# The effects of *Sargassum muticum* on fish species composition and population densities within *Zostera marina* beds.

**By: Kameron Dry**
MSc. Marine Environmental Management
Supervisors: Bryce Beukers-Stewart & Paul Chandler
19 September 2017

**DISCLAIMER**: I hearby declare that this dissertation is my own origional work and has not been submitted before to any institution for assessment purposes. Further, I have aknowledged all sources used and have cited these in the reference section.

***Word Count: 4811***

**ACKNOWLEDGEMENTS**: I would like to extend a huge thank you to Bryce Beukers-Stewart, Julie Hawkins and the members of the Community of Arran Seabed Trust for helping me develop this project as well as providing unwaivering support throughout the process. Also to Howard Wood and Hayley Woods for helping with data collection, Will Carney for providing mental support and keeping me saine and entertained throughout the summer and finally, thank you to Jim Henderson for putting me up this summer and providing exceptional accomodation. I could not have done this without all of your help.

UNIVERSITY of York

Isle of Arran COAST Community Of Arran Seabed Trust

*Environment Department*

*University of York*

# Assessment Submission Cover Sheet 2016/17

***This cover sheet should be the first page of your assessment.***

| | |
|---|---|
| **Exam Number:** Y 3 8 4 4 6 3 1 | **Module Code:** ENV00031 |
| **Module Title:** **Summer Placement** | **Assessment Deadline:** **19 September 2017** |

**I confirm that I have**

- **conformed with University regulations on academic integrity**
- **included an accurate word count**
- **not written my name anywhere in the assessment**
- **checked that I am submitting the correct and final version of my coursework**
- **saved my assessment in the correct format**
- **formatted my assessment in line with departmental guidelines**
  - I have ensured my work is compatible with black and white printing
  - I have ensured the compatibility of any graphs or charts included in my submission
  - I have used 12pt font (preferably Arial or similar)
  - I have ensured all pages are clearly numbered using the system 1 of 6, 2 of 6 etc. Page 1 will be your Assessment Submission Cover Sheet
  - I have ensured my examination number is on every page of the assessment

**PLEASE TICK BOX TO CONFIRM**

**Please note: if you have any questions please see the FAQs on the VLE-**

**ABSTRACT**

Invasive species are an increasing threat to seagrass ecosystems worldwide. It has been suggested that in Europe alone there are over 87 marine invasive species. Some of these alien species can alter the fish community composition within an area and in some cases cause reductions in the population densities of commercially important fish species. The invasive seaweed, *Sargassum muticum* was first identified in the UK in the 1973 and has recently been identified off the coast of the Isle of Arran, Scotland. The coasts of this island are host to several eelgrass beds (*Zostera marina*) which provide food, protection. and nursery habitat for many commercially important fish species, some of which are vulnerable such as the Atlantic Cod (*Gadus morhua*) and Haddock (*Melanogrammus aeglefinus*). Because these seagrass habitats are home to several commercially important fish species theThe aim of this study was to determine if *S. muticum* can alter the species richness and population densities of these fish using Baited Remote Underwater Videos (BRUV). BRUV's were collected within three separate areas containing differing benthic compositions; seagrass only (*Z. marina*), *Sargassum muticum* only, and a mix of both *Z. marina* and *S. muticum*. The findings from this study show that areas containing only *Z. marina* had the highest species richness and population density of commercial species. Of the five commercial species identified in the videos, only two species were shown to have significant differences in population density between sites, *G. morhua* and *M. aeglefinus*. Both species had a higher population density in seagrass only habitats compared to *S. muticum* or mixed habitats. This study suggests that *S. muticum* may play a role in community composition changes, however, the major cause for differences may be a result of the large losses of seagrass in the area.

## 1. INTRODUCTION

Seagrasses are a type of marine angiosperm that can be found all over the world. Currently, there are approximately 60 known species of seagrass that form underwater meadows which cover 0.1% of the ocean floor (Greiner *et al*, 2013). Lower estimates of seagrass cover are between 300,000 to 600,000km$^2$ and are suggested to be a major carbon sink, resulting in a removal of between 160 to 186g C m$^{-2}$ yr$^{-1}$ (Duarte *et al*, 2011). In addition to this, ecosystem services provided by seagrass habitats are feeding grounds, shelter and nursery habitats for many marine species, a large number of which are commercially important (Duarte *et al*, 2011; Stallings *et al*., 2015). A study that took place in Northern Wales identified 26 different fish species within a *Z. marina* bed off the coast of Porth Dinllaen, Wales, nine of which were of commercial importance (Bertelli & Unsworth, 2013). Inhabiting these areas appears to be advantageous to fish for one reason or another resulting in a statistically larger number of fish being caught within the seagrass beds when compared to surrounding sandy bottom habitats (Bertelli & Unsworth, 2013; Orth, Heck & Montifrans, 1984). These ecosystems have established themselves as effective nursery grounds for species such as the Atlantic cod who have been shown to actively select seagrass beds as nursery habitats (Lilly & Unsworth, 2014). Invertebrate species such as the blue crab also utilize seagrass beds as nursery habitats due to the seagrasses ability to provide protection from predation. It has been shown that juvenile crabs have a higher survival rate from predation when inside a seagrass bed (Pile *et al*., 1996).

These ecosystems have demonstrated their importance, however, they are known to be fragile and are currently in decline with reported losses of 7% yr$^{-1}$ since 1990 (Waycott *et al*., 2009). These reductions in habitat have been occurring naturally for many years as a result of

natural disasters and seasonal fluctuations in environmental variables such as sea-level and sea surface temperature (Orth *et al*., 2006). For example, in 1998 after hurricane Georges hit the Florida Keys, scientists reported a 19% decrease in the overall area of the local seagrass *Syringodium filiform* (Fourqurean & Rutten, 2004). Monitoring of the meadows after the storm revealed varying degrees of recovery with several areas showing very little recovery in several seagrass beds even three years after the storm (Fourqurean & Rutten, 2004). The fragility of this ecosystem is not just tested via natural threats, anthropogenic disturbances are currently the greatest threat to these ecosystems (Waycott *et al*., 2009). As international travel becomes easier, so does the spread of invasive species into non-native environments. The spread of invasive species into new areas is a natural phenomenon, that has been accelerated by more frequent travel from humans.

Invasive species are non-native organisms that have the ability to threaten ecosystems, habitats or other native-species (Pejchar & Mooney, 2009). Countless examples of the negative implications resulting from invasive species can be seen worldwide. It has been proposed that there are currently 87 different invasive marine species in Europe alone that have highly impacted the biodiversity or ecosystem services in their respective areas (Katsanevankis *et al*., 2014). In the Ligurian Sea. the invasive green algae, *Caulerpa taxifolia* spread rapidly, which reduced the amount of seagrass in the area and altered the catch composition (Relini, Relini & Torchia, 2000). In areas where *C. taxifolia* had taken over, the community structure was qualitatively and quantitatively richer. However, the number of commercially important species was lower in areas of *C. taxifolia* than in areas of seagrass, which could have wide reaching effects to the socio-economics of the areas fisheries, for example (Relini, Relini & Torchia, 2000). These invasive species not only have the ability to affect the macro-organisms, they can also affect the epibiotic

assemblages that are associated with the seagrass. A long term study that took place in a drowned river valley in Woodville Rocks, England, showed that the introduction of the invasive species *Sargassum muticum* into the environment altered the species composition and abundance distribution of the biofilm assemblages that are found on *Zostera marina* (DeAmicis & Foggo, 2015). The invasive species *S. muticum* is a species of macro-algae that was introduced into the United Kingdom in 1973 from France and is now distributed all along the coast of the United Kingdom (Farnham, Fletcher & Irvine 1973). *S. muticum* can be found world-wide and has the ability to spread rapidly. A study of the invasive macro-algae in Langstone Harbour found that after the introduction of *S. muticum* to the area in 1977, the invasive macro-algae increased its area 420% over a two-year span from 1977-1979 (Critchley, 1983). A separate study suggests that *S. muticum* has the ability to attach and co-habit the soft sediment with seagrass species such as *Z. marina*. Furthermore, it was found that the presence of *Z. marina* increased *S. muticum*'s ability to attach resulting in a higher success rate of *S. muticum* (Tweedley, Jackson & Attrill, 2008).

*Z. marina* meadows inhabit a narrow range of environmental conditions, as exemplified by Moore *et al*. after 25 sections of seagrass were transferred to a range of nutrient and turbidity conditions, none of which survived long term (Moore, Neckles & Orth, 1996). The Isle of Arran in the Firth of Clyde, Scotland is a small island roughly 432km$^2$ and home to approximately 5000 people[1].This island is also home to several seagrass beds with the main two being located in Whiting Bay and Kildonan (Figure 1). Both seagrass beds are located within the recently implemented South Arran Marine Protected Area that was established in 2016 due to the intense dredging and trawling pressure in the area which was having negative impacts on the marine ecosystems (Figure 2; Scottish National Heritage., 2013). The first of the two seagrass beds is located off the Eastern coast of the island in Whiting bay. This seagrass patch has not been mapped

extensively however, a local diver and the founder of the islands marine conservation group, "Community of Arran Seabed Trust" (COAST), estimated that the bed stretches roughly 4km down the coast (pers. Comm. Howard Wood, 2017). The second seagrass bed is located on the Southern part of the island off of the coast of Kildonan. This bed is studied more and has been mapped in 2012 and again in 2016. Both areas are home to a magnitude of sea life including many commercially important fish species, some of which, such as Haddock (*Melanogrammus* aeglefinus) and Atlantic Cod (*Gadus morhua*), are listed as vulnerable by the International Union for the Conservation of Nature and Natural Resources[2].

In the last several years, locals have begun reporting signs of *S. muticum* off of the coast of Whiting Bay and Kildonan (Pers. Comms. Bryce Beukers-Stewart, University of York Lecturer, 2017). In Kildonan, *S. muticum* is interspersed within the seagrass beds, while no *S. muticum* has established itself into the seagrass bed in Whiting Bay. Little is known about the effects of this alien species on fish communities within seagrass beds. However, because it is known that some invasive species have the ability to alter fish community composition, the aim of this study was to determine if *S. muticum* can alter the fish assemblages within the seagrass beds on the Isle of Arran by determining the species richness and population density of commercially important species within three areas of discrete benthic compositions including areas of; (1) *Zostera marina* only, (2) *Sargassum muticum* only and (3) Sites containing both *Zostera marina* and *Sargassum muticum.*

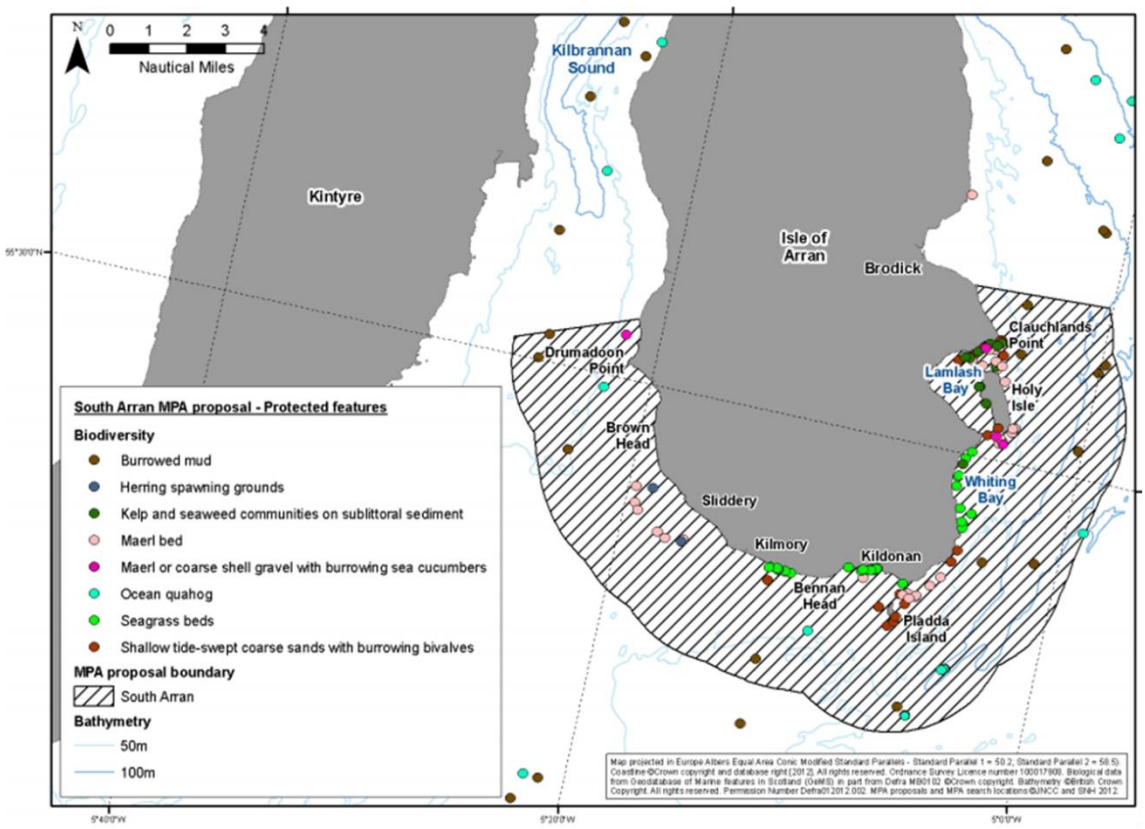


Figure 1 map depicts different habitats that are located within the South Arran MPA. Map was retrieved from the Scotish National Heritage South Arran MPA proposal Version 8 produced in 2013.

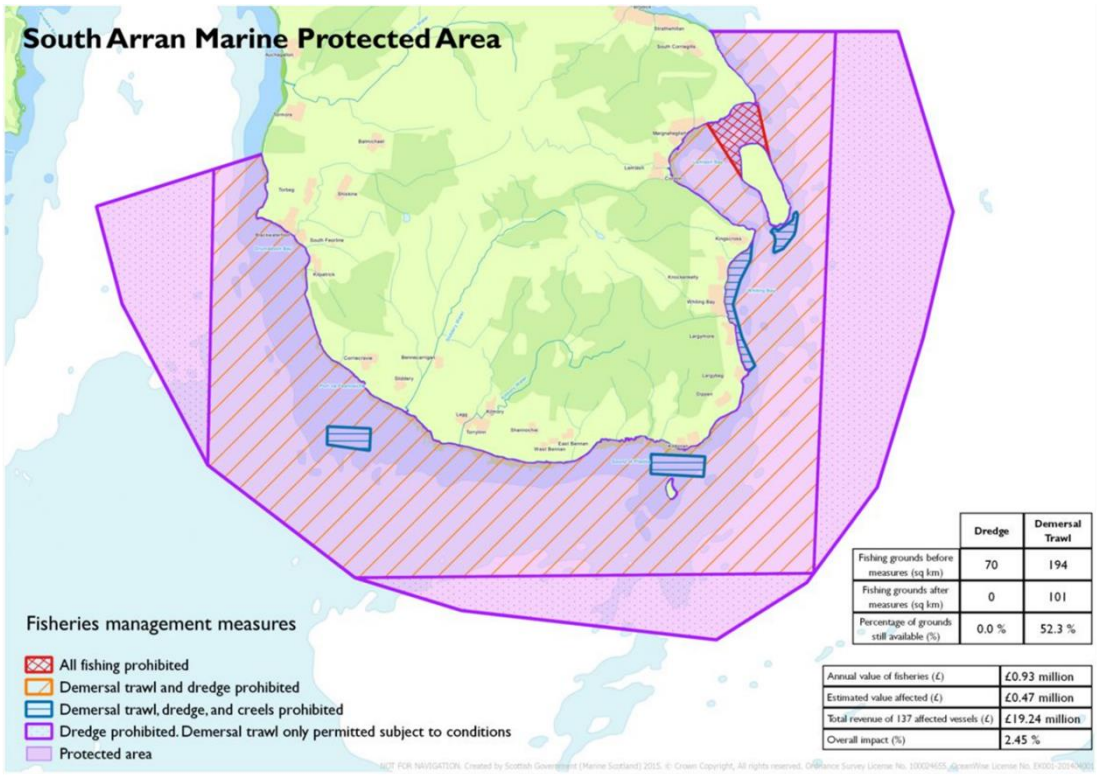


Figure 2 the area of the South Arran Marine Protected Area established in 2016 and areas of differing management strategies within the MPA. Map was obtained from the Community of Arran Seabed Trust website in 2017.

## 2. METHODS

### *2.1 Test Sites*

Seabed maps created in 2012 along with local knowledge were used to locate the seagrass beds. Preliminary snorkelling surveys were conducted to locate specific areas of *Z. marina* only, *S. muticum* only and areas containing a mixture of the two. It was determined that the *Z. marina* only videos would be taken in Whiting Bay only as the spread of *S. muticum* along the coast had not yet reached the deeper seagrass beds. Video data for areas containing a mix of *Z. marina* and *S. muticum* as well as areas of only *S. muticum* were collected in Kildonan, as the invasive species had become completely integrated within the seagrass beds in this area. Additionally, there were large areas of seafloor where *S. muticum* was found without seagrass.

### *2.2 Seagrass and Sargassum Density*

The density of *Z. marina* and *S. muticum* in both locations was determined using a $0.25m^2$ quadrat which was laid along a 20m transect (Figure 3). In both Whiting Bay and Kildonan six 20m transects were randomly placed within the seagrass beds along the coast corresponding with test site locations. A tape measure with an attached weight was snorkelled out to the seagrass beds and dropped to the seafloor. The researcher then flipped onto their back and finned, unreeling the tape measure until 20m had been unwound and then placed the tape measure on the bottom. A $0.25m^2$ quadrat was then placed along the transect at five separate locations, 0m, 5m, 10m, 15m and 20m, alternating sides of the tape measure each time.

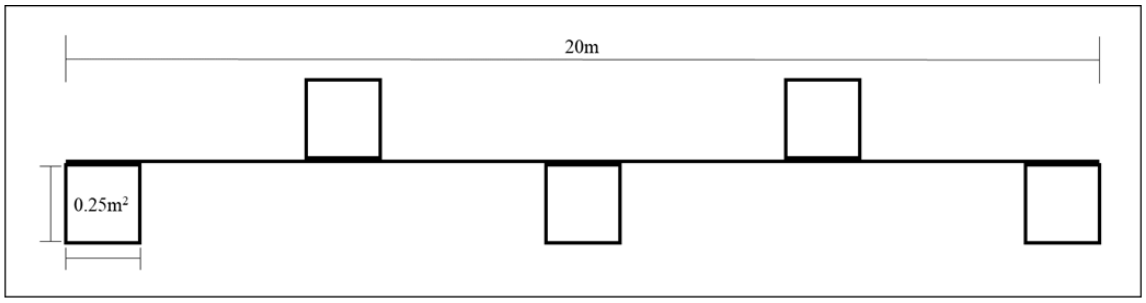


Figure 3 diagram representing the methodology used to collect data for quadrat analysis. Squares represent the $0.25m^2$ quadrats, the long line represents the tape measure stretched along the bottom to 20m.

In each quadrat, several variables were collected to help determine the composition of the substratum in the testing locations. Percent coverage of the substratum was determined by visually identifying and estimating the percent coverage within the quadrat of each of the following; *Z. marina, S. muticum,* macro-algae, sand, and rock/rubble. Along with this information, the number of individual shoots of *Z. marina* and *S. muticum* were recorded in each quadrat. In total 30 quadrats were collected at both locations, Kildonan and Whiting Bay, resulting in 60 total quadrats.

*2.3 Underwater Videos*

To determine species richness, or the total number of species found in an area, and the population density of these species, baited remote underwater videos (BRUV) were collected (Figure 4). These videos were obtained by attaching a GoPro Hero4 to a net-less lobster creel. All video settings on the GoPro were left on the default factory settings except frame view which was set to wide view, video quality and frames per second which were set to 1080p and 50 frames per second, respectively. On the opposite end of the creel, a small, transparent plastic Tupperware box was attached to the structure, which was situated directly in front of the camera. Before each deployment of BRUV, one-half of a Mackerel was diced into small pieces and added to the bait

box with the purpose of attracting local fish. All Mackerel were obtained from local fishermen and stored in a freezer until use.

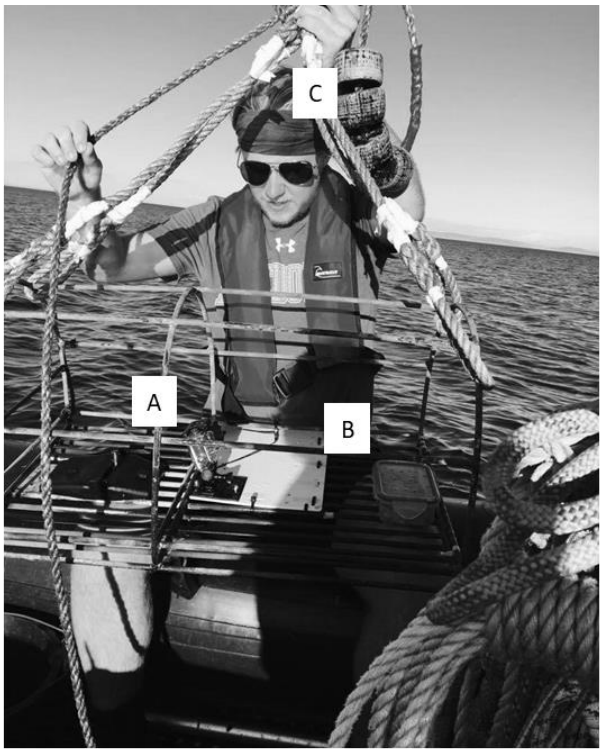


Figure 4 The structure used for the Baited Remote Underwater Video.. A net-less lobster creel with a GoPro Hero 4 attached at the bottom (A). At the other end directly in front of the camera lies a vented bait-box that is also attached to the bottom of the creel where the mackerel was located (B). Attached to the ropes at the top of the image are cork floats to keep the rope out of the video frame (C).

After the camera was mounted in the creel and facing the bait box, the BRUV was snorkelled or lowered over a boat onto a site with one of the three benthic criteria; 1) *Z. marina* only, 2) *S. muticum* only, or 3) mixed *Z. marina* and *S. muticum* substratum. Once the BRUV was settled on the seafloor, the camera was left for approximately 40 minutes to record the fish species in the area. After the time had elapsed, the camera was retrieved, re-baited, and redeployed. A maximum of four videos could be collected on a single day due to battery life. Additionally, the BRUV was only deployed when weather conditions were suitable for snorkelling or boating. Seven

videos were collected within each of the specified testing sites over a four-week period resulting in a total of 21 videos.

*2.3.1 Video analysis*

Each video was then analyed to determine the species composition and relative population density of each species. Video analysis began five minutes after BRUV had settled on the sea floor and concluded after 30 minutes had elapsed. This five-minute delay in data collection for each video was performed to allow the fish time to return the area if they had been scared off by the boat or snorkeler, as well as allow the fish time to acclimate to the new structure in their habitat.

To determine what fish species were in the area and population densities, several variables were extracted from each video. All fish that entered the video were identified to the lowest taxonomic level possible as well as the initial time of entry of each species ($t_0$). The variable MaxN and the time MaxN occurred ($t_{MaxN}$) were also collected for each species recorded in the videos. MaxN measures the maximum number of a single species in a one frame at a time (Cappo, Speare & De'ath, 2004). Given that it is difficult to determine whether a fish has re-entered the frame more than once, MaxN is used as a proxy for relative population density. Any fish that were too far away from the camera to be accurately identified were omitted from analysis.

*2.4 Data Analysis*

*2.4.1 Quadrat Analysis*

All quadrat data was tested for normality using a Shapiro-Wilks test. None of the variables were found to have a normal distribution and therefore all further tests used were non-parametric. A Mann-Whitney U-test was used to compare the seagrass and *S. muticum* density difference between Kildonan and Whiting Bay.

To evaluate differences in percent cover of the *Z. marina* and *S. muticum*, the percentage data was first converted from a discrete variable into a continuous variable using Equation 1. Where χ is the percent cover of the target species and α is the new continuous variable.

$$a = \arcsin\left(\sqrt{\frac{x}{100}}\right) \qquad \text{Equation 1}$$

These new continuous variables were then tested using a Mann-Whitney U-test to determine the percent cover differences of *Z. marina* and *S. muticum* between Kildonan and Whiting Bay.

*2.4.2 Video Data Analysis*

Data from the videos were averaged, based on the benthic composition the video was taken in to allow comparisons between the three site types. Variables that were tested included; average number of species per video, per site, and total population density for all commercially important species between sites, as well as the average MaxN for each commercial species including; Atlantic Cod (*Gadus morhua)*, Whiting (*Merlangius merlangus)*, Pollack (*Pollachius pollachius)*, Saithe (*Pollachius virens)* and Haddock (*Melanogrammus aeglefinus)*.

Due to the small sample size, the data was checked for normality using a Shapiro-Wilks test. All data appeared to be non-normally distributed except for total species count per video. Therefore, to determine if there was a difference in the total number of species between the three test sites a One-way analysis of variance (ANOVA) was performed. If significance was found a post hoc Tukey test was used to determine which groups were statistically different. To check for differences between sites for all other variables, a non-parametric Kruskal-Wallis test was used due to the non-normal distribution of the data. Because the Kruskal-Wallis test lacks the ability to determine which groups within the test are significantly different, any significant results of this test were then subjected to a post hoc Dunn's test to determine which groups within the test were significantly different.

## 3. RESULTS

### *3.1 Benthic Composition*

The benthic composition analysis of Whiting Bay and Kildonan revealed average seagrass coverage was about 18% and 16% per quadrat respectively (Figure 5). The average density of *Z. marina* and *S. muticum* was 18.5 and 4.4 shoots/$m^2$ respectively in the Kildonan seagrass beds. Whiting Bay seagrass beds possessed an average *Z. marina* density of 21 shoots/$m^2$ and contained no *S. muticum.* No significant difference between the two sites was found in respect to the *Z. marina* coverage or density. However, the benthic cover and density of *S. muticum* showed a significantly higher density (U= 165.00, n= 60, p< 0.001) and higher percent cover (U= 225.00, n= 60, p< 0.001) of *S. muticum* in Kildonan than in Whiting Bay.

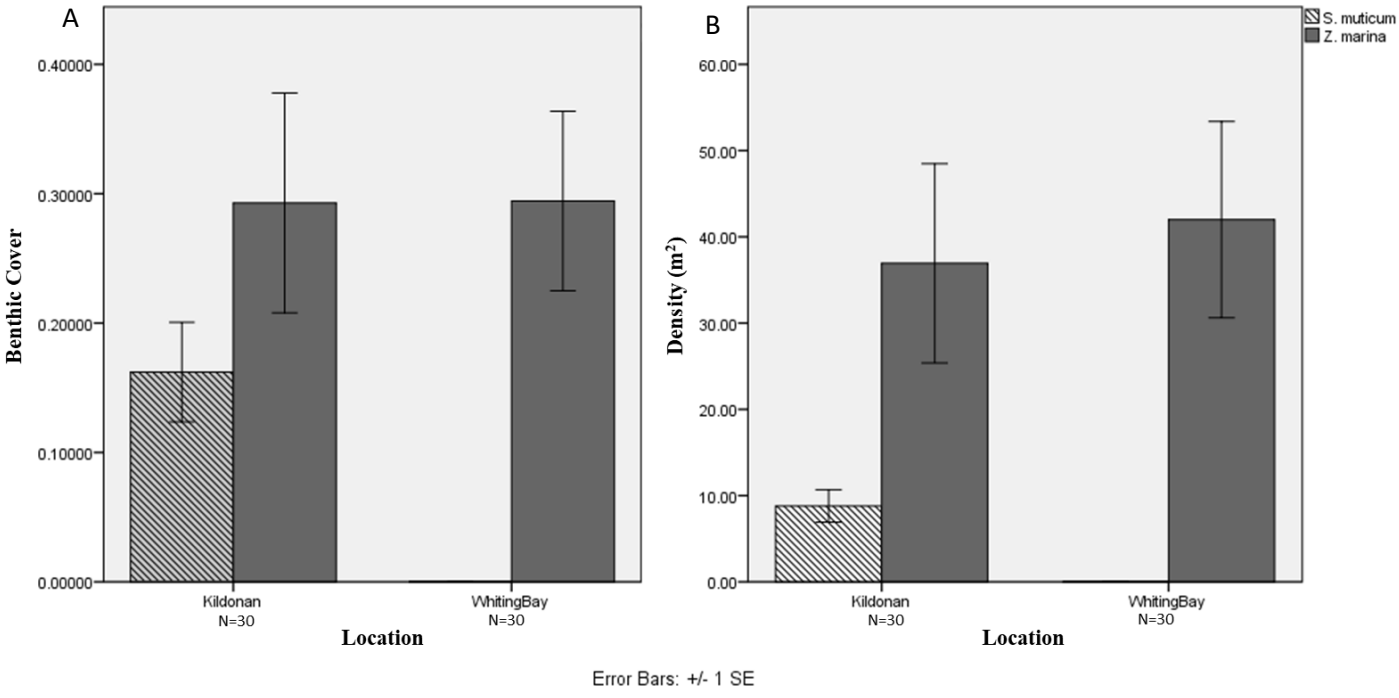


Figure 5 Site comparisons from quadrat data collected at Kildonan and Whiting Bay. Graph A shows the average percent cover of *Z. marina* and *S. muticum* within each quadrat. Graph B shows the average density per $m^2$ of both *Z. marina* and *S. muticum*. Error Bars represent +/- 1 the standard error.

*3.2 Species Richness*

A total of 18 species were identified after analysing the 21 videos. Of those 18 species the top three most common within the videos were the two-spotted goby (*Gobisculus flavescens)*, Atlantic Cod (*Gadus morhua)* and Saithe (*Pollachius virens).* Additionally, 5 of the 18 species were commercially important, these fish included, *Gadus morhua, Melanogrammus aeglefinus, Merlangius merlangus, Pollachius pollachius* and *Pollachius virens.*

A one-way ANOVA detected differences in the number of species between the sites (F= 3.701, df= 2, p= 0.045). A post hoc Tukey test was then used to determine which groups showed significance. The analysis showed that the mixed sites containing both *Z. marina* and *S. muticum* had an average of 3.29 species per video and were host to significantly fewer species than areas containing seagrass only, which had an average of 5.29 species per video (p= 0.036). No significant difference in species richness was found between areas of only *S. muticum* and the other two test sites (Figure 6).

*3.3 Commercially Important Species*

The total population of commercially important species within each area was compared across test sites. In the mixed locations containing both *Z. marina* and *S. muticum* and areas containing only *S. muticum* the average population density for commercially important fish was around two species per video, while in areas of only *Z. marina* population densities were roughly 8 fish per video. The Kruskal-Wallis test detected differences between the population density of the commercial species between sites (Figure 7; H= 9.724, df= 2, p= 0.008). Dunn's test showed that areas of *Z. marina* had significantly higher population densities of commercially important species compared to either site (p= 0.017). No significant difference between sites with *S. muticum* only and mixed sites were detected.

Population densities of individual commercial species were then compared between sites (Figure 8). All species appeared to have a higher population density in *Z. marina* only sites except for *P. virens*. However, statistical analysis found no significant differences were detected between sites for the following three species: *P. pollachius* (p= 0.322), *P. virens* (p= 0.091) and *M. merlangus* (p= 0.368). Significant differences were found between test sites for *M. aeglefinus* and *G. morhua*. Between sites the population density of *M. aeglefinus* was significantly higher in areas of *Z. marina* only compared to areas of mixed habitat or *S. muticum* only habitat (H= 12.224, df= 2, p= 0.002). No difference was found in regards to the number of *M. aeglefinus* in *S. muticum* only and mixed locations. *G. morhua* populations were found to be higher in areas of *Z. marina* only compared to areas of *S. muticum* only (H= 8.080, df= 2, p= 0.018). No significant differences were found between population densities of *G. morhua* between mixed sites and *Z. marina* only sites.

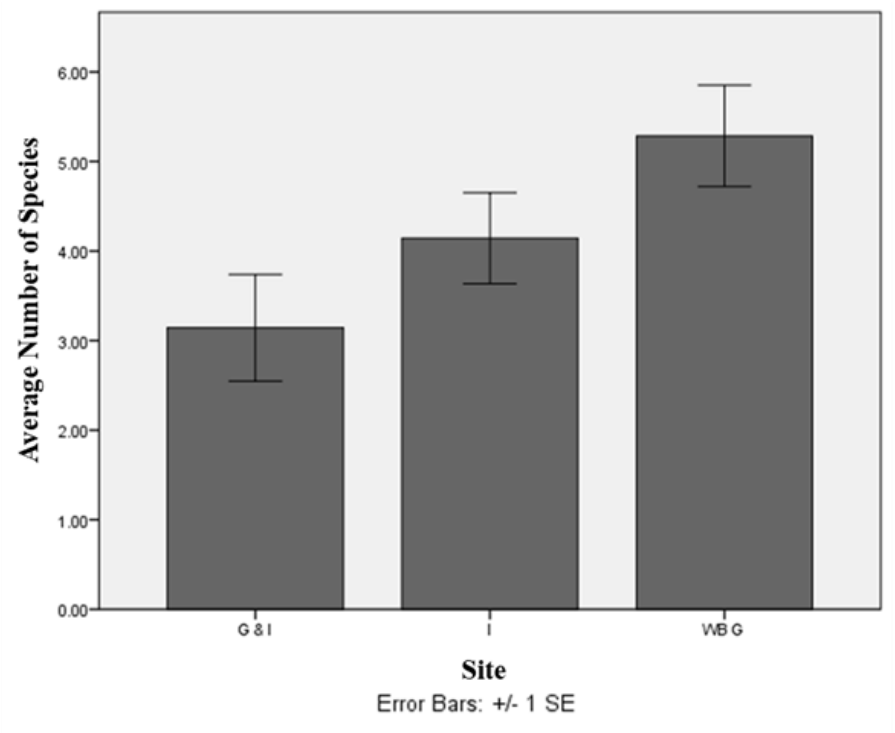


Figure 6 The average number of species found at each site where "G & I" represents locations of mixed *Z. marina* and *S. muticum*, "I" represents locations containing only *S. muticum* and "WB G" represents locations of only *Z. marina*. Error bars depict ±1 the standard error.

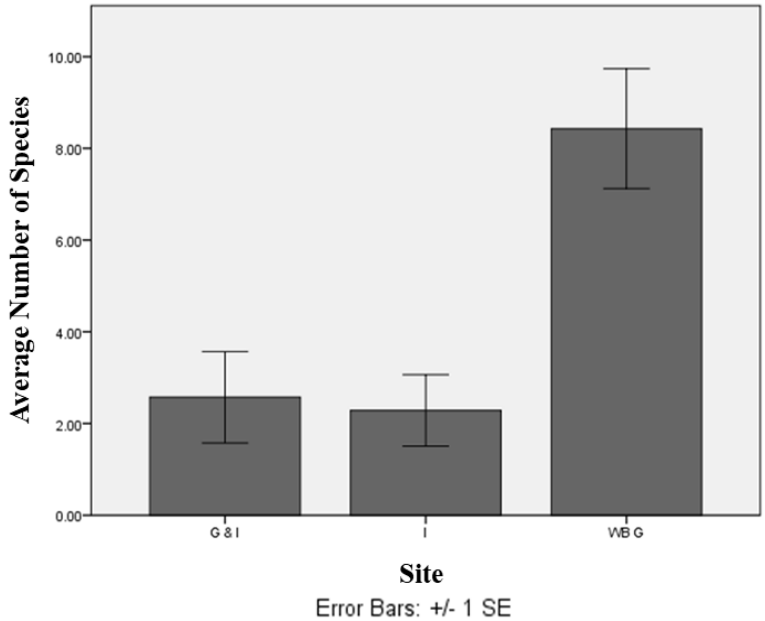


Figure 7 The combined MaxN for all commercially important species found at each site where "G & I" represents locations of mixed *Z. marina* and *S. muticum*, "I" represents locations containing only *S. muticum* and "WB G" represents locations of only *Z.* Error bars depict ±1 the standard error.

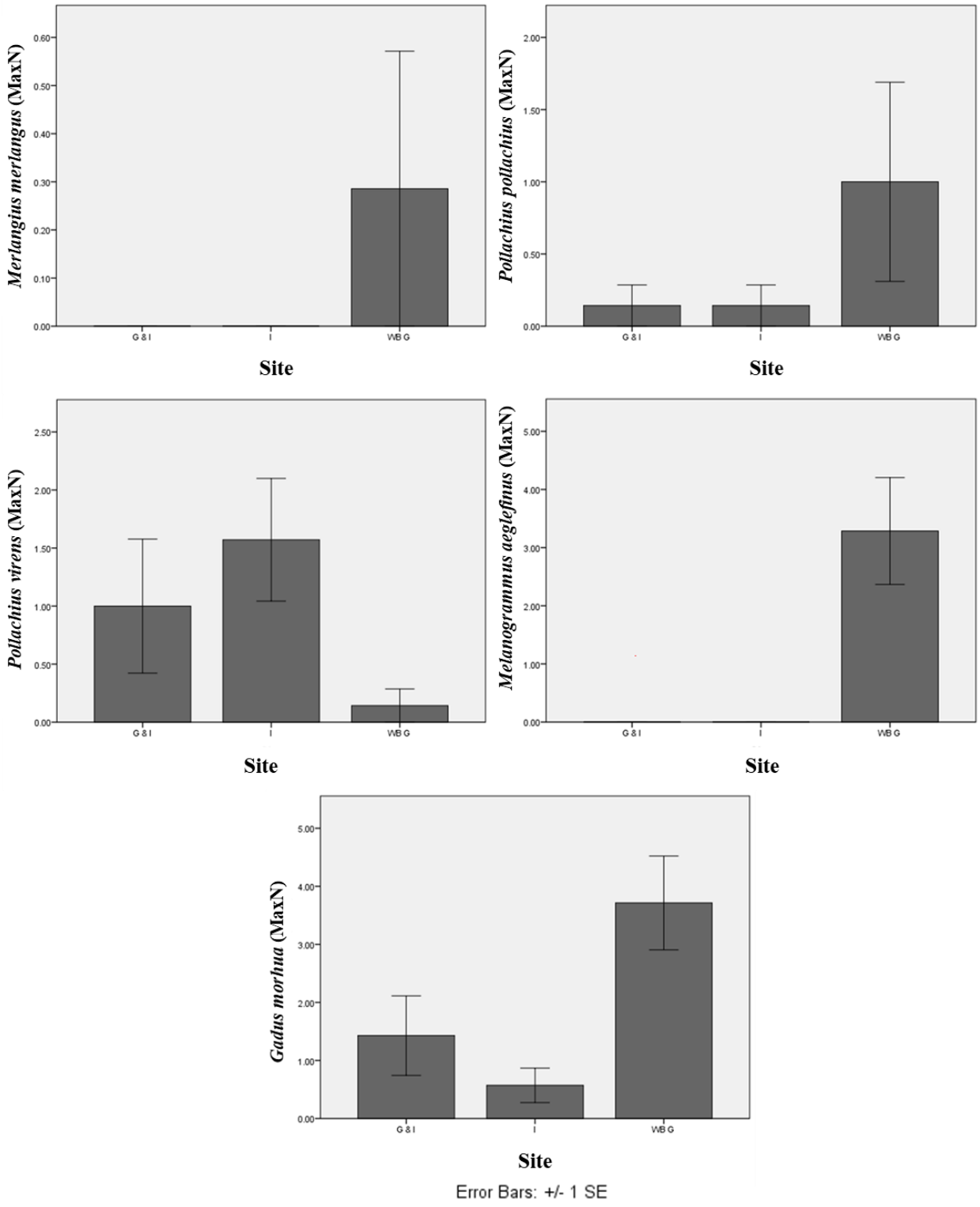


Figure 8 the average MaxN for individual commercial species found at each site where "G & I" represents locations of mixed *Z. marina* and *S. muticum*, "I" represents locations containing only *S. muticum* and "WB G" represents locations of only *Z. marina*. Graphs depict the following species; A) *Merlangius merlangus*, B)*Pollachius pollachius*, C)*Pollachius virens*, D) *Melanogrammus aeglefinus* and E) *Gadus morhua.* Error bars depict ±1 the standard error.

## 4. DISCUSSION

### *4.1 Zostera marina and Sargassum muticum Density and Benthic Cover*

Comparisons between Kildonan and Whiting Bay seagrass beds revealed that *Z. marina* density and benthic cover within each quadrat showed no significant difference. However, a significantly higher density and benthic cover of *S. muticum* was identified in Kildonan compared to Whiting Bay. The difference in *S. muticum* density and benthic cover was expected as local knowledge and preliminary snorkelling trips on these sites suggested that the alien species had not yet extended its range into the seagrass beds in Whiting Bay but had completely integrated within the seagrass beds off of Kildonan.

### *4.2 Species Richness and Commercial Species Population Density*

Fish community composition, or species richness, within the *Z. marina* only sites were found to contain more species when compared to mixed areas containing both *Z. marina* and *S. muticum.* Additionally, *Z, marina* only sites were shown to contain a significantly higher population density of commercially important species than either of the two sites containing *S. muticum*. While this could be a result of the *S. muticum* invasion, different physical characteristics between Whiting Bay and Kildonan are more likely driving these differences, like the size differences between seagrass beds. Local knowledge suggests the seagrass beds in Whiting Bay stretch approximately 4km down the coast while a study conducted in 2016 indicated that the seagrass beds in Kildonan extend just over $1km^2$ (Pers. Comm. Howard Wood, Founder of COAST, 2017; Thomas., 2016). The size differences could account for the differences in species richness and population density as larger patches of *Z. marina* are able to support a higher number of species and greater population density (Bowden *et al*., 2001). Not only are the seagrass beds in

Whiting Bay larger, they are also located at a greater depth and because of this are never exposed at low tide while the opposite is true for the Kildonan beds.

While depth and size differences between sites can alter fish community composition, the most likely cause for these differences is the recent loss in seagrass habitat in Kildonan. The seagrass beds were mapped in 2012 and again in 2016 and a 7,000$m^2$ or 84% decrease in seagrass extent was observed after the 2016 mapping (Binnie *et al*., 2012; Thomas, 2016). Studies have shown that as seagrass extent declines, so too does the species richness and population densities of the fish associated with that habitat (Hughes *et al*., 2002). For example, in Sweden, *Z. marina* beds have decreased by 60% since the 1980's (Pihl *et al*., 2006). Along with this decrease in seagrass, researchers found population densities to plummet. Some species, such as the Atlantic cod saw population reductions of up to 96% at sites where *Z. marina* had disappeared (Pihl *et al*., 2006). The reasons behind this loss in seagrass in Kildonan is largely unknown and could potentially be a result of the *S. muticum* invasion as it is known that the presence of *Z. marina* can increase the effectiveness of *S. muticum*'s ability to attach and settle in soft sediment (Tweedley, Jackson & Attrill, 2008). While it is unknown if *S. muticum* can outcompete *Z. marina* for nutrients, it has been found that any losses in *Z. marina* area are almost immediately utilized by *S. muticum* making it difficult for the seagrass beds to recover (den Hartog, 1997).

*4.2.1 Pollack, Saithe and Whiting (P. pollachius, P. virens and M. Merlangius)*

When comparing the population densities of each species between sites, no significant differences were noticed in *P. pollachius*, *P. virens* or *M. merlangus*. However, this may be due to the low frequency of these species entering videos. Average MaxN sightings for these species was below 0.3 fish per video for *P. pollachius* and *M. merlangus* and 1.0 fish per video for *P. virens*. With such low population densities recorded for these species it would be expected to not detect

population density differences between sites. Furthermore, it has been identified that populations of juvenile *P. virens* and *P. pollachius* in Scotland are highest September to January (Kamenos *et al*., 2004). Therefore, shifting the data collection time frame or extending it through September-January could potentially provide a more realistic population density for some of the commercially important species within the area.

*4.2.2 Haddock (M. aeglefinus)*

The comparisons of *M. aeglefinus* revealed significantly higher densities within the *Z. marina* only sites. This higher density of *M. aeglefinus* was quite significant as not a single haddock was found within either site in Kildonan. This finding was not surprising considering research suggests that haddock are typically found at greater depths and prefer sandy habitats compared to vegetated habitats (Elliot *et al*., 2017). Seagrass beds in Kildonan are surrounded by heavily vegetated areas consisting of mostly microalgal habitat with very minimal sand surrounding them. Not only does the Kildonan coast seem to have less sandy habitat, the BRUV locations in Kildonan were also much shallower than in Whiting Bay. With this in mind, it seems logical that there would be a difference in the haddock population densities between sites.

*4.2.3 Atlantic Cod (G. morhua)*

Juvenile Atlantic Cod (*G. morhua*) densities were significantly higher within areas containing only *Z. marina* when compared to areas of only *S. muticum*, with no difference between *Z. marina* only and mixed areas. Cod are known to inhabit the shallow waters of Scotland all year round and the patterns on their sides help to camouflage them within the intermediately dense seagrass habitats (Kamenos *et al*., 2004; Thistle *et al*., 2010). These species also actively seek out seagrass as they benefit greatly from these habitats (Lilly & Unsworth, 2014). Individuals who live in seagrass have been shown to exhibit higher growth rates compared to individuals in living in

surrounding habitats (Tupper & Boutilier, 1995). Since it is known that cod thrive within seagrass beds it was expected that there would be more cod in areas containing *Z. marina* compared to areas of *S. muticum.*

*4.3 Limitations and Future Research*

Before establishing a firm conclusion on whether *S. muticum* can alter species richness and population density the limitations of this study need to be addressed. First, the time required to collect and analyse BRUV is quite high which therefore resulted in a small sample size. A larger number of videos could have resulted in a greater number of species within the area being identified and would have strengthened statistical analysis. Another issue that was presented during this study was the differences in visibility between videos. Placing the BRUV in seagrass resulted in a reduced visual range and could have resulted in a lower number of fish being seen or identified. Additionally, increased water turbidity after storms or more intense wave conditions caused more sediments to become suspended in the water column which also reduced the visibility within the videos. This issue is common with BRUV analysis and are difficult to correct for (Lowry *et al.*, 2011). Continued monitoring of these sites would provide a more robust dataset on the fish community structure within the area, which could give us better insight into how these fish are being effected by the *S. muticum* invasion or seagrass extent changes.

Based on the information obtained in this study, it is difficult to determine whether the *S. muticum* invasion is the sole cause for the differences in species richness and population density between sites. The likely cause for many of these differences is the loss of 7,000$m^2$ of seagrass in Kildonan from 2012-2016 (Thomas, 2016). Because of this large decrease in seagrass extent, it is advised that the *Z. marina* beds are continually monitored and changes within the ecosystem are tracked. The Whiting Bay seagrass beds need to be mapped and monitored regularly as the findings

from this paper suggest that a large percentage of juvenile commercial species inhabit the seagrass in this area. Juvenile habitat extent has been shown to be the limiting factor for adult population sizes (Halpern, Gaines & Warner, 2004). As juvenile habitat decreases so does the adult population size as fewer juveniles survive to adulthood (Halpern, Gaines & Warner, 2004). With many commercially important juvenile fish utilizing this seagrass bed, some of which are vulnerable, such as *G. morhua* and *M. aeglefinus*, these seagrass habitats are of the utmost importance. Monitoring of these seagrass beds could be done through community involvement as the methodology for data collection, is not difficult. The quadrat analysis could be changed to photo-quadrats to allow trained persons to analyse images at a later date. Because these habitats provide so many ecosystem services it is important to understand how they are being effected and learn if there are way to help these ecosystems recover. Furthermore, monitoring the Arran seagrass habitat and associated faunal communities needs to continue in order to increase our understanding of these vital ecosystems.

REFERENCES

Bertelli, C. M., Unsworth, R. K. F. (2013). "Protecting the hand that feeds us: Seagrass (*Zostera marina*) serves as commercial juvenile fish habitat". Marine Pollution Bulletin. 83:425-429.

Binnie, A., Beecher, P., Gordon, D. (2012). "GIS Mapping of *Zostera marina* seagrass beds within the South Arran Proposed MPA" Community of Arran Seabed Trust (COAST). Lamlash, Isle of Arran, Scotland

Bowden, D. A., Rowden, A. A., Attrill, M. J. (2001). "Effect of patch size and in-patch location on the infaunal macroinvertebrate assemblages of two marine seagrass beds". Experimental Marine Biology and Ecology. 259:133-154.

Cappo, M., Speare, P., De'ath, G., (2004). "Comparison of baited remote underwater video stations (BRUVS) and prawn (shrimp) trawls for assessments of fish biodiversity in inter-reef areas of the Great Barrier Reef Marine Park." Exp.Mar. Biol. Ecol. 302:123-152.

Chapman, N. (2008). "UK Biodiversity Action Plan Priority Habitat Descriptions". DEFRA. [online]. Accessed on: 29 August 2017. Available on: http://jncc.defra.gov.uk

Critchley, A. T. (1983). "The establishment and increase of *Sargassum muticum* (Yendo) Fenshold populations within the Solent Area of Southern Britain". Botanica Marina. 26:547-552.

DeAmicis, S., Foggo, A. (2015). "Long term field study reveals subtle effects of the invasive alga *Sargassum muticum* upon epibiota of *Zostera marina*". PLoS ONE. 10:1-12.

Duarte, C. M., Kennedy, H., Marba, N., Hendriks, I. (2011). "Assessing the capacity of the seagrass meadows for carbon burial: Current limitations and future stratagies". Ocean and Costal Management. 1-7.

Elliot, S. A. M., Turrell, W. R., Heath M.R., Bailey D. M. (2017) "Juvenile gadoid habitat and ontogenetic shift observations using stereo-video baited cameras" Marine Ecology Progress Series. 568:123-135.

Farnham, W. F., Fletcher, R. L., Irvine, L. M. (1973). "Attached *Sargassum* found in Britain". Nature. 243:231-232.

Fourqurean, J. W., Rutten, L. M. (2004). "The impact of Hurricane Georges on soft bottom back reef communities: Site and species specific effects on South Florida seagrass beds". Bulletin of Marine Science. 75:239-257.

Greiner, J. T., McGlathery, K. J., Gunnel, J., Mckee B. A. (2013). "Seagrass restoration Enhances "Blue Carbon" sequestration in coastal waters". PLoS ONE. 8(8):e72469. https://doi.org/10.1371/journal.pone.0072469.

Hughes, J. E., Deegan, L. A., Wyda, J. C., Weaver, M. J., Wright, A. (2002). "The effects of eelgrass habitat loss on estuarine fish communities of Southern New England". Estuaries. 25:235-249.

Halpern, B. S., Gaines, S. D., Warner, R. R. (2004). “Habitat size recruitment and longevity as factors limiting population size in stage structured species”. The American Naturalist. 165:82-94.

Kamenos, N. A., Moore, P. G., Hall-Spencer, J. M. (2004). “Small-scale distribution of juvenile gadoids in shallow waters; what role does mearl play?”. Journal of Marine Science. 61:422-429

Katsanevankis, S., Wallentinus, I., Zenetos, A., Leppakoski, E., Cinar, M. E., Ozturk, B., Grabowski, M., Golani, D., Cardoso, A. C. (2014) “Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review”. Aquatic Invasions. 9:391-423.

Lilly, R. J., Unsworth, R. K. F. (2014). “Atlantic Cod (*Gadus morhua*) benefits from the availability of seagrass (*Zostera marina*) as nursery habitat”. Global Ecology and Conservation. 2:367-377.

Lowry, M., Folpp, H., Gregson, M., McKenzie, R. (2011) “A comparison of methods for estimating fish assemblages associated with estuarine artificial reefs”. Brazilian Journal of Oceanography. 59:119-131.

Moore, K. A., Neckles, H. A., Orth, R. J. (1996). “*Zostera marina* (eelgrass) growth and survival along gradient of nutrients and turbidity in lower Chesapeake Bay”. Marine Ecological Press Series. 142:247-259.

Orth, R. J., et al. (2006). A global crisis for seagrass ecosystems”. Bioscience. 56:987-996.

Orth, R. J., Heck, K. L., Montifrans, J. V. (1984). “Faunal Communities in seagrass beds: a review of the influence of plant structure and pre characteristics on predator-prey relationships.” Estuarine Research Federation. 7:339-350.

Pejchar, L., Mooney, H. A. (2009). “Invasive species, ecosystem services and human wellbeing”. Trends in Ecology and Evolution. 497-504.

Pihl, L. et al. (2006). “Shifts in fish assemblage structure due to loss of seagrass *Zostera marina* habitat in Sweden”. Estuarine Costal and Shelf Science 67:123-132.

Pile, J., Lipcius, R. N., Montfrans, J. V., Orth, R. J. (1996). “Density dependant settler-recruit-juvenile relationships in blue crabs”. Ecological Monographs. 66:271-300.

Relini, G., Relini, M., Torchia, G. (2000). “The role of fishing gear in the spreading of allochthonous species: the case of *Caulerpa taxifolia* in the Ligurian Sea”. ICES Journal of Marine Science. 57:1421-1427.

Stallings et al. (2015). “Faunal Community and Habitat Characteristics of the Big Bend Seagrass Meadows, 2009-2010”. Ecology of Ecological Society of America. 96:304

Scottish National Heritage. (2013). "Scottish MPA project management options: South Arran proposed MPA". Scottish National Heritage. [online]. Accessed on: 8/25/2017. Available at: www.snh.gov

Thistle, M. E., Scheneider, D. C., Gregory, R. S., Wells, N. J. (2010). "Fractal measures of habitat structure: maximum densities of juvenile cod occur at intermediate eelgrass complexity" Marine Ecology Progress Series. 405:39-56.

Thomas, O. R. (2016). "Ecology of Infralitroral seagrass beds in the South Arran MPA, temporal changes in extent and comparisons of associated Biota. Heriot Watts University.

Tupper, M. Boutilier, R. G. (1995). "Effects of habitat on settlement, growth and post settlement survival of Atlantic Cod (*Gadus morhua*)" Canadian Journal of Fisheries and Aquatic Science. 52:1834-1841.

Tweedley, J. R., Jackson, E. L., Attrill, M. J. (2008). "*Zostera marina* seagrass beds enhance the attachment of the invasive alga *Sargassum muticum* in soft sediments". Marine Ecological Progress Series. 254:305-309.

Waycott, M., et al. (2009). "Accelerating loss of seagrass across the globe threatens coastal ecosystems". Proceedings of the National Academy of Science 106:12377-12381

Websites Sourced

1. The Scottish Islands Federation. Accessed on: August 12, 2017. Available at: http://www.scottish-islands-federation.co.uk

2. The international Union for Conservation of Nature Endangered Species List. Accessed on: August 12, 2017, Available at: http://www.iucnredlist.org/

Personal Communication

1. Bryce Beukers-Stewert, Lecturer at the University of York. 2017.
2. Howard Wood. Founder of The Community of Arran Seabed Trust. 2017