. The project further aims to determine a 'minimum viable product' (MVP), defined as developing a scientifically robust monitoring strategy with sufficient features to satisfy desired analytical goals. Ultimately, advising on NIFCA's benthic communities monitoring strategies going forward through developing an MVP that is both cost and time effective by avoiding lengthy and unnecessary work.

This aim will firstly be achieved through conducting and recording image quality assessments, sediment type assignments and taxa identification in forms of respective count and percentage cover of SeaSpider camera imagery. While analysis will be undertaken through a combination of univariate statistical methods that include: Kruskal-Wallis H-tests, Spearman's Rank Correlation Coefficients, Shannon's Diversity Index and multivariate methods including: ANOSIM analysis for investigating similarities in non-target benthic communities between historic sites and sites currently dredged at various intensities, SIMPER analysis to calculate the contribution (%) of each taxa to the observed dissimilarity between sites and non-metric Multi-dimensional Scaling (nMDS) for visualising patterns and groupings in community composition of historic sites and currently dredged pressure categories. Developing an MVP will be achieved through working backwards with the analysed data to determine simpler but scientifically robust monitoring strategies which obtain effective results. By comparing Spearman's Correlation outputs of abundance, richness and diversity parameters across higher taxonomic classification (taxa level through to CATAMI Level 3 and 2) and determining the least number of images that need to be collected and analysed.

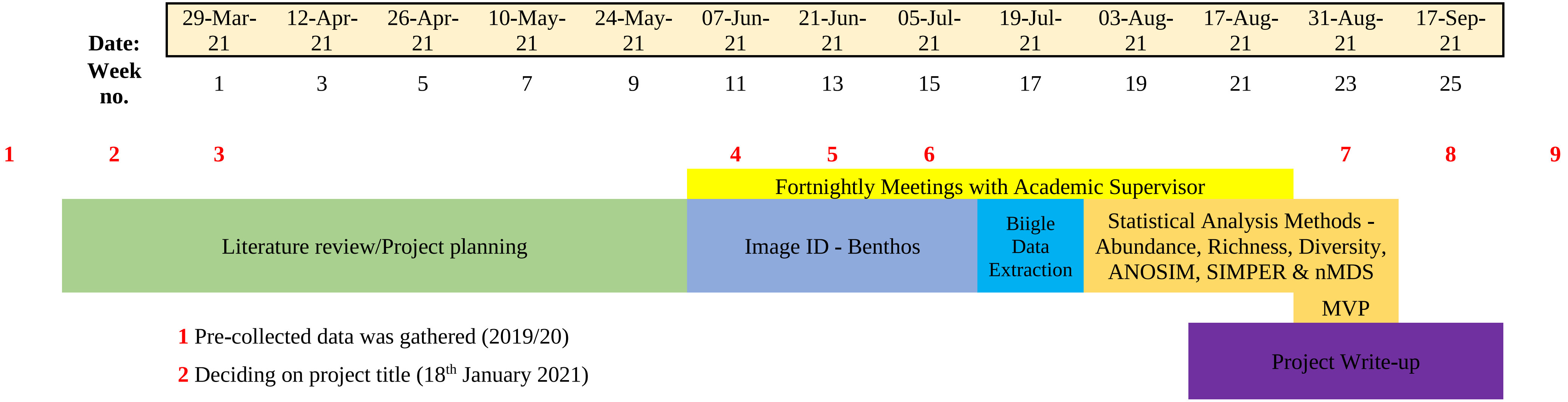
X JDuffy.

James Duffy
Consultant Newcastle University
Date: 15/07/21

X Alex Aitken

Alex Aitken
NIFCA
Signed by: e1ff849b-1fff-4b3a-9f6d-13410d2249a9
Date: 09/09/21

4. Project Timeline



1 Pre-collected data was gathered (2019/20)

2 Deciding on project title (18th January 2021)

3 Submission of project proposal (30th March 2021)

4 **Meeting with client** to discuss the project (7th June 2021)

5 **Meeting with client** to negotiate & establish ToR (24th June 2021)

6 **Contact with client** to discuss change to original ToR, TITAN analysis of historic sites no longer viable as all sites are moderate dredging pressure (5th July 2021)

7 Submission of draft to supervisor (7th September 2021)

8 Final submission (17th September 2021)

9 Project presentation (23rd September 2021)

Figure 1. Gannt chart displaying the project's timeline, important meetings with the client highlighted in bold.

5. Methodology

5.1. *Study Area*

The NIFCA district, situated off the English Northeast Coast extends from the northern Scottish-English border to the River Tyne in south and out to six nautical miles including all estuaries up to their normal tide limit (NIFCA, 2020, Figure 2A-B). Within this district, NIFCA is responsible for the sustainable management of fisheries such as those of scallop, NIFCA also has responsibilities regarding MPAs including the five SPAs, three MCZs and two SACs within NIFCA's district. The geography of the seabed consists of large areas of rocky reefs, interspersed by sandy and muddy sections that provide ideal grounds for numerous marine organisms (Howarth & Stewart, 2014). Inshore scallop dredging is regulated and occurs in relatively small amounts throughout the NIFCA district, as management within the region has been implemented in the BNNC SAC, restricting dredging in this area since 2014 (Figure 2A-B). However, scallop dredging is still permitted and is continuing around the BNNC SAC's boundaries, with five holders of dredge permits reportedly registered to dredge in 2018 (NIFCA, 2020, Figure 2A).

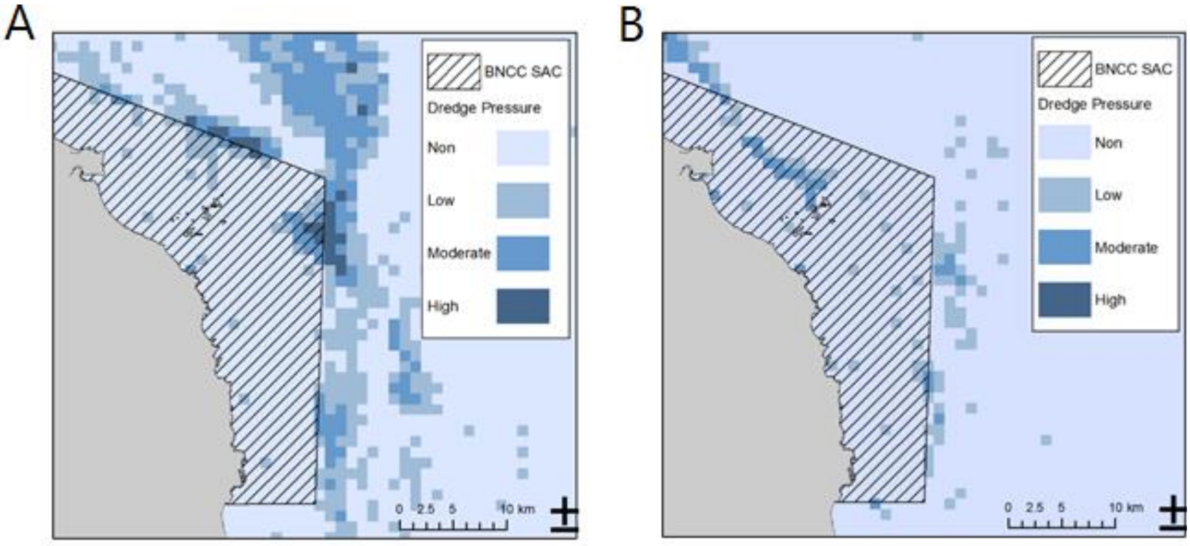


Figure 2. Dredging pressure gradiant around the southern boundaries of the BNNC SAC: **A)** after mobile gear ban 2016-2019 and **B)** before mobile gear ban 2010-2013 (Tinlin-MacKenzie, 2021). See table 1 for pressure values.

5.2. *Data Collection*

To track recovery of the historically dredged sites and advise on future monitoring approaches, effects of scallop dredging on non-target benthic abundance, richness and diversity were assessed utilising scallop dredging pressure maps created using Vessel Monitoring System (VMS) data supplied by the Marine Management Organisation (MMO) (Tinlin-MacKenzie, 2021), in combination with data derived from benthic imagery collected previously.

VMS data (one ping every two hours) are provided for vessels over 12m and were selected as 'dredging' if they were traveling at speeds below four knots (NIFCA, 2020), other vessel tracks were eliminated. 1km x 1km grid cells were used to create proxies characterised as historic (2010-2013) and current dredging pressure (2016-2019) (Table 1). Benthic sampling was conducted at 21 sites in and around the BNNC SAC over two days upon the St Aidan in 2019/20, where grid squares varying in degrees of dredge pressure were targeted with an equal spread (16 sites at current pressure, 5 moderate dredge pressure sites at historic, Figure 3). A SeaSpyder camera system (ED140716) was deployed at each of the 21 GPS coordinated sampling sites, where the camera was slowly towed above the seabed until 100 or more images at each site that were deemed adequate quality were captured.

Table 1. VMS pings per 1km x 1km grid cell for each dredge pressure category (Tinlin-MacKenzie, 2021)

Dredge Pressure Category	Current Pressure (2016-2019)	Historic Pressure (2010-2013)
None	0	0
Low	1-7	1-4
Moderate	8-22	5-18
High	23-61	18-49

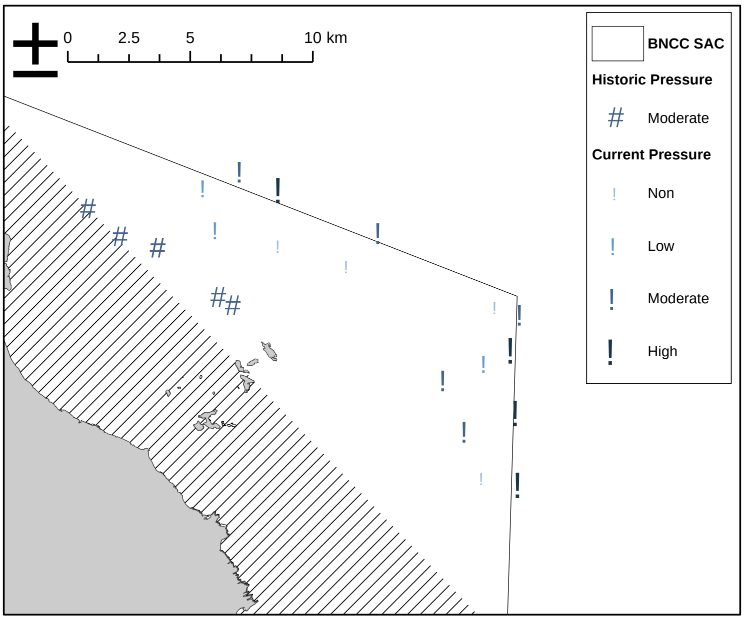


Figure 3. Sample sites for current (2016-2019) and historic (2010-2013) dredging pressure in and around the BNNC SAC, with associated pressure categories (Tinlin-MacKenzie, 2021). See table 1 for pressure values.

5.3. Data Handling and Processing

Following data collection, the SeaSpyder imagery was processed for compatibility within Biigle software through the removal of brackets from filenames, where the quality of each image was assessed, scaled by adding points to laser dots and classified by main substrate type prior to taxa identification (Table 2).

Table 2. SeaSpyder imagery quality assessment categories and guidelines while using Biigle software. Adapted from Tinlin-MacKenzie (2021).

Quality Assessment Categories	Guidelines
Excellent	Clear and fully focussed, optimal field of view with excellent exposure and colour. Scalable and >50% pebble/cobble/gravel substrate type. Full analysis conducted on characterised image.
Good	Focussed, being slightly over or under exposed, small amount of suspended matter. Scalable and >50% pebble/cobble/gravel substrate type. Full analysis conducted on characterised image.
Poor	Poor angle/position, lighting, suspended matter, focus. Non-scalable and/or <50% pebble/cobble/gravel substrate type. No analysis conducted on characterised image.
Very Poor	Very poor angle/position, lighting, suspended matter, focus. Non-scalable and/or <50% pebble/cobble/gravel substrate type. No analysis conducted on characterised image.

5.4. *Taxa Identification*

Throughout analysis, taxa identification was limited to the lowest level that could be confidently achieved from the image without speculation. Therefore, taxon ID ranged from species level to ’life form’ level (i.e. hydroid, crustacea), following Cefas Video and Stills Processing guidance for consistency (Cefas, 2020). To ensure comparable results, as suggested by MNCR guidance (Connor et al., 2004), huge/encrusting species were recorded using percentage cover (Table 3), while solitary individuals that could be confidently defined were recorded using counts. Taxa identification for the current dredge pressure sites was conducted by Tinlin-MacKenzie & Savage (2021), and for the historic dredge pressure sites by the author and a fellow researcher. An inter-observer agreement was conducted between the author and fellow researcher ($k = 0.81$, percentage agreement 88.7%), expressed as a kappa (k) statistic that was accepted as adequate, with a p-value < 0.05 to indicate statistical significance, as recommended by Ahmed et al. (2021). Following taxa identification, abundance data was generated within Biigle software and extracted to a Microsoft Excel spreadsheet for analysis through R studio.

Table 3. Taxa being difficult to tell apart and too frequent at sites were enumerated as percentage cover within Biigle.

Taxa Enumerated as Percentage Cover	
Sabellaria alveolata	Soft Coral
All Macroalgae	Barnacles
All Sponges	All Hydroids
All Brittlestars	Colonial anemones
Faunal Turf	Substrate
Faunal Crust	Spirobranchus sp.
Bryozoan	

5.5. *Data Analysis*

5.5.1. *Tracking Recovery*

Recovery of non-target taxa within the BNNC SAC, were assessed by describing the ‘state’ of benthic communities, derived from count and cover of taxa in terms of abundance, richness and Shannon’s

Diversity parameters. The historically dredged sites, which have been unfished since 2014, were compared with the same parameters of ‘control sites’ outside the byelaw that are currently subject to dredging pressure. As discussed, such sites were divided into dredge pressure categories according to MMO supplied VMS data (none, low, moderate and high, Table 1). Relationships between taxa and VMS derived dredge pressure data were firstly determined via Spearman’s Rank Correlation Coefficient analysis. Kruskal-Wallis H-tests then determined significant differences between parameters with pressure categories, and SIMPER analysis identified the highest contributors to observed dissimilarity amongst pressure categories. Spearman’s Correlation analysis initially gave inconsistent results with that of the available literature, while SIMPER analysis identified that opportunistic Ascidian species were the greatest contributor to the observed dissimilarity between pressure categories. Consequently, such Ascidian species were removed from further analysis to display true patterns in terms of tracking recovery, as ascidians are acknowledged by previous investigators for their rapid growth and ability to outcompete and outgrow other residing organisms (Lynch et al., 2016; Koplovitz et al., 2016). Significant, consistent patterns then followed. One-way ANOSIM (R-value) and SIMPER (overall % dissimilarity) analysis were utilised to compare the similarity of the historically dredged sites parameters with that of the ‘control sites’ of none and varying dredge intensities. For example, if the parameters of the historically dredged sites were most similar to the highly fished sites, it would suggest that the sites have not recovered since BNNC SAC implementation. Non-metric Multi-dimensional Scaling (nMDS) was also utilised for count and cover abundance data for visualising patterns in community composition between historic dredge pressure categories, which can be interpreted to represent underlying ecological and environmental gradients.

5.5.2. MVP Monitoring Approach

To determine the threshold for cost-effective but scientifically robust monitoring strategies Spearman’s Correlation outputs of dredge pressures for count and cover taxa across higher taxonomic classification levels were compared as data was sequentially removed, to see if the observed patterns remained consistent and significant. In this case, parameters were compared from taxa level through to CATAMI Level 3 and 2. CATAMI Level 2 is a broad classification of groups (i.e. Sponges and Crustacea), which vastly reduced the number of different classifications within the data, while Level 3 is more detailed, but is descriptive (Althaus et al., 2014). All taxa were filtered into adequate classifications in line with the CATAMI Classification Scheme guide (Althaus et al., 2014). A similar strategy reduced number of number of replicates (number of SeaSpyder images processed per dredge pressure category) until results were no longer robust. Spearman Correlation outputs were compared over varying levels of replication (original number, 100, 50, 25) to see if observed patterns remained consistent along the gradient with fewer images (effort). For both methods, points in count and cover taxa parameters where patterns disappeared were identified and recommendations of surveying above these points were made.

6. Results

6.1. Ascidians

Initial observations indicated significant increases in count taxonomic abundance with dredging pressure ($p < 0.001$, Figure 4A). Similarity percentage methods showed Ascidians to be responsible for the observed dissimilarity between all dredge pressure categories, with a significant cumulative contribution of 48.26% (SIMPER – Bray-Curtis, Permutations = 999). While investigating Ascidians and dredge pressure exclusively, Spearman's Correlation Coefficient indicated a highly significant increase in Ascidian abundance with dredging pressure ($r = 0.411$ $p < 0.001$), suggesting Ascidian taxa regularly occur in areas with higher dredging pressure. With their opportunistic nature and significant contribution to dissimilarity between dredge pressure categories in mind, all Ascidians were excluded from further analysis for the display of true patterns regarding tracking recovery of historically dredged sites. As a result, observed patterns in count taxa abundance with dredging pressure differed widely between the inclusion and exclusion of Ascidians within data analysis (Figure 4A-B).

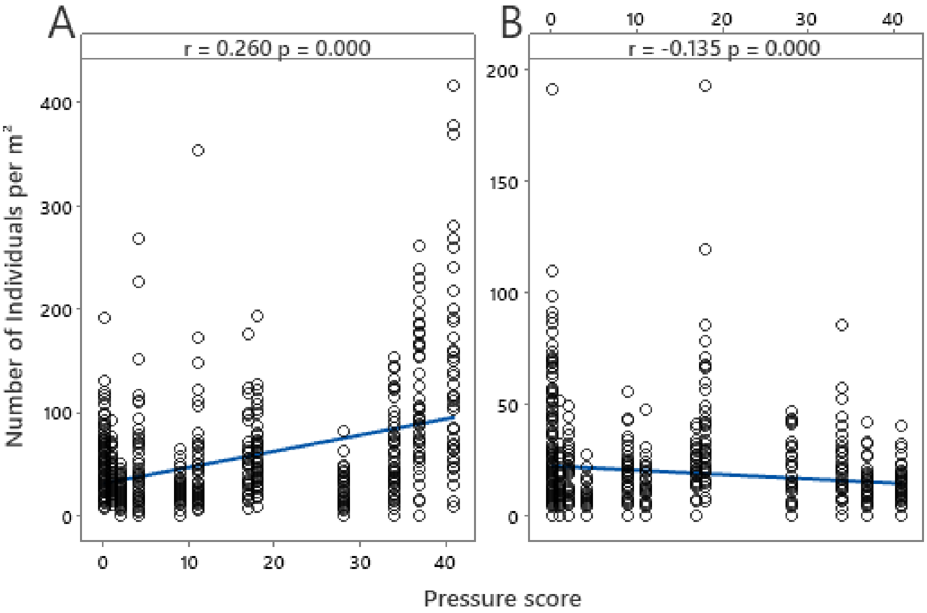


Figure 4. Scatterplots of individuals recorded in Historic sites displaying the relationship between **A)** count taxa abundance including Ascidians (number of individuals per m^2) against pressure score with regression line and Spearman's Correlation Coefficient. **B)** count taxa abundance excluding Ascidians (number of individuals per m^2) against pressure score with regression line and Spearman's Correlation Coefficient.

6.2. Tracking Recovery

6.2.1. Abundance

Kruskal-Wallis H-tests indicated that abundance for both count and cover taxa in all dredge pressure categories are significantly different from one another (Figure 5A-B, $p < 0.001$), with a significant negative correlation being observed for count taxa abundance (Spearman's Correlation, $r = -0.135$, $p <$

0.001, excluding historic), and a positive significant correlation for cover taxa (Spearman's Correlation, r = -0.163, p < 0.001, excluding historic). Further observation indicated that for both count and cover taxa, abundance is greatest in areas that have not previously experienced or are currently subject to any degree of scallop dredging, while abundance appears to be lowest for count taxa in areas that have undergone high degrees of dredging and for cover taxa in areas that have undergone low and historic forms of dredging.

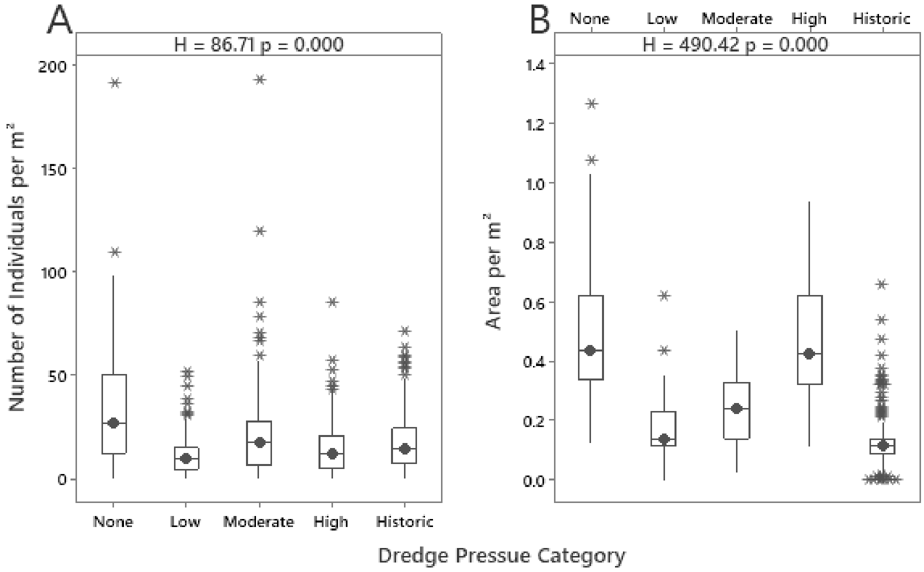


Figure 5. Boxplots showing the distribution, central value and variability of **A)** count taxa (number of individuals per m^2) and **B)** cover taxa (area per m^2) with dredge pressure categories through the display of then median and interquartile range. Outliers and Kruskal-Wallis H-test are also displayed (*d.f.* = 4).

ANOSIM and SIMPER analysis indicated that in terms of the number of individuals per m^2 (count taxa), abundance in the historically dredged sites is most similar to areas that have not previously experienced or are currently subject to any degree of scallop dredging, due to possessing both an R-value that is closest to 0 and the lowest percentage dissimilarity in comparison with other dredging pressure categories (R-value = -0.002, Dissimilarity = 88.39%, Table 4). Whereas abundance of individuals in the historically dredged sites is most dissimilar to that of low dredging pressures, possessing an R-value closest to 1 and the greatest percentage dissimilarity (R-value = 0.120, Dissimilarity = 93.42). In terms of cover taxa area per m^2, abundance in the historically dredged sites is most similar to areas that are experiencing a low degree of dredging pressure (R-value = 0.0135, Dissimilarity = 45.26%). Whereas abundance of cover taxa in the historically dredged sites is most dissimilar to sites experiencing high degrees of dredging pressure, possessing an R-value closest to 1 (0.4239). Paguroidea species contributed the greatest to count taxa observed dissimilarity between the historically dredged and the other dredge pressure categories, ranging from 20.31-17.21%. While faunal turf contributed the greatest to cover taxa observed dissimilarity, ranging from 89.51-69.2%.

Table 4. One-way ANOSIM and SIMPER comparing the similarity of the number of individuals/m^2 and area per m^2 between Historic and all other Dredge Pressure Categories for count and cover taxa respectively (ANOSIM: Permutations = 999, Similarity Index = Bray-Curtis & SIMPER: Similarity Index = Bray-Curtis). ANOSIM R-values closer to "1.0" indicating dissimilarity between groups and R-values closer to "0" suggesting an even distribution within and between groups.

		Historic		
		ANOSIM (R-value)	SIMPER (% contribution)	
			Overall Average Dissimilarity (%)	Highest Contributor to Dissimilarity (%)
Count Taxa	**None**	-0.002	88.39	20.31 (Paguroidea)
	Low	0.120	93.42	13.84 (Paguroidea)
	Moderate	0.029	89.97	18.20 (Paguroidea)
	High	0.043	91.27	17.72 (Paguroidea)
Cover Taxa	**None**	0.3981	65.61	69.2 (Faunal turf)
	Low	0.0135	45.26	74.12 (Faunal turf)
	Moderate	0.2028	51.25	74.12 (Faunal turf)
	High	0.4239	64.22	89.51 (Faunal turf)

Differences in count and cover taxa community composition between dredge pressure categories can be visualised in nMDS ordination plots (Figure 6A-B). However, in this instance, no obvious groupings can be observed in either count or cover taxa nMDS plot and thus no patterns can be interpreted to represent underlying ecological and environmental gradients. This is further supported by the high Stress values of each nMDS, suggesting the ordination is arbitrary.

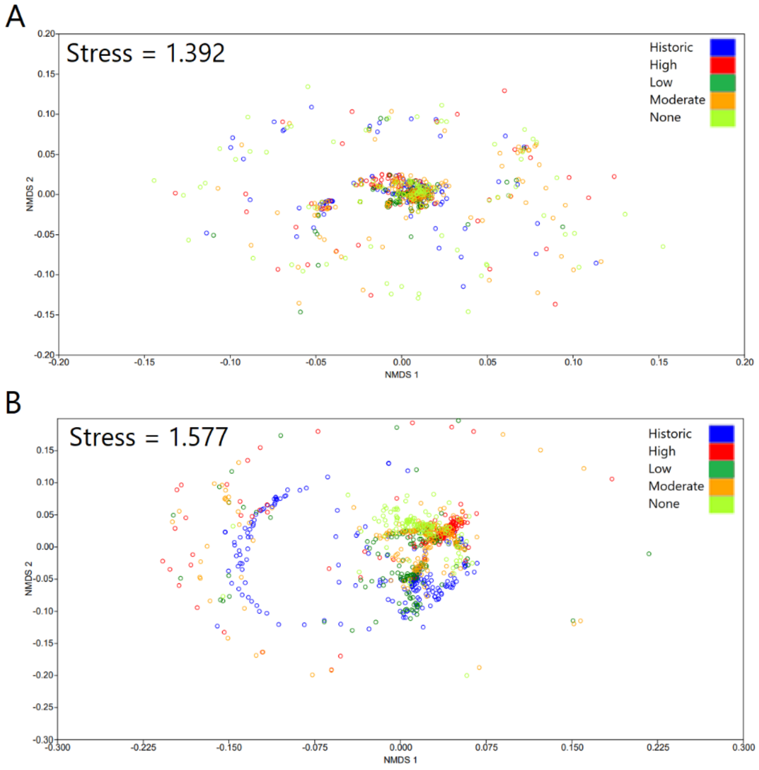


Figure 6. nMDS ordination plots of square root transformed abundance data of **A)** count taxa and **B)** cover taxa displaying the similarity of community composition between all dredge pressure categories along with Stress values (Similarity Index = Bray-Curtis). Points dissimilar to one another are ordinated further apart whilst similar points are ordinated closer together.

6.2.2. Richness

Kruskal-Wallis H-tests indicated that taxonomic richness for both count and cover taxa in all dredge pressure categories are significantly different from one another (Figure 7A-B, $p < 0.001$), with significant negative correlations for both count and cover taxa against dredge pressure score being observed (Spearman's Correlation $r = -0.138$ & $r = -0.309$ respectively, $p < 0.001$, excluding historic). Further observation indicated that for both count and cover taxa, taxonomic richness is greatest in areas that have not previously experienced or are currently subject to any degree of scallop dredging, while abundance appeared to be lowest for both count and cover taxa in areas that are subject to high and historic forms of dredging (Figure 7A-B).

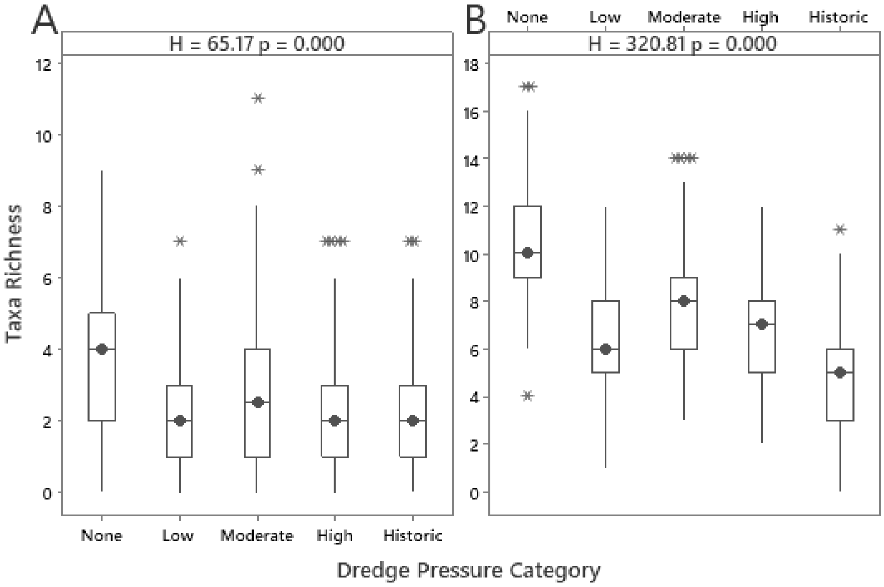


Figure 7. Boxplots showing the distribution, central value and variability of Taxa Richness for **A)** count taxa and **B)** cover taxa with dredge pressure categories through the display of the median and interquartile range. Outliers and Kruskal-Wallis H-test are also displayed (*d.f.* = 4).

ANOSIM analysis indicated that in terms of taxonomic richness, count taxa richness in the historically dredged sites is most similar to areas that have undergone high forms of scallop dredging (R closest to 0) when compared with the other dredging pressure categories (ANOSIM R-value = 0.0013, Table 5). Whereas count taxa richness in the historically dredged sites is most dissimilar to areas that have not previously experienced or are currently subject to any degree of scallop dredging (R closest to 1) (ANOSIM R-value = 0.0556). In terms of cover taxonomic richness, richness in the historically dredged sites is most similar to areas that are experiencing a low degree of dredging pressure (ANOSIM R-value = 0.0228), whereas cover taxa in the historically dredged sites is most dissimilar to areas that have not previously experienced or are currently subject to any degree of scallop dredging (ANOSIM R-value = 0.3736).

Table 5. One-way ANOSIM comparing the similarity of Taxa Richness for count and cover taxa between Historic and all other Dredge Pressure Categories (ANOSIM: Permutations = 999, Similarity Index = Bray-Curtis). ANOSIM R-values closer to "1.0" indicating dissimilarity between groups and R-values closer to "0" suggesting an even distribution within and between groups

	Count Taxa	Cover Taxa
	Historic	
	ANOSIM (R value)	
None	0.0556	0.3736
Low	0.0089	0.0228
Moderate	0.0027	0.1790
High	0.0013	0.0903

6.2.3. Diversity

Kruskal-Wallis H-tests indicated that Shannon's Diversity Index values for both count and cover taxa in all dredge pressure categories are significantly different from one another (Figure 8A-B), with significant negative correlations for both count and cover taxa against dredge pressure scores being observed (Spearman's Correlation r = -0.116 p < 0.01 & r = -0.515, p < 0.001 respectively, excluding historic). Further observation indicated that for both count and cover taxa, diversity is greatest in areas that have not previously experienced or are currently subject to any degree of scallop dredging, while diversity appears to be lowest for both count and cover taxa in areas that are subject to high forms of dredging (Figure 8A-B).

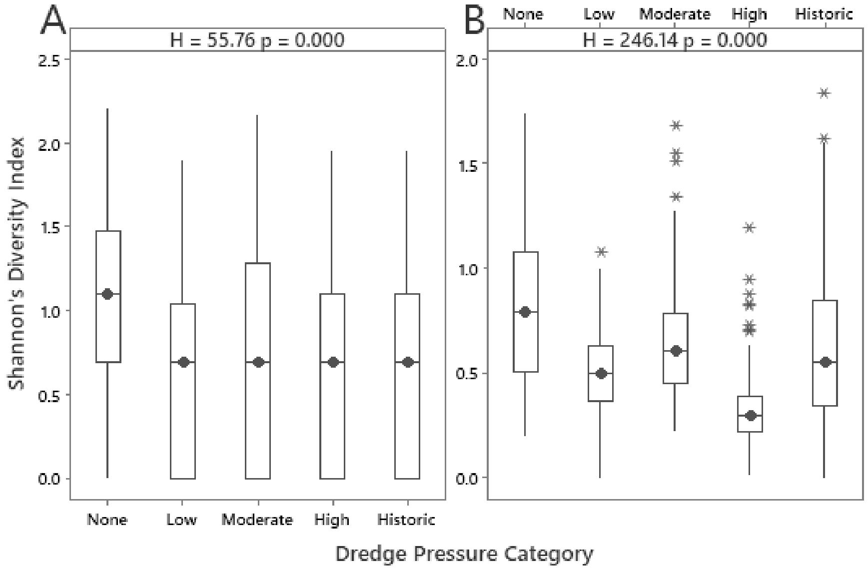


Figure 8. Boxplots showing the distribution, central value and variability of Shannon's Diversity Index values for **A)** count taxa and **B)** cover taxa with dredge pressure categories through the display of the median and interquartile range. Outliers and Kruskal-Wallis H-test are also displayed (*d.f.* = 4).

ANOSIM indicated that in terms of diversity, count taxonomic diversity in the historically dredged sites is most similar to areas that have undergone high forms of scallop dredging (R closest to 0) when compared with the other dredging pressure categories (ANOSIM R-value = 0.0014, Table 6). Whereas count taxa diversity in the historically dredge sites is most dissimilar to areas that have not previously experienced or are currently subject to any degree of scallop dredging (R closest to 1) (ANOSIM R-value = 0.0330). In terms of cover taxonomic diversity, diversity in the historically dredged sites is most similar to areas that are experiencing a low degree of dredging pressure (ANOSIM R-value = -0.0029), whereas cover taxa in the historically dredged sites is most dissimilar to areas that are currently subject to high forms of scallop dredging (ANOSIM R-value = 0.2296).

Table 6. One-way ANOSIM comparing the similarity of Shannon's Diversity Index values for count and cover taxa between Historic and all other Dredge Pressure Categories (ANOSIM: Permutations = 999, Similarity Index = Bray-Curtis). ANOSIM R-values closer to "1.0" indicating dissimilarity between groups and R-values closer to "0" suggesting an even distribution within and between groups

	Count Taxa	**Cover Taxa**
	Historic	
	ANOSIM (R value)	
None	0.0330	-0.0235
Low	0.0028	-0.0029
Moderate	0.0032	0.0157
High	0.0014	0.2296

6.3. MVP Monitoring Strategies

6.3.1. Taxonomic Classification

For both count and cover taxa, abundance did not change across taxonomic classification levels as Spearman's Correlation remained highly negatively correlated with dredge pressure throughout (Table 7). In terms of richness, the count taxa R-value dropped slightly between taxa level and CATAMI Level 3, but the correlation remained highly negatively significant. However, this relationship was lost with further higher taxonomic classification as an insignificant correlation can be observed between CATAMI Level 3 and 2. Similarly to count taxa, the richness R-value for cover taxa also dropped between taxa level and CATAMI Level 3 but the relationship remained highly negatively significant. However, in this case, the cover taxa R-value recovered between CATAMI Level 3 and 2, with an observed significant relationship remaining consistent across taxonomic classification levels. In terms of diversity, the count taxa R-value dropped between taxa level and CATAMI Level 3 with the significance level also becoming weaker. This relationship was then lost with further higher classification as an insignificant correlation can be observed between CATAMI Level 3 and 2. Differing from count taxa, cover taxa diversity's R-value and significance levels with dredge pressure remained consistent across taxonomic classification levels.

Table 7. Spearman's Correlation Coefficient results of count and cover taxa abundance, richness and diversity with dredge pressure compared across taxonomic classification levels. Significance levels interpreted as $p > 0.05$ = no symbol, $p \leq 0.05$ = *, $p \leq 0.01$ = **, $p \leq 0.001$ = ***.

		Taxa Level	**CATAMI Level 3**	**CATAMI Level 2**
Count Taxa	Abundance	-0.135 ***	-0.135 ***	-0.135 ***
	Richness	-0.138 ***	-0.126 ***	-0.048
	Diversity	-0.116 **	-0.096 *	0.008
Cover Taxa	Abundance	0.163 ***	0.163 ***	0.163 ***
	Richness	-0.309 ***	-0.284 ***	-0.343 ***
	Diversity	-0.515 ***	-0.515 ***	-0.522 ***

6.3.2. Removing Replicates

When replicates were removed from Spearman's Correlation calculations, a significant negative relationship for count taxa abundance with dredge pressure remained consistent (Table 8). However, with decreased replicates from 100 processed images per dredge pressure category, the observed relationship became gradually weaker. For cover taxa abundance, the significantly positive relationship with dredge pressure became immediately dissimilar and inconsistent with increased replicate removal. Regarding count taxa richness, the highly negative relationship with dredge pressure remained consistent with initial replication removal; however, this relationship became weaker and eventually insignificant with further removal. Cover taxa richness and diversity remained consistent in terms of pattern and significance between the original number and 100 replicates; however, these relationships became dissimilar and inconsistent with further replicate removal. Count taxa richness with dredge pressure pattern remained consistent but gradually became weaker between the original number and 50 replicates and became insignificant at 25. Count taxa diversity remained consistent between the original number and 100 replicates per dredge pressure category and became insignificant with further removal.

Table 8. Spearman's Correlation Coefficient results of count and cover taxa abundance, richness and diversity with dredge pressure compared across number of replicates (number of images processed per dredge pressure category). Significance levels interpreted as $p > 0.05$ = no symbol, $p \leq 0.05$ = *, $p \leq 0.01$ = **, $p \leq 0.001$ = ***.

		Replicates per Dredge Pressure Category			
		Original Number	**100**	**50**	**25**
Count Taxa	Abundance	-0.135 ***	-0.202 ***	-0.215 **	-0.202 *
	Richness	-0.138 ***	-0.197 ***	-0.148 *	-0.130
	Diversity	-0.116 **	-0.166 **	-0.108	-0.090
Cover Taxa	Abundance	0.163 ***	0.020	-0.152 *	-0.185
	Richness	-0.309 ***	-0.389 ***	0.630 ***	-0.472 ***
	Diversity	-0.515 ***	-0.538 ***	0.269 ***	-0.425 ***

7. Discussion

7.1. Tracking Recovery

7.1.1. Abundance

While tracking recovery of non-target benthos from historic scallop dredging in Northumberland, it became clear through analysis that count taxa abundance in the historically dredged sites is most similar to areas that have not previously experienced or are currently subject to any degree of scallop dredging (Table 4). This indicates that in terms of abundance, count taxa has fully recovered since the BNNC SAC dredging ban came into place in 2014 and that the time period since management implementation is sufficient enough to demonstrate evidence of dredge impact prevention and recovery. Such evidence is supported by a rising number of related studies that have also indicated the effectiveness of closed areas on the abundance of relevant benthic species (Bradshaw et al., 2001). For example, a previous investigation in Georges Bank, USA, found highly significant increases in benthic abundance (x4), production (x4) and biomass (x18) after five years following closure to bottom trawling (Valentine & Almeida, 2005). While a more species-specific study found that five years after Lamlash Bay's No-Take Zone (NTZ) in Scotland was established, legally sized European lobster Catch Per Unit Effort (CPUE) was 189% higher inside the NTZ than outside, suggesting further significant recovery (Howarth & Stewart, 2014).

Through analysis, cover taxa abundance in the historically dredged sites were found to be most similar to areas that are currently experiencing a low degree of dredging pressure (Table 4), indicating that in terms of abundance, cover taxa recovery has started, but will take more time to fully recover. Studies that utilised similar methods further support this through also indicating evidence for recovery, with abundance observations of epifaunal and sessile organisms three years after dredging closure within Lyme Bay's MPA indicating significant increases, particularly in hydroids (229%), branched sponges (414%), ross coral (385%) and pink sea fans (636%) (Sheehan et al., 2013a). Despite similar observations between this study and those of previous investigators, a significant positive correlation between abundance and dredge pressure score was observed (Figure 4), directly contradicting that of the available literature (Kaiser et al., 2018; Thrush & Dayton, 2002). SIMPER analysis identified that faunal turf contributed the most to the observed dissimilarity between pressure categories and after reviewing literature, it became clear that previous studies had found no clear evidence for dredging pressure impacting on the occurrence of faunal turf coverage on hard substrates (Boulcott et al., 2014). Considering this, it is recommended that future research in terms of tracking recovery should exclude faunal turf from analysis, for the display of true patterns.

7.1.2. Richness

While tracking recovery of non-target benthic richness from historic scallop dredging, it became clear through analysis that count taxa is most similar to areas that have undergone high degrees of scallop dredging (Table 5). This indicates that in terms of richness, count taxa has not recovered since the BNNC SAC dredging ban came into place and that the time period since management implementation is not sufficient enough to demonstrate evidence of dredge impact prevention and recovery. This directly contradicts evidence shown by previous investigations, where within three years of towed demersal fishing prohibition within Lyme Bay's MPA, definitive evidence of recovery was noted for species richness (Sheehan et al., 2013b). Another study conducted within Cardigan Bay also recorded recovery of benthic species richness within a closed site. However, through multivariate analysis, it was found that 'duration of closure' had no effect on overall richness, but instead the observed changes were mostly because of temporal patterns of natural variation related to processes like that of recruitment (Sciberras et al., 2013). Through analysis, cover taxa richness in the historically dredged sites were found to be most similar to areas that have and are currently experiencing a low degree of dredging pressure (Table 5), indicating that in terms of richness, cover taxa recovery has started, but will take more time to fully recover. This is supported by further research conducted in Lyme Bay's MPA, where significant increases in species richness and structural complexity of sessile and epifaunal life was observed (Sheehan et al., 2013a).

The observed difference between count (not recovering) and cover (recovering) taxa richness can firstly be explained by the inclusion of resilient faunal turf in analysis, which may have influenced results, as previously discussed. However, this difference can also be explained in terms of threshold of change and why it may differ between count and cover taxa (mobile vs sessile taxa). Studies suggest that rates of recovery are highly dependent on factors of life-history, such as dispersal ability and larval longevity (Kaiser et al., 2017). For example, sessile dead men's fingers possess a high recovery rate due to their mass spawning and high fecundity, as when fertilised, their planulae can disperse further than 10km and occur within the water column for longer the ten days (Kaiser et al., 2017). While in contrast, other organisms such as mobile Paguroidea possess less efficient reproductive capabilities and thus have a poorer recovery rate, through producing free swimming larvae that rely heavily upon local populations of adults (Kornienko, 2020).

7.1.3. Diversity

While tracking recovery of non-target benthic diversity from historic scallop dredging, it became clear through analysis that count taxa is most similar to areas that have undergone high degrees of scallop dredging (Table 6). This indicates that in terms of diversity, count taxa has not recovered since the BNNC SAC dredging ban came into place and that the time period since management implementation is not sufficient enough to demonstrate evidence of dredge impact prevention and recovery. Studies that utilised similar methods further support this, as no differences in terms of related taxa diversity were found between the seasonally dredged and permanently closed area of Cardigan Bay; however, it should be noted that this examination of recovery was only 23 months after closure (Sciberras et al., 2013).

Through analysis, cover taxa diversity in the historically dredged sites was found to be most similar to areas that have and are currently experiencing a low degree of dredging pressure (Table 6), indicating that in terms of diversity, cover taxa recovery has started, but will take more time to fully recover. The available literature supports such findings, as five years after a trawling ban was established in the Dutch coastal zone, higher overall diversity of benthic species was recorded (Bergman et al., 2014), while significant increases in sessile diversity was also observed in Lyme Bay's MPA three years after dredging prohibition (Howarth & Stewart, 2014).

Similarly to richness, observed differences between count (not recovering) and cover (recovering) taxa diversity can also be explained by mobile vs sessile taxa life-history factors and the inclusion of faunal turf in analysis, as previously discussed. However, it is also important to note that recovery rates of all parameters of benthic individuals can be influenced by depth (Collie et al., 2000). A study that investigated whether recovery of benthic communities following dredging activity is depth-related found that in shallower depths, communities demonstrated faster recovery in terms of abundance, richness and diversity (Constantino et al., 2008). It is recommended that further research factors depth into analysis through multivariate applications.

7.2. MVP Monitoring Strategies

7.2.1. Taxonomic Classification

For both count and cover taxa, abundance did not change across taxonomic classification levels as Spearman's Correlation remained negatively correlated with dredge pressure at consistent levels throughout (Table 7). This outcome was anticipated, abundance is not expected to change with CATAMI Level as it does not account for the different taxa, only how much of everything there is. Thus, it can be recommended abundance of individuals identified at CATAMI level 2 can be used as an effective monitoring strategy. Concerning richness, significant patterns for count taxa disappeared at CATAMI Level 2, while for cover taxa, patterns remained consistent throughout. Considering this, it is not recommended that monitoring strategies should surpass CATAMI Level 3, as identifying taxa at Level 2 lost to much detail and patterns were lost. Previous investigators also report altered perceived patterns with broader taxonomic levels (Monk et al., 2018; Thompson et al., 2003); however, others confidently report that family level, comparable with that of CATAMI Level 3, is a reliable predictor of taxa richness and can be used in cost effective monitoring strategies (Williams & Gaston, 1994). Similarly to richness, it is not recommended that monitoring strategies should surpass CATAMI Level 3, as identifying taxa at Level 2, particularly count taxa, lost to much detail and patterns were weakened and lost. Related CATAMI Level application in literature is limited, however, further studies indicate support for classification Level 3, as analysis on macroinvertebrates have shown family level data can be successfully utilised in biodiversity assessments, through observations of consistent diversity outputs across classification levels (Heino & Soininen, 2007).

7.2.2. Removing Replicates

In general, patterns along a gradient of fewer used images became weaker and were eventually lost (Table 8). However, patterns between the original number and 100 replicates remained significant and at consistent levels, excluding that of cover taxa abundance. As discussed, it can be assumed however that cover taxa abundance with dredge pressure had a relatively weak relationship to begin with and can thus be considered as an anomaly, due to the inclusion of resilient faunal within analysis. Considering this, it can be confidently recommended that reducing the number of replicates to 100 from the original number can produce simpler, but robust results. Previous investigators who also investigated effectiveness of simpler monitoring approaches found similar results; however, they enforce that larger data sets are generally best suited for environmental impacts and are generally more representative (Elmendorf et al., 2014).

8. Conclusions and Recommendations

To conclude, while tracking recovery of non-target benthos from historic scallop dredging in Northumberland, it became clear that count taxa abundance had fully recovered since the BNNC SAC dredging ban came into place in 2014, while cover taxa abundance recovery has started, but would take more time to fully recover. Thus, in terms of abundance, the time period since management implementation is sufficient enough to demonstrate evidence of dredge impact prevention and recovery. Observed outputs of count taxa richness however indicated no degree of recovery since 2014, while cover taxa richness recovery was found to have started but would take more time to fully recover. These observed differences in count and cover taxa richness can be attributed to the inclusion of resilient faunal turf in analysis and factors of life-history between mobile and sessile taxa, such as dispersal ability and larval longevity (Kaiser et al., 2017). Similarly to richness, count taxa diversity indicated no recovery, while cover taxa had shown recovery had started but need more time to fully recover. This difference can again be explained through mobile vs sessile taxa life-history factors and the inclusion of faunal turf in analysis, as previously discussed. However, it was also noted that recovery rates of all parameters of benthic individuals can be influenced by depth (Collie et al., 2000). Thus, for these reasons, it is recommended that further analysis should incorporate depth and other environmental factors into analysis, while also excluding all dredge resilient organisms such as faunal turf for the display of true results.

In terms of developing an MVP monitoring strategy, is recommend that monitoring of discussed parameters should not be surveyed above CATAMI Level 3, as Level 2 lost too much detail and patterns were either lost or weakened. It is also recommended that monitoring should not analyse less than 100 images per dredge pressure category, as again, too much detail was lost and patterns either weakened or became insignificant.

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