MST8003: TERMS OF REFERENCE

NAME: Imogen Dent

PROJECT SUPERVISORS:

Dr Clare Fitzsimmons – Newcastle University.

Dr Ashleigh Tinlin-Mackenzie – Newcastle University.

CLIENTS:

Alex Aitken – Northumberland Inshore Fisheries & Conservation Authority (NIFCA).

Dr Catherine Scott – Natural England.

TITLE:

Dredging up the past – Assessing current scallop dredging impacts in Northumberland & tracking recovery from historic dredging efforts.

1. RATIONALE:

Implementing mobile gear management in the Berwickshire and North Northumberland Coast Special Area of Conservation (BNNC SAC) in 2014 has provided a unique opportunity to observe the effects of dredging within inshore waters of Northumberland. Whilst many have reviewed the impact dredging can have, the impact of this fishing method in Northumberland is unknown. This is of particular interest with regard to supporting management measures in order to protect the benthic community and its associated species. There has been a growing demand on the use of marine protected areas (MPAs) to sustain species and the associated environment from anthropogenic and physical threats that have negative consequences including reducing resistance and reliance, which have perturbing cascading effects (Dayton et al.1995; Shears and Babcock, 2003). Few have identified an MPA to aid the protection of benthic species and the associated habitats from scallop dredging (Bradshaw *et al*., 2001; Beukers-Stewart *et al*., 2005; Sciberras *et al*., 2013). Bradshaw *et al*. (2001) demonstrated an increase in the mean age of individuals above the minimum landing size and increased density of *Pecten maximus* in an MPA in the Irish Sea. Recent research corroborates this and suggests that the protected area at the Isle of Man and Cardigan Bay has had success in protecting *P. maximus* in the juvenile phase and assisted the increased size and longevity observed, facilitating recovery (Beukers-Stewart *et al*., 2005). These findings are of particular interest to this study with regard to Northumberland Inshore Fisheries and Conservation Authority (NIFCA) and Natural England in view of monitoring the potential success the Berwick and North Northumberland Coast Special Area Of Conservation (BNNC SAC) can have and its ability to promote the marine environment in the area.

The use of underwater imagery following appropriate technique provides significant quantitative information (Ferrari *et al*., 2018). It provides prospective insights into changes in the benthic composition that can be surmised by changes in fishing activity (Ferrari *et al*., 2018). Some papers have shown historic changes to the benthic community using imagery techniques (Williams *et al*., 2012; Piazza *et al*., 2019), underwater still imagery can also be used to infer variation with regards to the condition, availability and the recovery of the ecosystem (Pizarro *et al*., 2017). There is growing evidence to suggest that scallop dredging is vital economically to the fishing industry nationally (Lindeboom and DeGroot, 1998). Fishers have recently seen a decline in inshore opportunities and have therefore been required to diversify fishing methods along the Northumberland coast. Consequently there is a high dependence in one fishery in the region and further restrictions to the scallop dredge fishery would increase the reliance on this fishery further. This research is required to observe the effects scallop dredging has on the benthos and support future management regimes of multi-gear fisheries for an already pressurised fishing community.

2. AIM:

Investigate the impact scallop dredging has on the benthos and target species, *P. maximus* in Northumberland, using current marine protection afforded by Berwick and North Northumberland Coast Special Area of Conservation (BNNC SAC) prohibiting mobile fishing practices including dredging and trawling.

3. OBJECTIVES:

- Analyse effects of dredging pressure on benthos by comparing underwater imagery at sites within the BNNC SAC that were dredged pre mobile gear closure and post mobile gear closure.
- Analyse the relationship between intensity of dredging, scallop density and community diversity.
- Analyse effects dredging has on the size on of *P. maximus* by comparing underwater imagery at sites dredged pre mobile gear closure and post mobile gear closure.

4. HYPOTHESES:

- There will be a significant difference in the benthos between dredged sites dredged pre mobile gear closure and post mobile gear closure.
- There will be a significant relationship between dredging intensity, scallop density and community diversity.
- There will be a significant relationship between scallop dredging pressure and the size of *P. maximus*.

5. METHODS:

Imagery of historically dredged sites was obtained from NIFCA from underwater observations conducted on-board MV St Aidan in the BNNC SAC which lies within ICES rectangles 39E8 and 40E8. The SeaSpyder System (ED140716) was towed at a constant speed of 0.3-0.8 knots to obtain underwater stills during the summer of 2019 and 2020. At each SeaSpyder tow, the positions, depth and visual observations were noted. Deployment site for SeaSpyder were deduced using fishing vessel monitoring system (VMS) data recorded by Marine Management Organisation (MMO) and sightings observed by NIFCA. Fishing pressure categories was calculated using the number of points in each grid cell and jenks natural break using GIS.
The observations from each still image at each camera analysis were then put onto a Microsoft Excel Spreadsheet and the images were from both time periods were then uploaded for subsequent analysis. The software BIIGLE was used to undertake analysis of each image with <5% suspended sediment. Suitable images were quality assessed and conditions were scaled to identify fauna and flora of the benthic community present to the lowest taxonomic group where possible. The abundance of each species present was then assessed and the size of individual live *P. maximus* was determined using BIIGLE measure tool where present in imagery observations. 40 still images from each site with >50% gravel/pebble sediment was selected for data analysis. The historical and contemporary dredged site data was then manipulated into an Excel spreadsheet for data analysis.

6. DATA ANALYSIS:

Data manipulated in Excel will be imported to R Studio, Minitab and SPSS and analysed using a series of univariate and multivariate analysis to address the aims and objectives as appropriate.

Kruskal Wallis test will be undertaken to analyse effects of dredging pressure on benthos by comparing underwater imagery at sites within the BNNC SAC that were dredged pre mobile gear closure and post mobile gear closure. Man Whitney U will be used to determine the relationship between pressure and abundance of species. One-way analysis of similarities (ANOSIM) will be conducted to detect differences in taxa between the dredge pressure sites and similarity percentage analysis (SIMPER) to identify which taxa contributes to the similarities between the dredge pressure sites.

Pearson's correlation will then be used if the data conforms to normal distribution to analyse the relationship between intensity of dredging, scallop density and community diversity. Where not normally distributed data will be transformed or analysed using Spearman's rank. Further regression analysis will be undertaken to analyse any relationship present.

Further ANOVA's will then be used if the data conforms to homogeneity and normal distribution to analyse the effect of dredging pressure on the size of *P. maximus*.

7. Project scope:

7.1 The student is expected to be commence work immediately upon agreement of this TOR and to perform the activities contemplated in this document before the end of the module 28th August 2021.

7.2 The student will perform all tasks within the scope of work with high professional skill based on its due diligence. The student will perform the work in an efficient manner and use appropriate means of communication without compromising the thoroughness or quality of the work.

7.3 The student will be available to attend meetings with the clients on an as-needed basis, if required.

7.4 The student shall prepare a complete final Report that will be used by the clients.

7.5 The final report produced by the student shall be in the format of a scientific report using Marine Ecology Progress Series reference format.

7.6 The student should be prepared to produce documents and conduct meetings in English language.

7.7 The student will have responsibility for advising the clients and supervisors on any situation that might arise that could impact successful completion of the Project.

8. Reports to be delivered by the student:

- Draft report – 19th August 2021 – 9am
- Final report – 27th August 2021 – 2pm

9. Schedule:

9.1 The project must be completed 27th August 2021 – 2pm

9.2 The student shall submit a draft report to supervisor, Dr Ashleigh Tinlin-Mackenzie via email on 19th August 2021 for review and comments which shall contain at least the following elements:

- Introduction, methods, data analysis.

9.3 The student shall submit a final report prior to 27th August 2021 – 2pm reflecting on comments received on the Draft report. The final report will also highlight outstanding issues or items, which the clients deem particularly pertinent. The final report shall be submitted via Newcastle University Canvas online assessment submission portal and copies will be sent to both clients, Dr Catherine Scott and Alex Aitken.

9.4 All reports shall be in the English Language and should be prepared in MS Word, PDF Format or MS Excel, using Marine Ecology Progress Series referencing format as required. All reports should be submitted by email to the following addresses:

Dr Catherine Scott (catherine.scott@naturalengland.org.uk)

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

10. Literature Cited

Beukers-Stewart, B.D., Vause, B.J., Mosley, M.W.J., Rossetti, H.L., and Brand, A.R. (2005) Benefits of closed area protection for a population of scallops. *Marine Ecology progress Series*, 298, pp. 189-204**.**

Bradshaw, C., Veale, L.O., Hill, A.S. and Brand, A.R (2001) The effects of scallop dredging on the Irish Sea benthos: experiments using a closed area. *Hydrobiology*, 465, pp.129-138.

Dayton, P.K., Thrush, S.F., Tundi Agardy, M. and Hofman, R.J. (1995) Environmental effects of marine fishing. *Aquatic Conservation*, 5, pp. 205-232.

Ferrari, R., Marzinelli, E.M., Ayroza, C.R., Jordan, A., Figueira, W.F., Byrne,M., Malcolm, H.A., Williams, S.B. and Steinbery, P.D. (2018) Large-scale assessment of benthic communities across multiple marine protected areas using an autonomous underwater vehicle. *PLOS ONE*, 13, pp.1-20.

Lindeboom, H.J. and De Groot. S.J. (1998) Impact-II: The effects of different types of fisheries on the North Sea and Irish Sea benthic ecosystems. NIOZ-rapport. *Royal Netherlands Institute for Sea Research*, 1, pp.1-404.

Pizarro, O., Friedman, A., Bryson, M., Williams, S.B. and Madin, J. (2017) A simple, fast, and repeatable survey method for underwater visual 3D benthic mapping and monitoring. *Ecology and Evolution*, 7, pp.1770–1782.

Piazza, P., Cummings, V., Guzzi, A. Hawes, I., Lohrer, A., Marini, S., Marriott, P., Menna, F., Nocerino, E., Peirano, A., Kim, S. and Schiaparelli, S. (2019) Underwater photogrammetry in Antarctica: long-term observations in benthic ecosystems and legacy data rescue. *Polar Biology* 42, pp. 1061–1079.

Sciberras, M., Hinz, H., Bennell, J.D., Jenkins, S.R., Hawkins, S.J. and Kaiser, M.J (2013) Benthic community response to a scallop dredging closure within a dynamic seabed habitat. *Marine Ecology Progress Series*. 480, pp. 83-98.

Shears, N.T., and Babcock, R.C. (2003) Continuing trophic cascade effects after 25 years of no-take marine reserve protection. *Marine Ecology Progress Series*. 246, pp. 1–16.

Williams, S.B., Pizarro, O.R., Jakuba, M.V., Johnson, C.R., Barrett, N.S. Babcock, R.C., Kendrick, G.A., Steinberg, P.D., Heyward, A.J., Doherty, P.J., Mahon, I., Johnson-Robertson, M., Steinberg, D. and Friedman, A. (2012) Monitoring of Benthic Reference Sites: Using an Autonomous Underwater Vehicle," in *IEEE Robotics & Automation Magazine*, 19, pp. 73-84.

Faculty of Science, Agriculture & Engineering

Newcastle University

CERTIFICATE OF ETHICAL APPROVAL

Project #: 21-006-DEN

Project Title: Dredging the past - Assessing current scallop dredging impacts in Northumberland & tracking recovery from historic fishing effort.

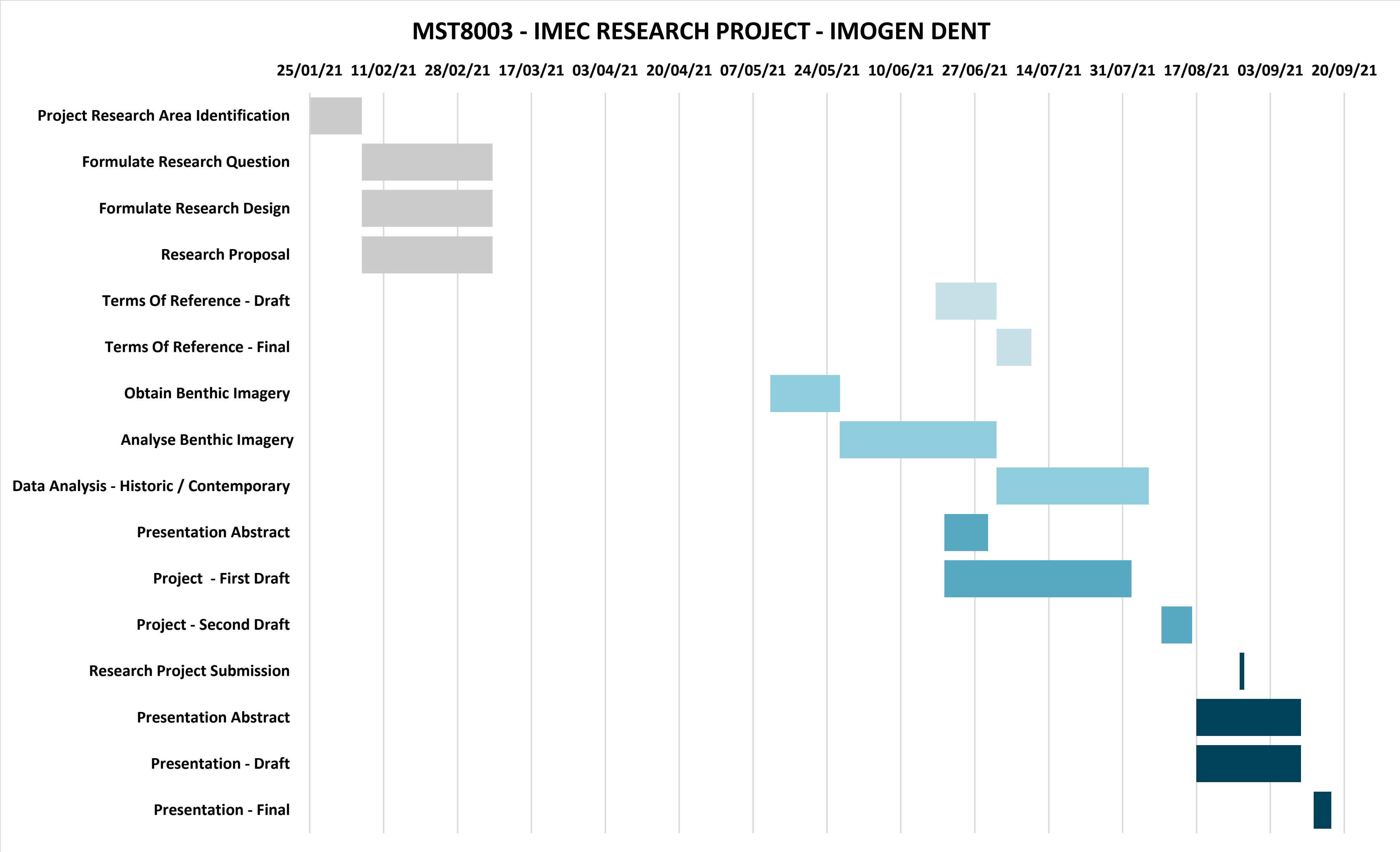
This certificate confirms that the application made by **Imogen Dent (School of Natural and Environmental Sciences), supervised by Clare Fitzsimmons,** was **APPROVED** on 25/05/2021

It is the responsibility of the applicant to ensure that any conditions of approval are fully met before proceeding with the research. Applicants are also required to notify the Faculty Ethics Committee (sage.ethics@ncl.ac.uk) if they wish to make any changes to the design/methods/participants of the study ***before*** *commencing with any changes.*

If you receive any complaints or encounter any issues during the implementation of your research study, please contact the Ethics Committee via SAGE.Ethics@newcastle.ac.uk. Please **do not** *respond directly to the complaint.*

Signed: Stuart Dyer

Date: 03/07/2021


MST8003 - IMEC RESEARCH PROJECT - IMOGEN DENT
25/01/21
11/02/21
28/02/21
17/03/21
03/04/21
20/04/21
07/05/21
24/05/21
10/06/21
27/06/21
14/07/21
31/07/21
17/08/21
03/09/21
20/09/21
Project Research Area Identification
Formulate Research Question
Formulate Research Design
Research Proposal
Terms Of Reference - Draft
Terms Of Reference - Final
Obtain Benthic Imagery
Analyse Benthic Imagery
Data Analysis - Historic / Contemporary
Presentation Abstract
Project - First Draft
Project - Second Draft
Research Project Submission
Presentation Abstract
Presentation - Draft
Presentation - Final

Important Dates:

DATE/TIME	ATTENDEES	DISCUSSION / OUTCOME
19/02/2021 – 11am	NIFCA	Project proposal – methodology
25/03/2021 – 2:30 pm	Dr A Tinlin-Mackenzie	Project background
12/04/2021 – 1pm	Dr A Tinlin-Mackenzie/ NIFCA	Project scope
15/04/2021 – 3pm	Dr A Tinlin-Mackenzie / Jonathan Savage	Current dredging stats / project background
20/04/2021 – 2pm	Dr A Tinlin-Mackenzie	BIIGLE introduction
13/05/2021 – 3pm	Dr A Tinlin-Mackenzie	ToR ideas / dates
27/05/2021 – 3pm	Dr A Tinlin-Mackenzie	BIIGLE photo downloads
17/06/2021 – 3pm	Dr A Tinlin-Mackenzie	Image analysis
24/06/2021 – 9am	NIFCA / Natural England	ToR
24/06/2021 – 3pm	Dr A Tinlin-Mackenzie	ToR / dates
08/07/2021 – 3pm	Dr A Tinlin-Mackenzie	BIIGLE – scallop measures / dates
22/07/2021 – 3pm	Dr A Tinlin-Mackenzie	BIIGLE / ToR feedback
29/07/2021 – 10 am	Dr A Tinlin-Mackenzie	Stats
05/08/2021 – 3 pm	Dr A Tinlin-Mackenzie	Stats
11/08/2021 – 3pm	Dr A Tinlin-Mackenzie	Stats
19/06/2021 – 3pm	Dr A Tinlin-Mackenzie	Draft feedback

Dredging up the past – Assessing current scallop dredging impacts in Northumberland & tracking recovery from historic dredging efforts.

Imogen Dent

School of Natural & Environmental Sciences, Ridley Building 2, Newcastle University, Newcastle-Upon-Tyne NE2 4AA.

Journal Format: Marine Ecology Progress Series.

Word Count: 4785

Project Supervisors:

Dr Clare Fitzsimmons, Newcastle University

Dr Ashleigh Tinlin-Mackenzie, Newcastle University.

Project Clients:

Dr Catherine Scott, Natural England.

Alex Aitken, Northumberland Inshore Fisheries And Conservation Authority (NIFCA).

Declaration

a) I declare that this thesis is my own work and that I have correctly acknowledged the work of others. This submission is in accordance with University and School guidance on good academic conduct

b) I certify that no part of the material offered has been previously submitted by me for a degree or other qualification in this or any other University.

c) I confirm that the word length is within the prescribed range as advised by my school and faculty

d) Does the thesis contain collaborative work, whether published or not? Yes / No

If it does please indicate what part of the work is your independent contribution on a separate sheet.

PLEASE NOTE THAT THIS WORK WAS UNDERTOOK INDEPENDENTLY HOWEVER, DATA USED IS PART OF AN UNPUBLISHED PROJECT (Savage 2021, Tinlin-Mackenzie 2021)

Signature of candidate: I .Dent Date: 24/08/2021

Dredging up the past – Assessing current scallop dredging impacts in Northumberland & tracking recovery from historic dredging efforts.

ABSTRACT

Bottom fishing is controversial with respect to associated impacts that modify diversity and productivity of the marine ecosystem. Fisheries management in the form of marine protected areas allow species and habitats response to cessation of fishing to be observed and thereby influence implementation of future management regimes. There are new marine conservation zones however, there is little evidence of efficacy. Underwater still imagery was observed inside a marine protected area in Northumberland that has prohibited all bottom fishing methods including scallop dredging. Scallop size data suggests an overall negative impact with dredge pressure. Abundance data shows notable increase with prohibiting dredging however, no impact is significantly noted with cover groups and dredge pressure. These observations offer potential insight to the ongoing effects dredge pressure has on the benthos, even after activities are banned. The study underpins the value of using underwater imagery to assess the potential role of the gear management in The Berwickshire and North Northumberland Coast Special Area of Conservation (BNNC SAC) and potential recovery of MCZs from dredging.

KEY WORDS: Dredging, scallop, underwater imagery, marine protected areas.

1. INTRODUCTION

The growth in anthropogenic activities has increased pressures on the marine ecosystem (Hinz et al. 2009). Subsequently this has had significant impacts to habitats and ecosystem service provisions (Kaiser et al. 2006). Changes to habitat heterogeneity, complexity, and species, as a consequence to bottom fishing are well documented (Kaiser et al.1998; Sciberras et al. 2013). Bottom fishing is noted to be the most prominent anthropogenic threat to the inshore marine ecosystem (Dayton et al. 1995; Jennings & Kaiser 1998; Kaiser et al. 2000). Bottom fishing influences physical and biochemical processes, in which the perturbations have notable effects on the trophic dynamics and community structure of the benthic community (Sciberras et al. 2013). The magnitude and frequency of fishing notably influences the severity of disturbance which governs the recovery from fishing impacts (Thrush et al. 1995; Kaiser et al. 2006). Many studies have described these changes in conditions (Jenkins et al. 2001; Thurstan et al. 2010; Hiddink et al. 2019). Notable changes to the benthic community have been observed as a consequence to dredging since 1960 when bottom fishing became a dominant fishery (Kaiser et al. 2000; Thurstan et al. 2010). Studies have shown changes to the benthic community as a result of towing of metal dredges that terminate with steel teeth penetrating the seabed (Craven et al. 2013). Observed is notable reduction in abundance, biomass and diversity that is more pronounced in areas where disturbance is previously minimal (Beukers-Stewart et al. 2005). Decline in habitat complexity and benthic macrofauna has been associated with greater mortality of larger long lived marine organisms and a subsequent shift to smaller shorter lived organisms due to the interaction with the seabed that has experimentally been documented (Bradshaw et al. 2001; Kaiser et al. 2007). Little research has been done regarding the size and abundance of scallops in relation to dredge activity (Maguire et al. 2002). Negative effects on the benthic community, for example potentially impaired recruitment could therefore be expected (Beukers-Stewart et al. 2005; Kaiser et al. 2007). The morphological and physiological composition of scallop species has been shown to be at a disadvantage of dredging with decline in growth of scallops (Maguire et al. 2002). Whilst scallop dredging is well noted to be the most destructive bottom fishing method with respect to marine habitats and species, there is evidence to suggest that this remains minimal when compared to pollution and climate change (Kaiser et al.1998; Sciberras et al. 2013).

The scallop fishery is the third most exploited fishery in the UK with 2019 landings of 29,200 tonnes and estimated to be worth £62.4 million (Marine management Organisation 2020). It has been suggested that the increase in landings of the King scallop (*Pecten maximus*) and queen scallop *(Aequipecten opercularis)* has been associated with no quota, high demand, and economic value along with a decline in whitefish populations. Climate induced factors has been attributed to have gonadal and larval effects and promote recruitment (Shephard et al. 2010). Furthermore, dredging activities promotes food availability by enhancing nutrients and thereby influence surrounding biota. Currently the Northumberland fishing fleet is composed of 120 vessels of which 8 held permits in 2019 and subsequently 3 in 2020 (NIFCA 2020) to scallop dredge within the Northumberland Inshore Fisheries and Conservation Authority (NIFCA) district however, no dredging has occurred since November 2019 (NIFCA 2020).

Marine protected areas (MPAs) are the most prominent implement for fisheries management (Kaiser 2005) and could potentially address anthropogenic impacts to the marine ecosystem and promote species and habitats to reach favourable conditions (DEFRA 2018). Currently there are 317 MPAs in the UK. Fisheries management use MPAs in conformation with the marine and coastal access act 2009 (Marine conservation society 2021). There are UK MPAs that prohibit dredge gear management (Beukers-Stewart et al. 2005; Howarth et al. 2011), but few have undertaken studies to understand the effects of implementing gear restrictions and marine protected areas in view of scallop dredging impacts (Bradshaw et al. 2001; Howarth et al. 2011; Hart et al. 2013; Sciberras et al. 2013). Assessments have established increased density and mean age above landing size of *Pecten maximus* in an MPA in the Irish Sea (Bradshaw et al. 2001; Hinz et al. 2011). Observations in The Isle of Man and Cardigan Bay MPAs have demonstrated success to protecting *P. maximus* in the juvenile phase and assisted in the increased size and longevity facilitating recovery (Beukers-Stewart et al. 2005). However, evidence remains contradictory in places. Management requires impacts and distribution of species to be identified further to appropriate implementation, management, and compliance (Sciberras et al. 2013; Caveen et al. 2014). While marine protected areas facilitate species and habitat recovery to favourable conditions, it is important to mention that these do not allow full protection, recovery, and delivery of ecosystem services (Klein & Watters 2020). Consequently, implementing an MPA can displace dredging impacts to other benthic communities (Klein & Watters 2020). The Berwickshire and North Northumberland Coast European Marine Site (BNNC EMS) was first established in 2000 and encompasses the BNNC Special Area of Conservation (SAC) to protect important habitats, reefs and species. Gear management is in place, but the Northumberland scallop fishery has not yet been studied; further understanding the impacts dredging has on the benthic community and the ability gear restrictions have to potentially promote recovery within the BNNC SAC is required.

Understanding benthic ecology is of great importance for fisheries management with regards to abundance, biomass and diversity. This information can be used to implement future strategies. Data is derived from various techniques including underwater imagery (Zarco-Perello & Enriquez 2019). Few have linked benthic trends to management potential. The ability to use underwater imagery to infer recovery is crucial to management. This technique may allow inferences to be made with regards to recovery overtime and the effectiveness of management regimes. The implementation of mobile gear management within the Berwickshire and North Northumberland Coast Special Area of Conservation (BNNC SAC) in 2014 provides a unique opportunity to infer recovery within the Northumberland coast. This study therefore examined the underwater still imagery at sites within the BNNC SAC, which were analysed to explore changes in benthic community. Specifically, underwater still imagery data will be used to:- (1) Analyse effects of dredging pressure on benthos at sites within the BNNC SAC that were dredged pre-BNNC SAC gear ban and post BNNC SAC gear ban. (2) Analyse the relationship between intensity of dredging, scallop density and community diversity. (3) Analyse effects dredging has on the size on of *P. maximus* by comparing underwater imagery at sites dredged pre BNNC SAC gear ban and post BNNC SAC gear ban. It is envisioned that the outputs of this study may be used for future management plans.

2. MATERIALS AND METHODS

2.1 STUDY AREA

The study was carried out at twenty one sites along the Northumberland Coast located within The Berwickshire & North Northumberland Coast Special Area of Conservation (BNNC SAC), ICES statistical rectangle 40E08 (Figure 1).The BNNC SAC spans 635 km^2 of coastal shoreline and waters that encompasses Lindisfarne, St Abbs and the Farne islands marine reserves (Natural England 2015), use of active fishing gear within the site was prohibited in 2014 due to the importance of habitats. The area is predominantly composed of sand < 2mm, pebbles and gravel sediment type and is exposed to prevailing moderate energy southerly inshore currents and westerly winds (Natural England 2015). The BNNC SAC remains open to the static gear fishery that target *Cancer Pagurus*, *Homarus Gammarus* and *Necora Puber* which extends beyond the Northumberland Inshore Fisheries Conservation and Authority boundary of 6nm. Prior to the dredge ban, *Pecten maximus* and *Aequipecten opercularis* were the target species of the Northumberland Coast scallop fishery, which was active at several sites located within the BNNC SAC prior to implementation of gear restrictions.

The twenty one study sites were determined using VMS data recorded by the Marine Management Organisation between 2010 and 2020 that were used to estimate pressures and map dredging activity in the NIFCA district (Figure 2). The VMS pings of dredging vessels targeting scallops in 2014 - 2020 were mapped as point data using ArcView GIS version 10.2 and dredging pressure categories (Table 1) was calculated using the number of VMS pings in each grid cell and jenks natural break (Tinlin-Mackenzie 2021). Therefore the sites used in this study comprise areas that have differing dredge pressures that were historically dredged pre gear management and sites dredged post gear management.

2.2 Data collection: survey design

Sampling comprised of a series of underwater images taken throughout July and August 2019- 2020 at each of the twenty one dredged sites using a SeaSpyder system (ED140716). The SeaSpyder system was towed just above the seabed in a horizontal orientation at < 0.8 knots from the stern of the NIFCA patrol vessel St Aidan, during daylight conditions. The geographical location and depths at the start and end of each tow were recorded with Furuno WASSP multibeam 3230 echo-sounder and VS330 GPS. Visual observations were noted and the subsequent images were then downloaded for further analysis.

2.3 Still image analysis

All images from each site were uploaded to BIIGLE 2.0 software for further analysis. In correspondence with CEFAS video still guidance (Curtis 2014) and general consensus, images with excellent and good visual quality and < 5% suspended sediment were analysed. Those images of poor and very poor quality were discarded. Suitable images were quality assessed and conditions were scaled to identify fauna and flora of the benthic community present to the lowest taxonomic group where possible. Those species that were difficult to identify or too enumerate were recorded as percentage cover.

Collaborative and Automated Tools for Analysis of Marine Imagery (CATAMI) Level 3 taxa groups identified with significance during threshold indicator taxa analysis (TITAN) of Savage (2021) study was used for data analysis in this study (Table 2). The abundance and cover of each species present was then assessed and the size of individual live pectinidae, where present, was determined using BIIGLE measure tool in imagery observations. Still images from each site with > 50% gravel/pebble sediment was randomly selected for data analysis, this standardised imagery that may be targeted by fisheries. The historical and contemporary dredged site data was then manipulated into a Microsoft 365 Excel spreadsheet for data analysis using R studio 4.0.4.

2.4 Quality Assurance

Interobserver variability is a key problem with image analysis that leads to incorrect identification of taxa (Schoening et al. 2012). Image analysis in this study was in cooperation with another student. Initially, practice images were undertaken to ensure image analysis was correct. An external body ensured all images observed had identified all taxa where present. Quality assessment of image analysis was undertaken by the other student and Cohen's kappa coefficient (K) was applied to observe the interobserver agreement of taxa identified within the images (McHugh 2012). Kappa output showed that there was an excellent interobserver agreement within the image analysis of this study (K = 0.81, percentage agreement 88.7 %) and therefore the image data was used for further analysis.

3. Data analysis

Data were then exported from BIIGLE which was then imported to R Studio to produce a series of Microsoft Excel 365 spreadsheets and manipulated to obtain the size of scallop where present, species count and cover observed. Minitab and SPSS was used to undertake a series of univariate analysis and R studio to conduct multivariate analysis. Shannon's diversity indices were calculated for each of the significant taxon groups found in proceeding studies (Savage 2021) at each dredge pressure category and further analysed using Kruskal Wallis to identify effects. The effects of dredge pressure on the count and percentage cover of important indicator taxa groups observed in proceeding analysis (Savage 2021) was analysed using Kruskal Wallis analysis and further Mann-Whitney U tests where significant differences indicated. One-way analysis of similarities (ANOSIM) were conducted to detect differences in taxa between the dredge pressure sites and similarity percentage analysis (SIMPER) was used to identify which taxa contributed to the similarities between the dredge pressure sites. The relationship between the dredging pressure, scallop density and community density (those species groups significant in Savage (2021) findings) was analysed using Pearsons correlation coefficient as the data conformed to normal distribution. As there was no significant difference, no further analysis was undertaken. The differences between the dredging pressure intensity and size of scallops was assessed using Analysis of Variance (ANOVA). Before undertaking an ANOVA, the data was examined for homogeneity for variance using Levene's and normality using Kolmogorov-Smirnov test.

4. RESULTS

4.1 Community Diversity

The community diversity for count abundance taxon was not significantly different between the dredge pressure categories (Kruskal Wallis, $p > 0.05$). General consensus is that only crustaceans had the greatest diversity at the historically dredged sites and the highly dredged sites had greater diversity of scallops, unstalked ascidians, nudibranchs and coral. Further, the community diversity for cover taxon was also not significantly different (Kruskal Wallis, $p > 0.05$). General observations demonstrated that only hard bryozoans had the greatest diversity in the historically dredged sites.

4.2 Species abundance

The count abundance of individuals of the taxa groups was significantly different between the dredge pressure categories (Kruskal-Wallis, $p < 0.05$, ANOSIM, $R = 0.101$, $p < 0.05$). The significance of the observed average abundance of the taxa groups varied however, the Kruskal-Wallis test showed squat lobsters and unstalked ascidians were significantly impacted by dredge pressure (Table 3). Subsequent Mann-Whitney U tests showed that the average abundance of squat lobster and unstalked ascidians differed significantly between the dredge pressures (Table 4). Visualisation of this difference in nMDS plots (Figure 3) showed no obvious patterns however, moderately dredged sites had different abundance. SIMPER revealed that all dredge pressures were 70-80 % dissimilar to each other. Of the eight taxa, unstalked ascidians were responsible for the largest dissimilarity between the dredge pressures (54 %). Figure 4 shows that the greatest counts individuals were consistently observed at sites that were historically dredged. The average abundance of crustacean had the most pronounced abundance at the historically dredged sites, 9.44 per m^2. The average abundance of unstalked ascidian at historic dredge pressure (59.1 per m^2) was nearly double to that of non dredge pressure sites. The pattern of nudibranchs in the historically dredged sites were similar to those of no dredge pressure sites at 6.39 per m^2. Pectinidae average abundance was greater at the historically dredged sites (7.36 per m^2) than of the non (5.57 per m^2) or low (5.08 per m^2) dredged sites. However, corals showed no abundance at the historically dredged site, a decline compared to other dredge pressures.

Further, the percentage cover of taxa groups was not significantly different between the pressure categories (Kruskal-Wallis, $p > 0.05$, ANOSIM $R = 0.2776$, $P < 0.05$). Visualisation of this difference in nMDS plots (Figure 5) showed no obvious patterns however, historically dredged sites had different taxa cover. SIMPER revealed that all dredge pressures were 30-47 % dissimilar to each other. Of the taxa studied, faunal turf was responsible for the largest dissimilarity between the dredge pressures (77 %). Most cover species showed a pattern of high percentage cover per m^2 in the historically dredged pressure however, faunal turf, macroalgae and ophiuroids had lower cover in the historically dredged sites compared to those observed with dredging pressure (Figure 6). Unexpectedly the pattern of hard and soft bryozoans and polychaetes demonstrated a high cover in the historically dredged sites both of which were higher than those of no dredge pressures.

4.3 Community diversity, scallop density and dredge pressure

The dredging pressure, scallop density and community diversity (those taxa groups significant of Savage (2021) findings) were not significantly correlated (Pearsons Correlation Coefficient, $r = 0.112$, n = 40, $P > 0.05$).

4.4 Scallop size

The effect of scallop dredge pressure in the areas that were historically dredged prior to the implementation of the BNNC SAC and recently dredged sites was assessed. There was a significant difference between the scallop size observed and the dredging pressure (ANOVA, $F = 4.91$, df = 4, $P < 0.05$) (Table 5, Figure 7). *Post hoc* Tukey pairwise comparison ($P = 0.05$) showed that the sites with low dredge pressure had significantly larger scallop size (mean = 52.48 mm ± 30.84 mm S.D). *Post hoc* Tukey pairwise comparison ($P = 0.05$) showed that scallop size was significantly smaller at historically dredged sites (23.55 mm ± 19.59 mm S.D.) than sites with non (37.69 mm ± 25.41 mm S.D.), moderately (36.10 mm ± 35.33 mm S.D.) and high dredge pressures (39.13 mm ± 27.05 mm S.D.).

5. DISCUSSION

Determining the effects of scallop dredging at sites within the BNNC SAC through underwater still imagery has provided insights into effects on the benthos. This study has demonstrated observable differences in relation to the abundance and scallop size between the low and historically dredge sites. There was no observable relationship between community diversity, scallop density and dredge pressure. The observable differences in abundance of groups from dredge pressure on average were higher at the historically dredged sites than the sites with non and low dredge pressures. Interestingly this observation was noted in Pectinidae and size patterns suggest smaller individuals in the historically dredged sites of the BNNC SAC. The observation of size and abundance in Pectinidae within the historically dredge sites is in accordance with other studies that demonstrated community effects with dredge pressure, providing confidence to propose that implementing a closed area has benefited stocks (Kaiser et al. 2000; Bradshaw et al. 2001, Hinz et al. 2011). Sciberras et al. (2013) demonstrated changes within the community after cessation of dredging within a closed area. There are a number of reasons supporting the abundance of species observed. One is that recruitment within the area is occurring. Recruitment of scallops was demonstrated at Cardigan Bay and the Irish Sea (Bradshaw et al. 2001; Sciberras et al. 2013). Although the abundance of Pectinidae was greater to that of the non and low dredged sites, the relatively small size of Pectinidae within the historically dredged sites suggest recruitment is established and slowly undergoing. Larval supply and settlement is important for the recolonization of species and the homogeneity of a community (Bradshaw et al. 2001). It has been documented that ecosystem protection from fishing pressures enhances scallop recruitment by enabling spat to attach to epifaunal structures (Bradshaw et al. 2001; Howarth et al. 2011). The recruitment observed may have been due to substrate provided for larval settlement by the high abundance of unstalked ascidians and percentage cover of bryozoans observed.

Patchiness of pectinidae and fishers choice may be another reason for the notable abundance patterns of scallops observed at the moderately and highly dredged areas. Further, studies have noted that physical parameters influence disturbance effects (Collie et al. 2000; Kaiser et al. 2006) and that natural disturbance may be of greater significance than fishing effects on benthic community (Stokesbury & Harris 2006). The high abundance of unstalked ascidians at the historically dredged sites is indicative of previously dynamic conditions (Coma et al. 1998). Literature has demonstrated fast colonisation with ascidians after ice scour events (Lagger et al. 2017). It can be considered that scallop dredge activity can have similar impacts as ice scour events removing benthic biota creating space allowing colonisation of unstalked ascidians to gain a firm foothold which is suggested by the high average abundance in the historically dredged sites and greatest dissimilarity between the groups. Further, dredge induced turbidity is noted to influence the benthic composition (Currie & Parry 1996). Noted to be up to three orders of magnitude greater than storm events, taxa will be influenced significantly (Black & Parry 1994). It can therefore be inferred that the presence of filter and suspension feeders observed in the historically dredged sites are likely due to the lack of dredged induced sedimentation.

Comparison of the abundance is indicative with a shift of gear management, more so previous studies including that of Bradshaw et al. (2001), Howarth et al. (2011) and Sciberras et al. (2013) have demonstrated the effects of implementing gear restrictions to have the potential to facilitate recruitment and recovery of the area by enhancing ecosystem diversity and complexity. The findings of the present study along with others show the importance gear management has had within the Northumberland coast in view of facilitating recovery to the benthic community, notably scallops and crustaceans. The key to a healthy ecosystem is biomass consisting of differing life stages (Garcia et al. 2012) however, the trend observed in squat lobsters suggest interspecific variation and habitat selection may be apparent, with the low observations in historically dredge sites. Kaiser et al. (1998)

suggested bottom type to influence community composition but given that all images with > 50% gravel/pebble sediment was used in data analysis, the influence of bottom type is a limited explanation. Nudibranch abundance was higher at the historically dredged sites than that of non and low sites. In combination with the high unstalked ascidian abundance, the importance of predatory-prey opportunities may play a pivotal role in the findings. Whilst, polychaete and ophiuroids abundance has been linked with pollution and eutrophication influences (Frid & Clark 2000; Rijnsdorp & Vingerhoed 2001), the pattern observed in this study further suggests that a low abundance and cover of scavengers are due to the lack of prey opportunities present with no dredging in the historic sites. The expectedly low ophiuroid and polychaetes are in common with Thrush et al. (1998) findings that had similar trends of low scavenger abundance and percentage cover in the historically dredged sites.

The results present are the first in which underwater imagery was used to make comparisons relating to dredging and the benthic community in Northumberland. While previous studies have identified successfully trends in abundance, no previous approaches have been made to infer effects on scallop size. The lack of data prior to the implementation of gear management within the BNNC SAC was a challenge in view of assessing impacts within the BNNC SAC. These result are suggestive of recovery and allow a baseline for management in the future. Whilst this study shows trends it only provides a snapshot in time and like all studies limitations may be apparent. VMS data was used with vessels of speeds of 0.1 – 4 knots. Although this VMS data provides strong confidence of position, speeds and times allowing inferences of potential activity to be made, the use of VMS ping data can be relatively inaccurate with respect to definite vessel activity. Sightings data would have provided strong association with actual dredging activity. Vessel speeds 0.1 – 4 knots cannot be attributed to dredging alone. Commercial vessels tow scallop dredges at speeds of 2-3 knots, therefore over estimations of dredge pressure may be apparent.

Benthic community composition has been postulated to be linked to fishing pressure (Kaiser & De Groot 2000). Although the data corroborates to that of closed area strategies in view of managing bottom dredged activity (Bradshaw et al. 2001; Howarth et al. 2011; Sciberras et al. 2013), a true reflection of the benthic community may not be demonstrated by underwater still imagery. While the trends observed follow patterns expected with recruitment and subsequent recovery, it does not seem unreasonable to exclude other parameters.

Bottom fishing gear has notable impacts on the benthic community composition resulting in changes from larger long-lived individuals to smaller short lived opportunistic species however, determined by organic matter content, the community structure may be driven by climatic factors (Reid et al. 1998;

Carmichael et al. 2012). Frid & Huliselan (1996) noted Northumberland phytoplankton concentrations to increase over the last three decades therefore, reflection of this could be expected in the benthic community. Hinz et al. (2011) showed that there was no negative relationship observed with respect to scallop size and abundance. Therefore, physical parameters may be apparent with respect to the structure of the community observed.

Whilst literature has speculated that dredge impacts somatic growth and size (Howarth et al. 2011), no dredging currently takes place at the sites studied which show variable sizes however, in the past dredging had occurred. The data suggests recruitment with small sized scallops in the historically dredged sites. Interestingly, there was a 28.92 mm difference in scallop size between the historical and low dredged sites. Water depth, salinity and quality are key factors that influence growth, fecundity and longevity of an organism (Langton et al. 1987; Harris & Stokesbury 2006). Local fishers have noted that spatial observations with scallop shell size. Spatial variability may support the biggest shell size observed in this study at the low dredged sites. Depth is also a limiting factor for scallop abundance and size (Lorrain et al. 2004; Harris & Stokesbury 2006). It is difficult to ascertain as other dredge pressure sites had greater depths but as the water depth at the low dredged sites was 10 m greater than the historically dredged sites, hydrological and hydrostatic factors may be suggestive of the size differences. Ontological differences in carbon availability for calcification and metabolic activity was the driver of *P. maximus* shell size (Lorrain et al. 2004). Talmage & Gobler (2009) found similar carbon availability to impact size trends. Indirectly this carbon availability can be linked to pollution and eutrophication (Rijnsdorp & Van Leeuwen 1996; Carmichael et al. 2012). Given there is more juveniles present in the historically dredged areas oncological carbon differences are likely to be the driver in the size patterns observed.

Whilst the potential causes for dictating the observed trends remain consistently clear, definite decisions cannot be made thereby inferences governing the changes can only be suggested. Nevertheless, with support of others, this study underpins the use of underwater imagery analysis to infer benthos changes and subsequent effects. The comparison of data collected between July and August of the consecutive years of 2019 and 2020 demonstrate differences in the abundance of benthic species groups with dredge pressure. However, there was no significant difference in the diversity of cover species. Thus, it can be inferred that recruitment is occurring species specific and that scallops within the historically dredged sites are repopulating as supported by size distribution observed. It is worth noting that the recovery of the benthic community is also indicative however, physical parameters may not be excluded. The success of gear ban and protected areas is noted to be time dependent in view to species', reproductive success and their longevity (Hinz et al.2011).

6. CONCLUSION

This study has revealed that scallop abundance and size within the historically dredge sites are consistent with some recruitment within the area, whilst the abundance suggest fishers choice, it is hard to conclude recovery and thereby future analysis may be warranted in order to ascertain. The observations are pertinent for management to infer the success of the current gear management regime within the BNNC SAC. This study also demonstrated that individual benthic community groups are similar to Howarth et al. (2011). Whilst the abundance of Pectinidae is greater than that of non and low dredge sites, the abundance is similar to that of moderate and high dredged sites. It is therefore important to consider the socio-economic importance the fishery has to the coast with respect to current management measures. There is scope for the results gained from this study to be used for fisheries management measures as a proxy for the potential of implementing marine protected areas and gear management in view of scallop stock recovery and sizes however, further analysis may be required to ascertain the key causes for the abundance and size observations noted.

Acknowledgements: This research was coordinated by Dr Ashleigh Tinlin-Mackenzie and Dr Clare Fitzsimmons, Newcastle University. Special thanks to Jonathan Savage, James Duffy and Dr Paula Lightfoot for their assistance with image analysis. Dr Catherine Scott and Alex Aitken for useful discussions and advice. Thanks also to the crew of St Aidan at Northumberland Inshore Fisheries Conservation Authority for conducting the underwater SeaSpyder imagery.

LITERATURE CITED

Beukers-Stewart BD, Vause BJ, Mosley MWJ, Rossetti HL, Brand AR (2005) Benefits of closed area protection for a population of scallops. Mar Ecol Prog Ser 298: 189-204

Black KP, Parry GD (1994) Sediment transport rates and sediment disturbance due to scallop dredging in Port Philip Bay. Mem. Queensl 36: 327–341

Bradshaw C, Veale LO, Hill AS, Brand AR (2001) The effects of scallop dredging on the Irish Sea benthos: experiments using a closed area. Hydrobiol. J 465: 129-138

Carmichael RH, Shriver AC, Valiela I (2012) Bivalve Response to estuarine eutrophication: The balance between enhanced food supply and habitat alterations. J.Shellfish Res 31:1-11

Caveen A Fitzsimmons C, Pieraccini M, Dunn E, Sweeting C, Johnson M, Bloomfield H, Jones E, Lightfoot P, Gray T, Stead S, Polunin N (2014). Diverging Strategies to Planning an Ecologically Coherent Network of MPAs in the North Sea: The Roles of Advocacy, Evidence and Pragmatism in the Face of Uncertainty. In: Magnus L. Johnson and Jane Sandell, editors, Advances in Marine Biology, Vol. 69, Oxford: Academic Press, p 325-370

Collie JS, Escanero GS, Valentine PC (2000) Photographic evaluation of the impacts of bottom fishing on benthic epifauna. ICES J Mar Sci 57: 987-1001

Coma R, Ribes M, Zabala M, Gili JM (1998) Growth in a modular colonial marine invertebrate. Estuar Coast Shelf Sci 47: 459−470

Craven HR, Brand AR, Stewart BD (2013) Patterns and impacts of fish bycatch in a scallop dredge fishery. Aquat Conserv Mar Freshw Ecosyst 23: 152-170

Currie DR, Parry GD (1996) Effects of scallop dredging on a soft sediment community: a large-scale experimental study. Mar Ecol Prog Ser 134: 131 -150

Curtis M (2014). Cefas Video & Stills Processing Protocol Guidelines. First Edition. Science Series Technical Report. Cefas, Lowestoft, p 1-43

Dayton PK, Thrush SF, Tundi Agardy M, Hofman RJ (1995) Environmental effects of marine fishing. Aquat Conserv 5: 205-232

Department for Environment Food & Rural Affairs (2018) Marine Protected Areas Network Report 2012 - 2018, Presented to Parliament pursuant Section 124 of the Marine and Coastal Access Act 2009, p3-87

Frid CLJ, Clark RA (2000) Long-term changes in North Sea benthos: Discerning the role of fisheries. In Ecosystem effects of fishing (ed. M. Kaiser and S.J. de Groot), Blackwell Scientific, p 198-216

Frid CLJ, Huliselan NV (1996) Far-field control of long-term changes in Northumberland (NW North Sea) coastal zooplankton. ICES J Mar Sci 53: 972–977

Garcia SM, Kolding J, Rice J, Rochet MJ, Zhou S, Arimoto T, Beyer JE, Borges L, Bundy A, Dunn D, Fulton EA, Hall M, Heino M, Law R, Makino M, Rijnsdorp AD, Simard F, Smith ADM (2012) Reconsidering the Consequences of Selective Fisheries. Sci 335:1045-1047

Harris BP, Stokesbury KDE (2006) Shell growth of sea scallops (Placopecten magellanicus) in the southern and northern Great South Channel, USA. ICES J Mar Sci 63: 811-821

Hart DR, Jacobson LD, Tang J (2013) To split or not to split: Assessment of Georges Bank Sea scallops in the presence of marine protected areas. Fish Res 144: 74-83

Hiddink JG, Jennings S, Sciberras M, Bolam SG, Cambie G, McConnaughey RA, Mazor T, Hilbron R, Collie JS, Pitcher CR, Parma AM, Suuronen P, Kaiser MJ, Rijnsdorp AD (2019) Assessing bottom trawling impacts based on the longevity of benthic invertebrates. J. Appl. Ecol 56: 1075-1084

Hinz H, Prieto V, Kaiser MJ (2009) Trawl disturbance on benthic communities: chronic effects and experiemental predictions. Ecol Appl 19:761-773

Hinz H, Tarrant D, Ridgeway A, Kaiser MJ, Hiddink (2011) Effects of scallop dredging on temperate reef fauna. Mar Ecol Prog Ser 432:91-102

Howarth LM, Wood HL, Turner AP, Beukers-Stewart BD (2011) Complex habitats boost scallop recruitment in a fully protected marine reserve. Mar Biol 158:1767-1780

Jenkins SR, Beukers-Stewart BD, Brand AR (2001) Impact scallop dredging on megafauna: a comparison of damage levels in captured and non-captured organisms. Mar Ecol Prog Ser 215: 297-301

Jennings S, Kaiser MJ (1998) The effects of fishing on marine ecosystems. Adv Mar Biol 34:297-301

Kaiser MJ (2005) Are marine protected areas a red herring or fisheries panacea. Can. J. Fish. Aquat. Sci 62: 1194–1199

Kaiser M, Hiddink J, Shephard S (2007). Spatial management of scallop dredging: Consequences for the recovery of benthic communities. J. Shellfish Res. 26: 1318-1319

Kaiser MJ, Clarke KR, Hinz H, Austen MCV, Somerfield PJ, Karakassis I (2006) Global analysis and prediction of response of benthic biota to fishing. Mar Ecol Prog Ser 311:1-14

Kaiser MJ, de Groot B (2000) The effects of fishing on non-target species and habitats: biological, conservation and socio-economic issues. Blackwell Scientific, p 1-37

Kaiser MJ, Edwards DB, Armstrong PJ, Radford K, Lough NEL, Flatt RP, Jones HD (1998) Changes in megafaunal benthic communities in different habitats after trawling disturbance. ICES J Mar Sci 55: 353- 361

Kaiser MJ, Ramsay K, Richardson CA, Spence FE, Brand AR (2000) Chronic fishing disturbance has changed shelf sea benthic community structure. J Anim Ecol 69:494-503

Klein ES, Watters GM (2020) What's the catch? Profiling the benefits and costs associated with marine protected areas and displaced fishing in the Scotia Sea. PLOS ONE 1:1-24

Lagger C, Servetto N, Torre N, Sahade R (2017) Benthic colonization in newly ice-free soft-bottom areas in an Antarctic fjord. PLoS ONE 12: 1-15

Langton RW, Robinson WE, Schnick D (1987) Fecundity and reproductive effort of sea scallops Placopecten magellanicus from the Gulf of Maine. Mar Ecol Prog Ser 37: 19-25

Lorrain A, Paulet YM, Chauvaud L, Dunbar R, Mucciarone D, Fontugne M (2004) δ13C variation in scallop shells: Increasing metabolic carbon contribution with body size? GCA 68: 3509-3519

Maguire JA, Coleman A, Jenkins S, Burnell GM (2002) Effects of dredging on undersized scallops. Fish. Res 56: 155-165

Marine conservation society (2021) https://www.mcsuk.org/ocean-emergency/marine-protected-areas/uk-protected-areas/ (accessed 12 Jul 2021)

McHugh ML (2012) Interrater reliability: the kappa statistic. Biochem. Med 22:276–282

Marine Management Organisation (2020) UK fisheries statistics 2019. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/920679/UK_Sea_Fisheries_Statistics_2019_-_access_checked-002.pdf

Natural England (2015) National Character Area profile: 1. North Northumberland Coastal Plain, p 1-62

Northumberland Inshore Fisheries and Conservation Authority (2020) Consultation: Changes to NIFCA scallop dredging management, p 1-4

Reid PC, Edwards M, Harold GH, Warner AJ (1998) Phytoplankton change in the North Atlantic. Nat 1:391: 546

Rijnsdorp A, Vingerhoed B (2001) Feeding of plaice *Pleuronectes platessa* L. and sole *Solea solea* (L.) in relation to the effects of bottom trawling. Neth J Sea Res 45: 219-229

Rijnsdorp AD, Van Leeuwen PI (1996) Changes in growth of North Sea plaice since 1950 in relation to density, eutrophication, beam-trawl effort, and temperature. ICES J Mar Sci 53: 1199–1213

Savage J (2021) Scallop Dredge Project. Unpublished manuscript.

Schoening T, Bergmann M, Ontrup J, Taylor J, Dannheim J, Gutt J, Purser A, Nattkemper TW (2012) Semi-Automated Image Analysis for the Assessment of Megafaunal Densities at the Arctic Deep-Sea Observatory HAUSGARTEN. PLoS ONE 7

Sciberras M, Hinz H, Bennel JD, Jenkins SR, Hawkins SJ, Kaiser MJ (2013) Benthic community response to a scallop dredging closure within a dynamic sedbed habitat. Mar Ecol Prog Ser 480: 83-98

Shephard S, Beukers-Stewart B, Hiddink JG, Brand AR, Kaiser MJ (2010). Strengthening recruitment of exploited scallops Pecten maximus with ocean warming. Mar Biol 157: 91-97

Stokesbury KDE, Harris BP (2006) Impact of limited short-term sea scallop fishery on epibenthic community of Georges Bank closed areas. Mar Ecol Prog Ser 307: 85–100

Talmage SC, Gobler CJ (2009) The effects of elevated carbon dioxide concentrations on the metamorphosis, size, and survival of larval hard clams (Mercenaria mercenaria), bay scallops (Argopecten irradians), and Eastern oysters (Crassostrea virginica). Limnol. Oceanogr 54: 2072–2080

Thrush SF, Hewitt JE, Cummings VJ, Dayton PK (1995) The impact of habitat disturbance by scallop dredging on marine benthic communities: what can be predicted from the results of experiments? Mar Ecol Prog Ser 129:141-150

Thrush SF, Hewitt JE, Cummings VJ, Dayton PK, Cryer M, Turner SJ, Funnel GA, Budd RG, Milburn CJ, Wilkinson (1998) Distrubance of the marine benthic habitat by commerical fishing: impacts at the scale of the fishery. Ecol Appl 8: 866-879

Thurstan RH, Brockington S, Roberts CM (2010). The effects of 118 years of industrial fishing on UK bottom trawl fisheries. Nat Comms. 1: 1-6

Tinlin-Mackenzie A (2021) Dredging up the past project. Unpublished manuscript.

Zarco-Perello S, Enriquez S (2019) Remote underwater video reveals higher fish diversity and abundance in seagrass meadows, and habitat differences in trophic interactions. Sci. Rep 9:2-11

TABLES:

Table 1: VMS pings per 1 km grid cell for each fishing pressure category (Tinlin-Mackenzie 2021).

Fishing Pressure Category	**Current Pressure (2016-2019)**	**Historic Pressure (2010-2013)**
Non	0	0
Low	1-7	1-4
Moderate	8-22	5-18
High	23-61	18-49

Table 2: Reduced count and cover taxa groups used based on Savage (2021) TITAN CATAMI 3 species.

Taxa Groups	
Count	**Cover**
Sea Urchins	Sponge Crusts
Squat Lobster	Sponge Erect Forms
Crustacea	Hydroids
Bivalves	Polychaetes
Corals (*Caryophyllia smithii*)	Corals (*Alcyonium digitatum*)
Nudibranchs	Hard Bryozoan
Unstalked Ascidians	Soft Bryozoan
Pectinidae	Ophiuroids
	Macroalgae: Filamentous/Filiform
	Faunal Crust: Orange
	Faunal Crust: Yellow
	Faunal Turf

Table 3: Differences in count abundance taxa (H value, Kruskal-Wallis) and correlations with dredge pressure. Significance level depicted by asterisk (blank = not significant, * = p < 0.05, ** = p < 0.005).

Taxa Group	**Correlation**	**Difference**
Sea Urchin	0.174	6.355
Squat Lobster	< 0.01*	37.040
Coral	0.327	4.635
Nudibranch	0.030	10.679
Unstalked Ascidians	<0.001**	105.343
Bivalves	0.02	11.707
Crustacea	0.422	3.886
Pectinidae	0.397	4.071

Table 4: Differences in count abundance of squat lobster and unstalked ascidians (Mann-Whitney U value) and correlations with dredge pressure. Significance level depicted by asterisk (blank = not significant, * = p < 0.05, ** = p < 0.005).

	Historic		Non		Low		Mod		High	
	Difference	Mann Whitney U	Difference	Mann Whitney U	Difference	Mann Whitney U	Difference	Mann Whitney U	Difference	Mann Whitney U
Squat Lobster										
Hist										
Non	< 0.001**	2637								
Low	0.046	917	<0.001**	18.107						
Mod	0.213	2736	0.042	2366	0.002*	538				
High	0.040	1994	<0.001**	1239	0.361	650	<0.001**	1198		
Unstalked Ascidians										
Hist										
Non	0.24	1619								
Low	< 0.001**	2929	0.020*	2525						
Mod	< 0.001**	3675	<0.001**	3023	8848	0.228				
High	0.014*	4951	<0.001**	2460	<0.001**	4464	<0.001**	5601		

Table 5: ANOVA outputs for scallop size differences between the dredge pressure sites and significance between the scallop size observed at the sites studied (blank = not significant, * = p , 0.05, ** = p < 0.05).

	Historical		**Non**		**Low**		**Mod**	
	P	Difference	P	Difference	P	Difference	P	Difference
Non	> 0.05	14.14						
Low	< 0.05*	28.92	> 0.05	14.80				
Mod	> 0.05	12.54	> 0.05	-1.59	> 0.05	-16.38		
High	> 0.05	15.58	> 0.05	1.40	> 0.05	-13.35	> 0.05	3.03

FIGURES

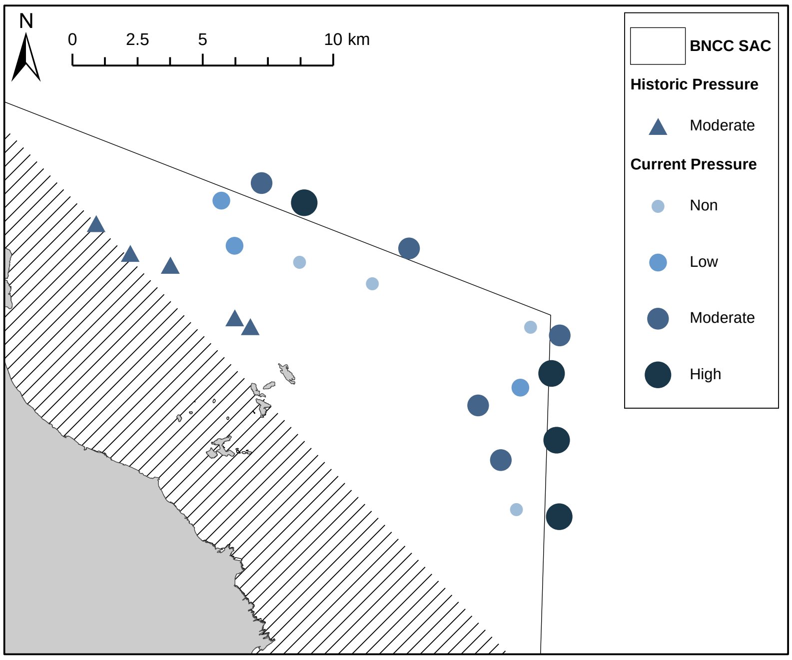


Figure 1: Sample sites for current (2016-2019) and historic (2010-2013) dredging pressure in and around the BNNC SAC, with associated pressure categories (see Table 2 for values) (Tinlin-Mackenzie 2021).

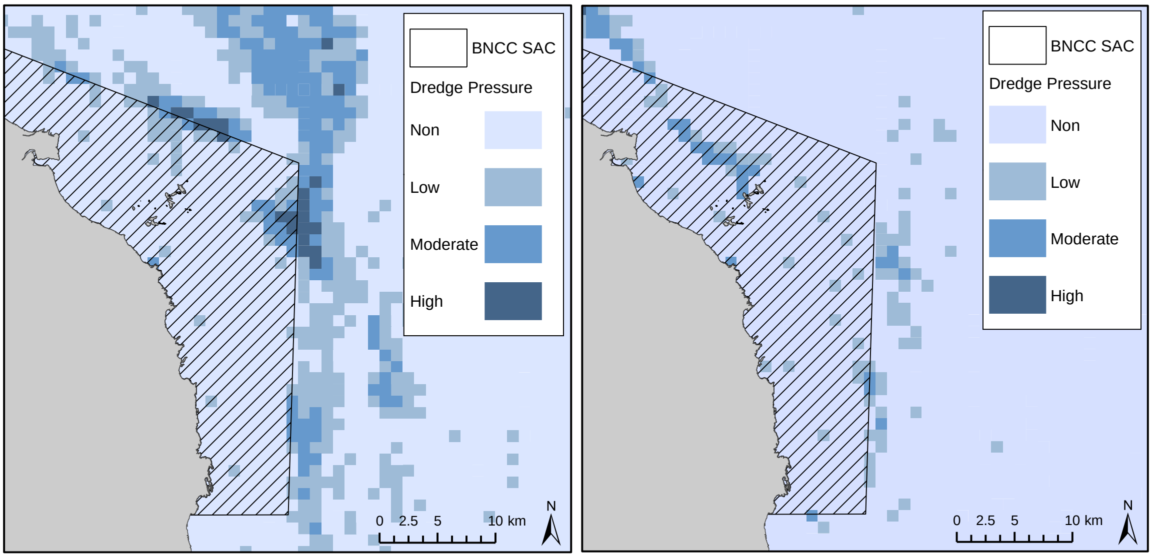


Figure 2: Dredging pressure gradient around the southern boundaries of the BNNC SAC: A) after mobile gear ban 2016-2019, B) before mobile gear ban 2010-2013. See Table 1 for pressure values) (Tinlin-Mackenzie 2021).

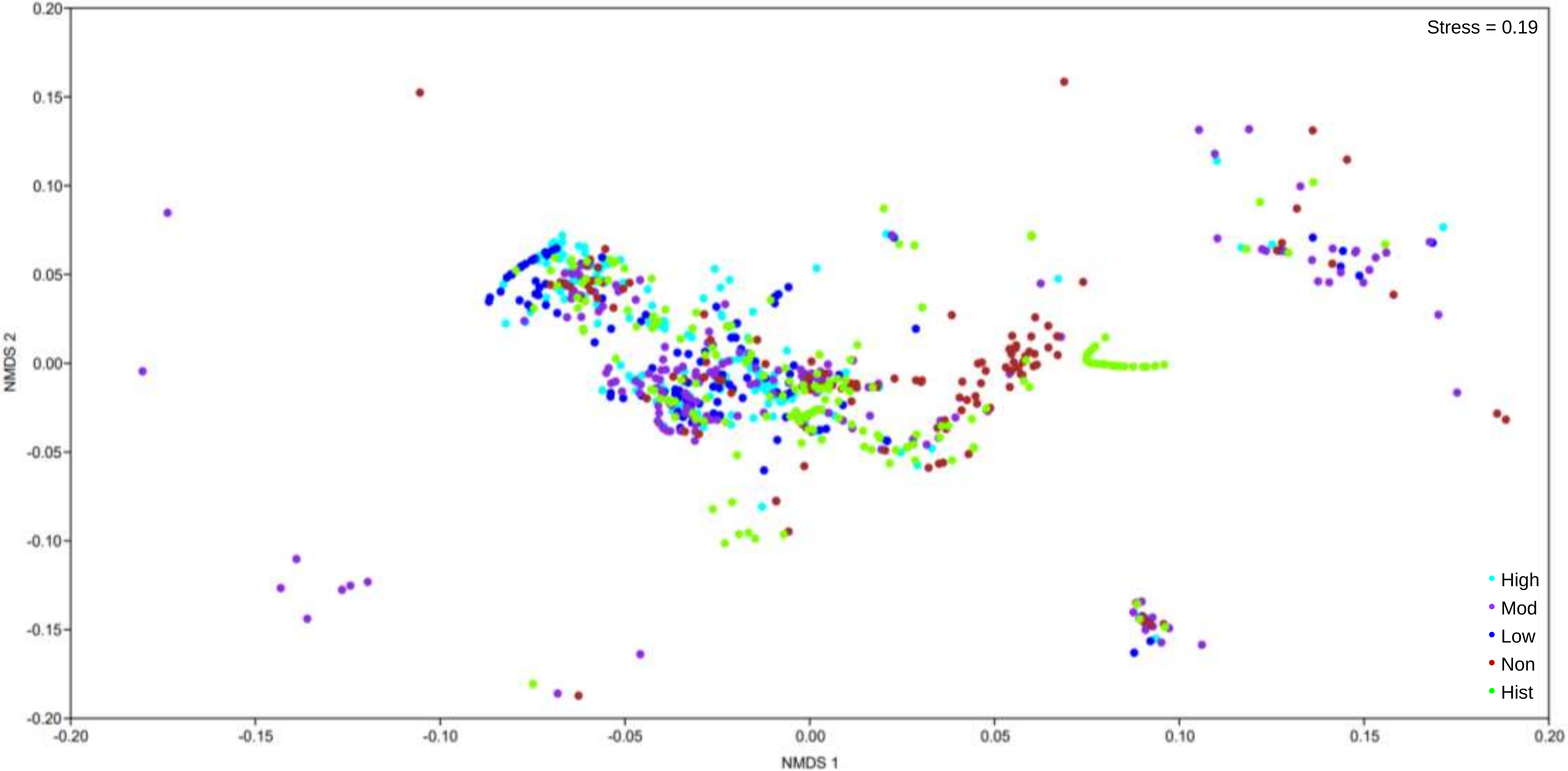


Figure 3: nMDS plot of all count abundance taxa groups data showing the similarity in the abundance of taxa groups between the dredge pressure sites in and around the BNNC SAC.

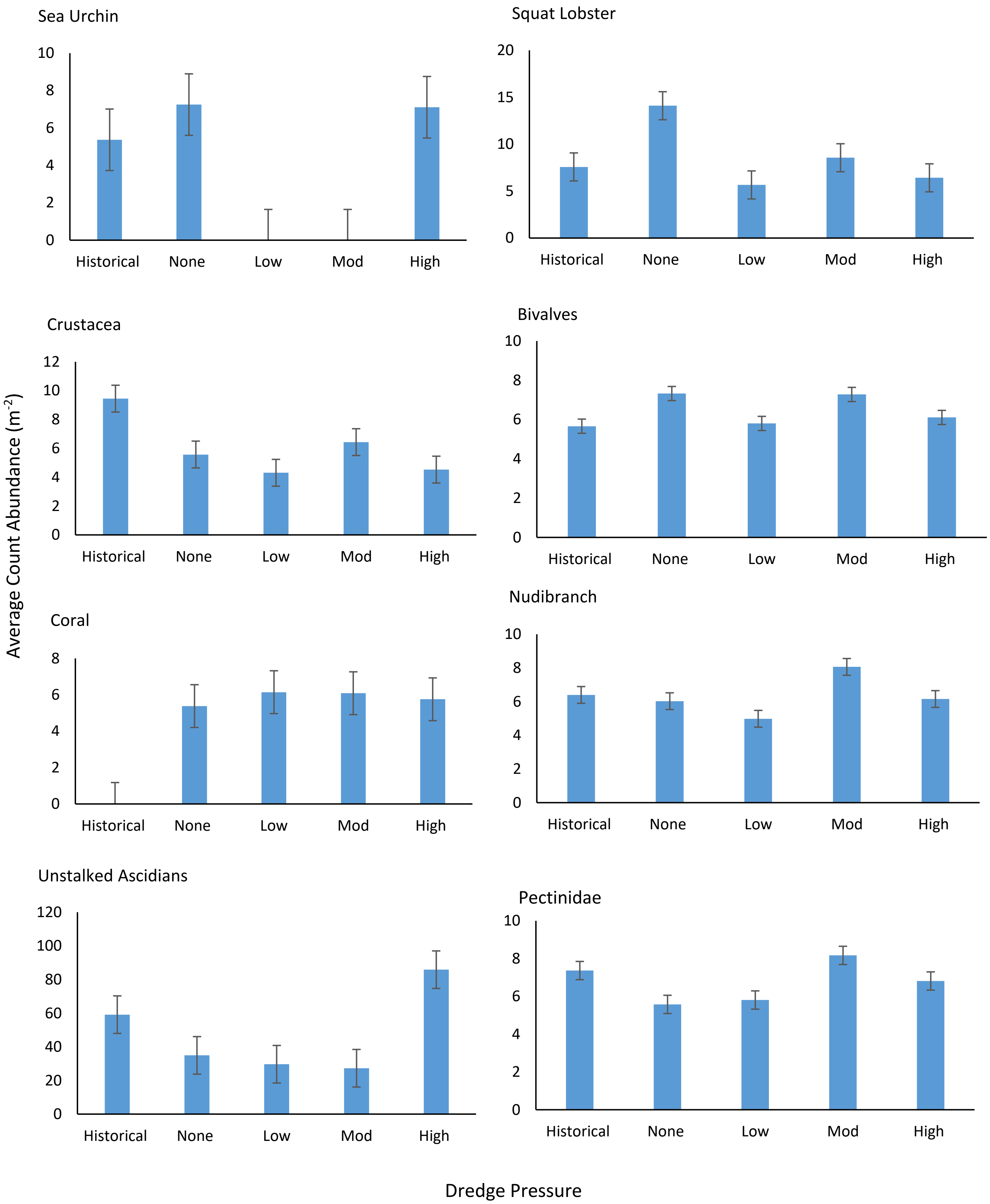


Figure 4: Average Count abundance (±SE) of selected taxa groups at differing dredge pressure sample sites conducted July-August 2019-2020.

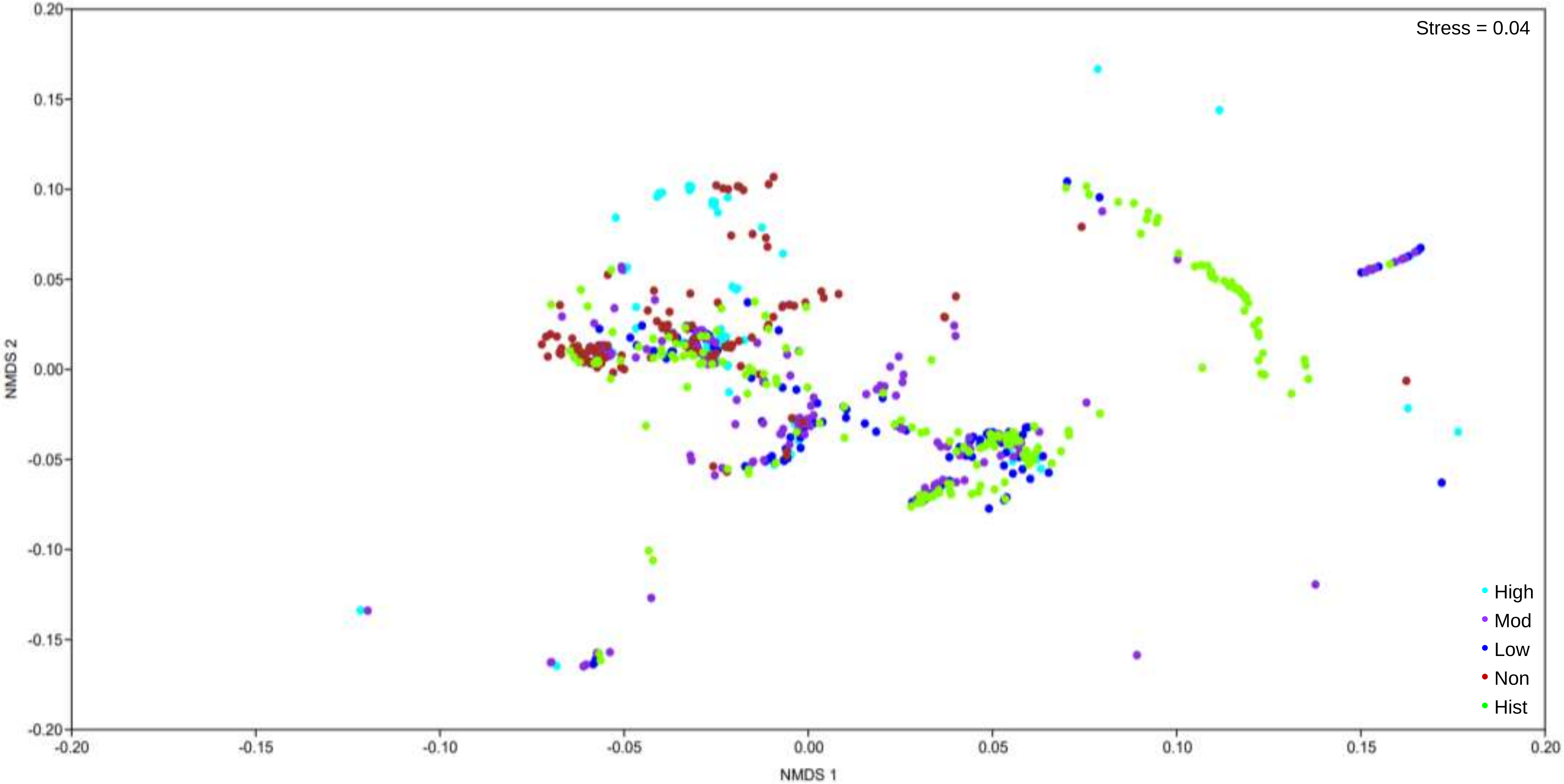


Figure 5: nMDS plot of all percentage cover taxa groups data showing the similarity in the percentage cover of taxa groups between the dredge pressure sites in and around the BNNC SAC.

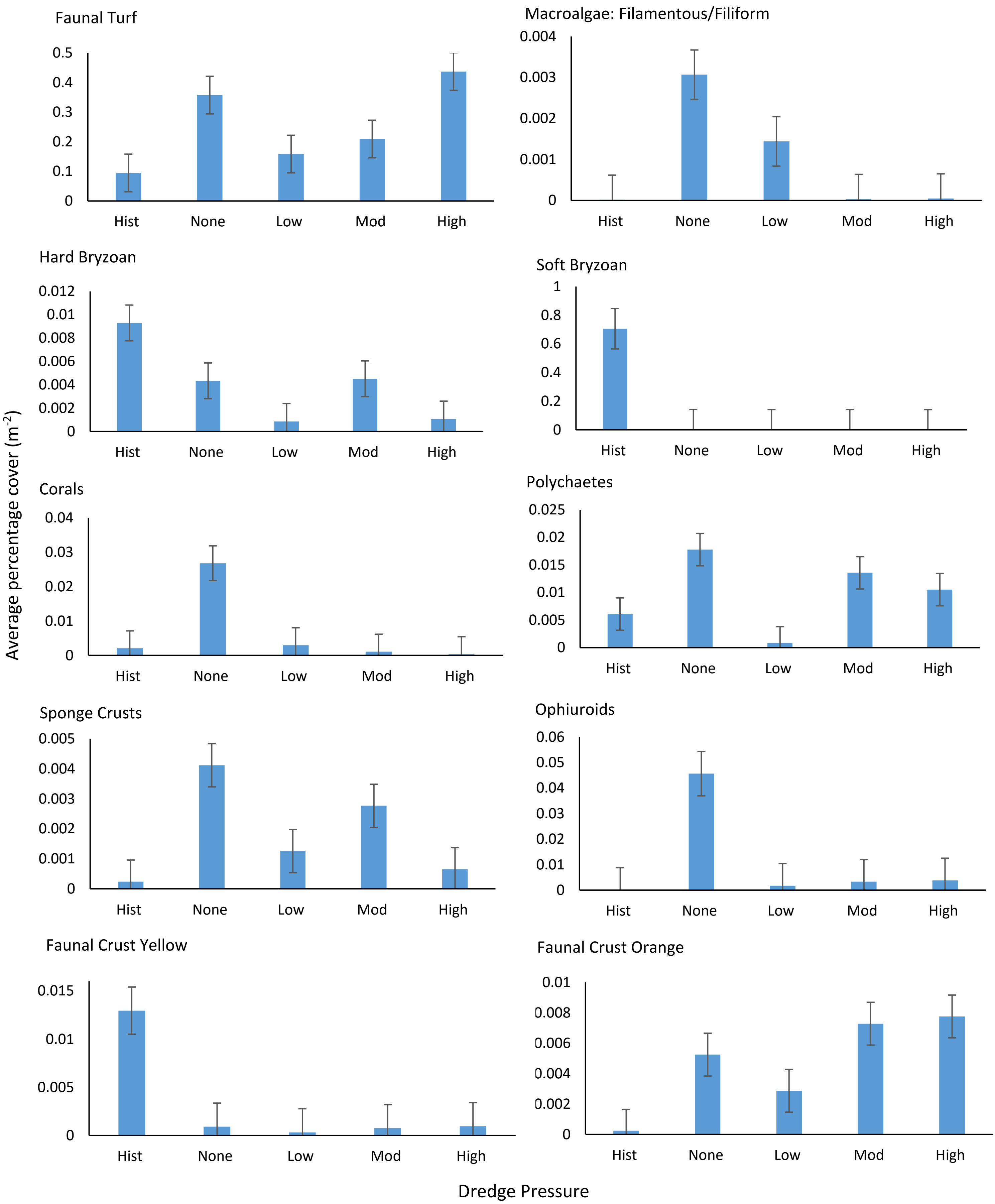


Figure 6: Average percentage cover (m^{-2}) (±SE) of selected taxa groups at differing dredge pressure sample sites conducted July-August 2019-2020.

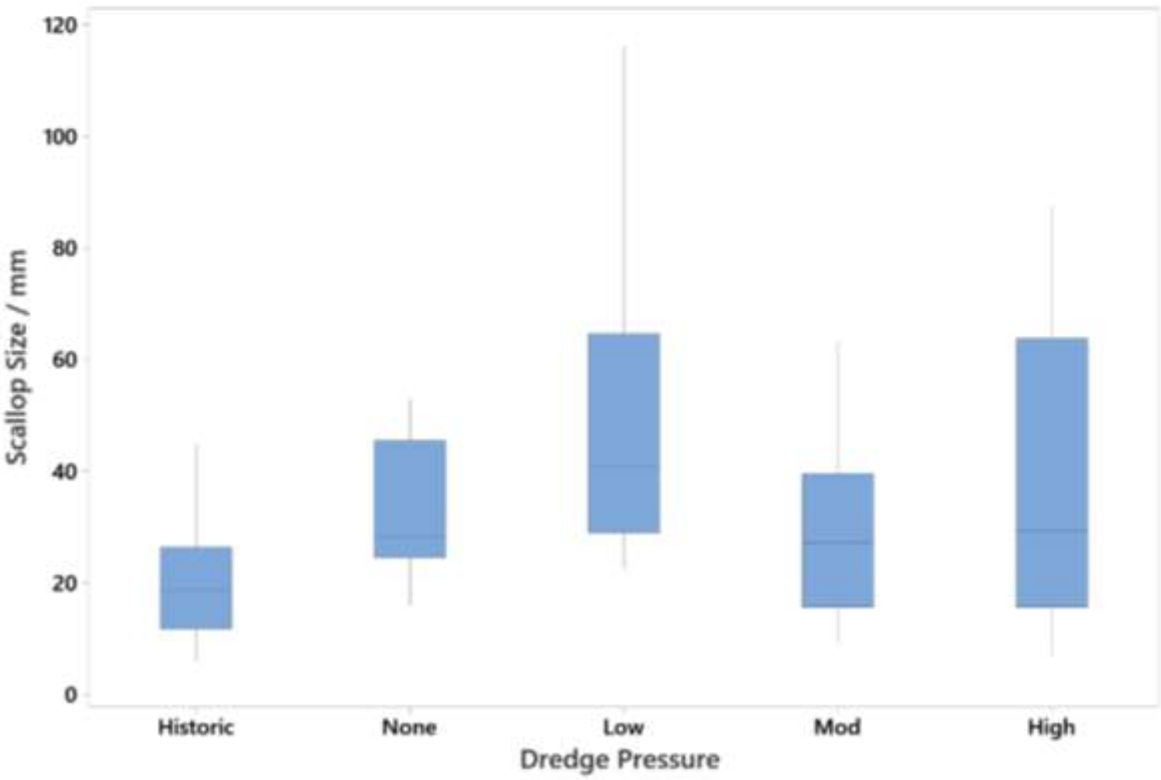


Figure 7: Observed mean scallop size (mm) at the dredge pressure sites in and around the BNNC SAC. Surveys were conducted in July-August 2019-2020.