Assessing the Biodiversity of Intertidal Region within BMR (St Abbs, Coldingham, Killiedraughts) for Spatial and Temporal Comparisons

Abstract

The aim of this report is to compare the biodiversity of three sites within the Berwickshire Marine Reserve on a spatial and temporal scale. The results from the transect and quadrat surveys are analysed using The Simpson's Index for faunal species richness and the related context of the Ecological Quality Ratio for seaweed richness, as well as an analysis of species average number and coverage. The findings reveal that total species richness and population richness are higher in Coldingham and Killiedraughts than in St Abbs, and that species richness increases and subsequently decreases from summer to winter. The seasonal variation in species abundance cannot be determined due to the limited data and the fact that small number of relevant influences are taken into account.

Introduction

This report of the research project aims to present the data survey of three sites within the Berwickshire Marine Reserve (BMR), which are St Abbs, Coldingham and Killiedraughts. The data collected is thoroughly analysed in order to examine spatial and temporal comparisons of biodiversity and to use the findings from these habitats to facilitate understanding of the dynamic changes of the BMR and to mitigate anthropogenic influences.

According to the Living Planet Report 2020 report published by The World Wildlife Fund (WWF), monitored population sizes of mammals, birds, amphibians, reptiles and fish declined by an average of 68% between 1970 and 2016 [1]. The long-accelerating extinction of species and the human alteration of natural habitats [2] have led to a growing awareness of the importance of biodiversity. The richness of species provides many essential services to society, such as producing material goods, helping with climate regulation [3], ensuring regional stability and resilience to environmental change [4]. In the case of the BMR, being as a nature reserve in the Scottish region, biodiversity could be a natural indicator of the effectiveness of conservation in the area. Measuring species richness in the habitats can therefore be used to inform management decisions within protected areas. By ensuring the diversity of species within the BMR, the area is better able to ensure its sustainability and resilience in the current climate change environment.

(Berwickshire Marine Reserve [5])

Figure 1. The map of BMR and three contrast sites

As the Figure 1 has shown, the number 1- 3 labels the approximate location of each of the three contrast sites. St Abbs is a small fishing village and has seen an increase in the number of visitors to the area in recent years as a result of having more people's sights in this area due to the film *Avengers: Endgame*. [6] Coldingham bay is a sandy beach located in the north west of

Eyemouth, while the other beaches in the BMR region are mostly rocky. [7] Killiedraughts bay is quite close to the Eyemouth beach and is part of the St Abbs and Eyemouth Voluntary Marine Reserve (VMR) supported by the Scottish Wildlife Trusts, which is also highly praised as one of the finest rock pooling sites in Scotland. [8] The BMR survey data sampled so far from all three sites within the nature reserves have a wide variety of seaweeds (bladder wrack, channel wrack, kelp etc.) and faunal species (limpets, winkles, anemones etc.).

Methods

1. Transect and Quadrat Survey

   In three seasons (summer, autumn, winter), three sites were sampled. During the summer and fall seasons, three transects were laid out, with four randomly placed 1m x 1m quadrats sampled along the transect in the upper, middle, and lower shore areas. Species that are not suited for counting should be documented in the quadrat area's coverage, while countable faunal species are counted. In addition, the investigators only put one transect in the winter, the rest of the procedure was set to be the same.

2. Biodiversity Analysis

   In the analysis of species biodiversity in the BMR, the report considers to divide all the species into two main categories: faunal species and seaweeds. The Simpson's Diversity Index (*D*) (2.1) is used for countable faunal species, while seaweeds are analysed in the context of the Ecological Quality Ratio (EQR) (2.2) for its richness.

   2.1 The Simpson's Diversity Index

   The Simpson's Diversity index (*D*), which was introduced by Simpson in 1949 [9], could be used to quantify the biodiversity of a certain area. Since its introduction, the Simpson Diversity Index has been of considerable importance as it can be applied to many species, such as birds [10], benthic fauna [11], microbial communities [12], and so on. According to related definitions, the value of D should be between 0 and 1, with a value close to 1 indicating a high level of biodiversity and the opposite indicating a low level of biodiversity. [9]

   The formula is:

$$D = 1 - \left(\sum \left(\frac{n}{N}\right)^2\right)$$

   n = total number of organisms for a single species

   N = total number of organisms for all species

   2.2 Analysis of seaweed richness in the context of EQR

   Under the requirements of the EU Water Framework Directive (EC 2000) and the goal of achieving 'good water status' in all European waters by 2015 [13], a new framework for ecological status assessment using biological indicators was developed and the concept of the 'Ecological Quality Ratio' (EQR) was introduced was introduced. [14] It takes a comprehensive approach to the management of rivers, lakes, transitional and coastal waters by paying attention to the complete ecology and function of ecosystems. [18] Besides, macroalgal communities, which can be easily recognized, are considered as one of the ecological quality factors for assessing the ecological quality of coastal and transitional waters. [15]

As the table 1 shows, in the process of analysis, it is necessary to distinguish the certain species of seaweeds recorded by observation into three types: Phaeophyta (brown algae), Rhodophyta (red algae) and Chlorophyta (green algae), and to record whether they are opportunistic species and to distinguish the ecological status group (ESG) of them. [14] The higher the final value of species richness, the higher the level of biodiversity in the area.

Table 1. Species checklist (presence or absence of algal species) and associated scoring system. G, green algae; B, brown algae; R, red algae; ESG, Ecological Status Group.

No.	Species name	UK-ROI	Algae colour	Opp	ESG	No.	Species name	UK-ROI	Algae colour	Opp	ESG
1	*Blidingia* sp.	1	G		2	48	*Audouinella* sp.		R		1
2	*Bryopsis plumosa*	1	G		2	49	*Calcareous encrusters*	1	R		1
3	*Chaetomorpha linum*	1	G	1	2	50	*Callophyllis laciniata*		R		2
4	*Chaetomorpha mediterranea*	1	G	1	2	51	*Catenella caespitosa*	1	R		2
5	*Chaetomorpha melagonium*	1	G	1	2	52	*Ceramium nodulosum*	1	R		1
6	*Cladophora albida*		G		2	53	*Ceramium shuttleworthanium*	1	R		1
7	*Cladophora rupestris*	1	G		2	54	*Ceramium* sp.	1	R		1
8	*Cladophora sericea*	1	G		2	55	*Chondrus crispus*	1	R		1
9	*Enteromorpha* sp.	1	G	1	2	56	*Corallina officinalis*	1	R		2
10	*Monostroma grevillei*		G		2	57	*Cryptopleura ramosa*	1	R		1
11	*Rhizoclonium tortuosum*		G		2	58	*Cystoclonium purpureum*	1	R		1
12	*Spongomorpha arcta*		G		2	59	*Delesseria sanguinea*		R		1
13	*Sykidion moorei*		G		2	60	*Dilsea carnosa*	1	R		1
14	*Ulothrix* sp.		G		2	61	*Dumontia contorta*	1	R		1
15	*Ulva lactuca*	1	G	1	2	62	*Erythrotrichia carnea*	1	R		1
16	*Alaria esculenta*	1	B		1	63	*Furcellaria lumbricalis*	1	R		1
17	*Ascophyllum nodosum*	1	B		1	64	*Gastroclonium ovatum*	1	R		2
18	*Asperococcus fistulosus*		B		1	65	*Gelidium* sp.	1	R		2
19	*Chorda filum*	1	B		1	66	*Gracilaria gracilis*	1	R		2
20	*Chordaria flagelliformis*		B		1	67	*Halurus equisetifolius*	1	R		1
21	*Cladostephus spongious*	1	B		2	68	*Halurus flosculosus*	1	R		1
22	*Desmarestia aculeata*		B		1	69	*Heterosiphonia plumosa*	1	R		2
23	*Dictyosiphon foeniculaceus*		B		1	70	*Hildenbrandia rubra*	1	R		1
24	*Dictyota dichotoma*	1	B		1	71	*Hypoglossum hypoglossoides*	1	R		2
25	*Ectocarpus* sp.	1	B	1	1	72	*Lomentaria articulata*	1	R		1
26	*Elachista fucicola*	1	B		1	73	*Lomentaria clavellosa*		R		1
27	*Fucus serratus*	1	B		1	74	*Mastocarpus stellatus*	1	R		1
28	*Fucus spiralis*	1	B		1	75	*Melobesia membranacea*		R		1
29	*Fucus vesiculosus*	1	B		1	76	*Membranoptera alata*	1	R		2
30	*Halidrys siliquosa*	1	B		2	77	*Nemalion helminthoides*	1	R		1
31	*Himanthalia elongata*	1	B		1	78	*Odonthalia dentata*		R		1
32	*Laminaria digitata*	1	B		2	79	*Osmundea hybrida*	1	R		1
33	*Laminaria hyperborea*	1	B		2	80	*Osmundea pinnatifida*	1	R		1
34	*Laminaria saccharina*	1	B		2	81	*Palmaria palmata*	1	R		1
35	*Leathesia difformis*	1	B		2	82	*Phycodrys rubens*		R		2
36	*Litosiphon laminariae*		B		2	83	*Phyllophora* sp.	1	R		1
37	*Pelvetia canaliculata*	1	B		1	84	*Plocamium cartilagineum*	1	R		2
38	*Petalonia fascia*		B		2	85	*Plumaria plumosa*	1	R		2
39	*Pilayella littoralis*	1	B	1	2	86	*Polyides rotundus*	1	R		1
40	*Ralfsia* sp.	1	B		1	87	*Polysiphonia fucoides*	1	R		2
41	*Saccorhiza polyschides*	1	B		1	88	*Polysiphonia lanosa*	1	R		2
42	*Scytosiphon lomentaria*	1	B		1	89	*Polysiphonia* sp.	1	R		2
43	*Sphacelaria* sp.		B		1	90	*Porphyra leucosticta*		R	1	2
44	*Spongonema tomentosum*		B		1	91	*Porphyra umbilicalis*	1	R	1	2
45	*Aglaothamnion/Callithamnion*	1	R		2	92	*Ptilota gunneri*		R		2
46	*Ahnfeltia plicata*	1	R		2	93	*Rhodomela confervoides*	1	R		2
47	*Audouinella purpurea*		R		1	94	*Rhodothamniella floridula*	1	R		2

(C. Cusack et al., 2005)

Results

1. The comparison of species richness

As an article first published in 2006 in Encyclopedia of Statistical Sciences stated, 'Species richness (i.e., the number of species) is the simplest, most intuitive and most frequently used measure for characterizing the diversity of an assemblage.' [16]

Table 1. Species richness in BMR in different season

	summer	autumn	winter
Coldingham	36	37	18
Killiedraughts	32	39	29
St Abbs	25	30	21

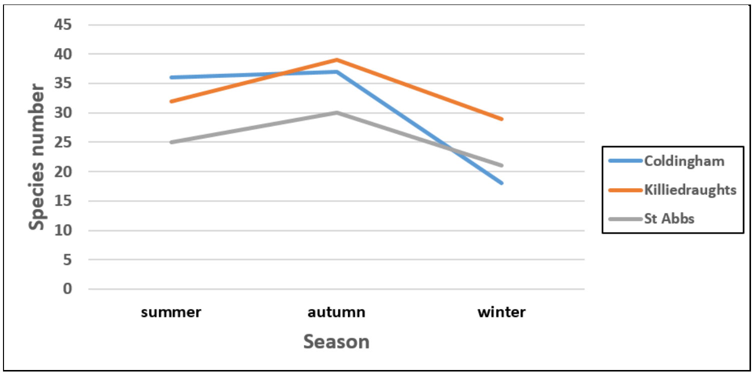

Figure 2. The richness in three sites within BMR

From Figure 2, it can be seen that there is some variation in the total species diversity of the three sites. In general, the other two sites (Coldingham and Killiedraughts) have a higher species richness than St Abbs. Species richness at both Coldingham and Killiedraughts remained above 30 in the summer and autumn, with a maximum difference of 17 kinds of species from the St Abbs data. And in terms of seasonal changes, from summer to winter, all three sites show a trend of increasing numbers first, peaking in autumn time and then decreasing. During the change in species richness from autumn to winter, the Coldingham region shows the most significant number of decreases (19 species), while Killiedraughts and St Abbs show less decreases, with 9 and 10 species respectively.

2. The comparison of faunal species richness

After conducting richness analyse for all species in the three regions, Simpson's diversity analysis is considered for countable faunal species as the value of *D* could be used to calculate the data. The different species of organisms within all quadrats in each region are counted and the value of (n/N) is calculated.

Table 2. The Simpson's Index *(D)* for faunal species in BMR

	summer	autumn	winter
St Abbs	0.706805	0.640877	0.583291
Killiedraughts	0.706174	0.751044	0.644487
Coldingham	0.692678	0.769154	0.64557

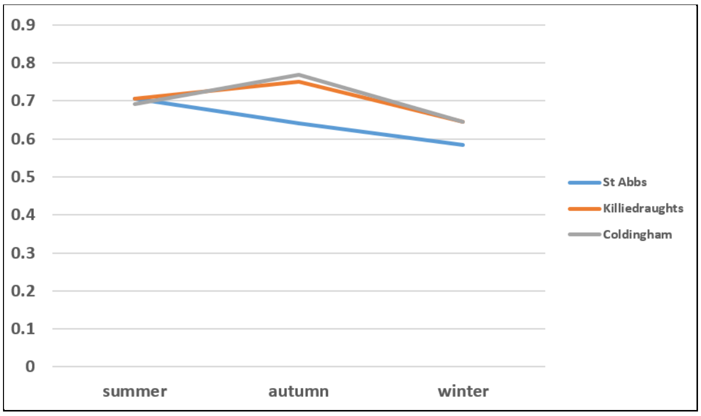

Figure 3. The Simpson's Index *(D)* changes

The data in Table 2 and the line graph demonstrate the results of The Simpson's Index analysis for countable faunal species group, including winkles, limpets, anemones etc. It can be seen that, similar to the overall species richness comparison above, the faunal species richness in Coldingham and Killiedraughts is generally higher than that of St Abbs. Especially during autumn and winter, the value of *D* is about 0.12 and 0.06 higher than St Abbs, respectively. Observing the values of different seasons in the same area, it can be found that the index of St Abbs shows a continuous declining trend, which means the diversity of biological populations is declining, while the other two sites have an relatively same tendency to rise and then fall to approximately 0.64 (Figure 3).

3. The comparison of seaweed in autumn

As the two previous data comparisons both showed a higher species richness in autumn, which means this season could be relatively representative, for the seaweed analysis this report looks to compare the seaweed proportions of the three sites in autumn. By analysing specific seaweed species as well as opportunistic species, the differences in richness can be compared to see which area is more diverse in autumn.

Table 3. The analysis of seaweed in BMR

	Phaeophyta	Rhodophyta	Chlorophyta	Number of opportunists	Total algal species
St Abbs	5	5	2	0	12
Killiedraughts	11	8	3	1	22
Coldingham	9	7	3	2	19

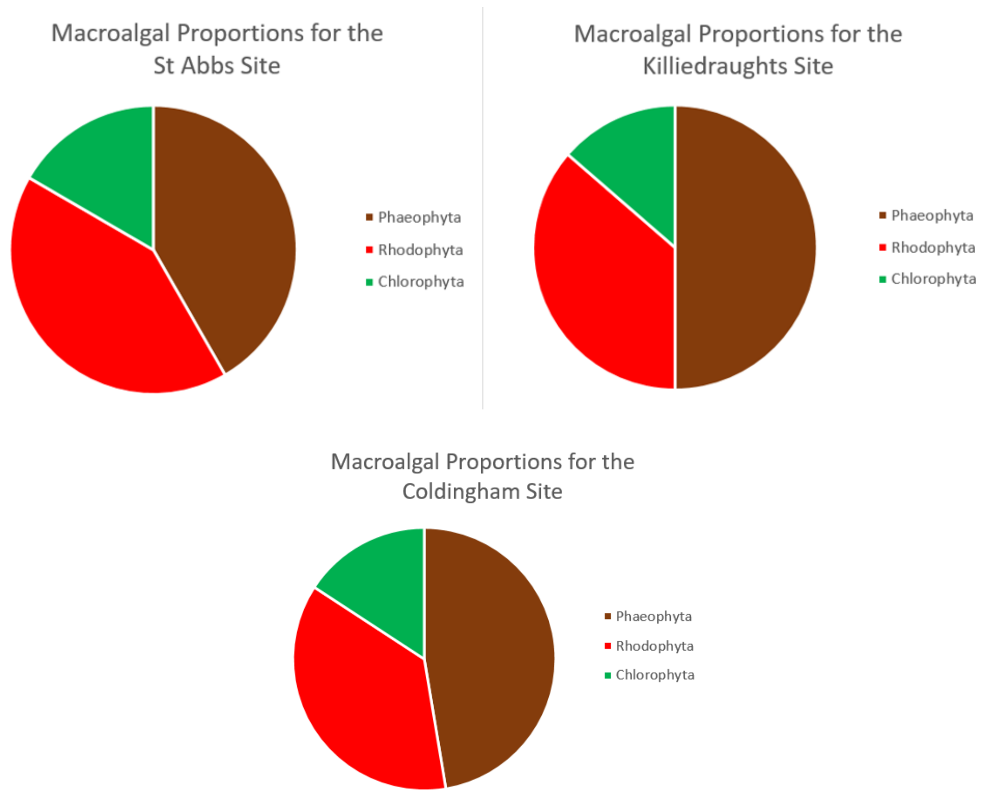

Figure 4. Macroalgal Proportions for the three sites

Table 3 shows that in autumn the richness of seaweed is higher in Coldingham and Killiedraughts with 19, 22 species respectively than in St Abbs (12 species). In addition, the macroalgal proportions in these regions show that all three sites have the same pattern of seaweed richness, which is brown algae ＞ ₌ red algae ＞ green algae. This suggests that brown algae and red algae species are richer in these three sites.

As for opportunistic species, Killiedraughts has *Ulva lactuca* and Coldingham has *Ulva lactuca* and *Porphyra umbilicalis*. Opportunistic species, by definition, are not limited by resources and can rapidly increase in numbers once they become available in response to favourable conditions. [17] Overgrowth of opportunistic macroalgal species may result in blooms that disrupt the natural balance of associated species communities. [18] Therefore having too many opportunistic macroalgal species in a region could have a potentially negative impact to the environment.

4. The seasonal changes of faunal species average number

To study the average number of faunal species, the number of species of all transects in one site is counted and divided by the total area of the contrast site to obtain the average value (Figure 5). For example, to calculate the average number of faunal species in summer, since there are three transects and 12 quadrats are randomly placed on each transect, it means that the total number counted for one species should be divided by 36 (3x12) to obtain the final result.

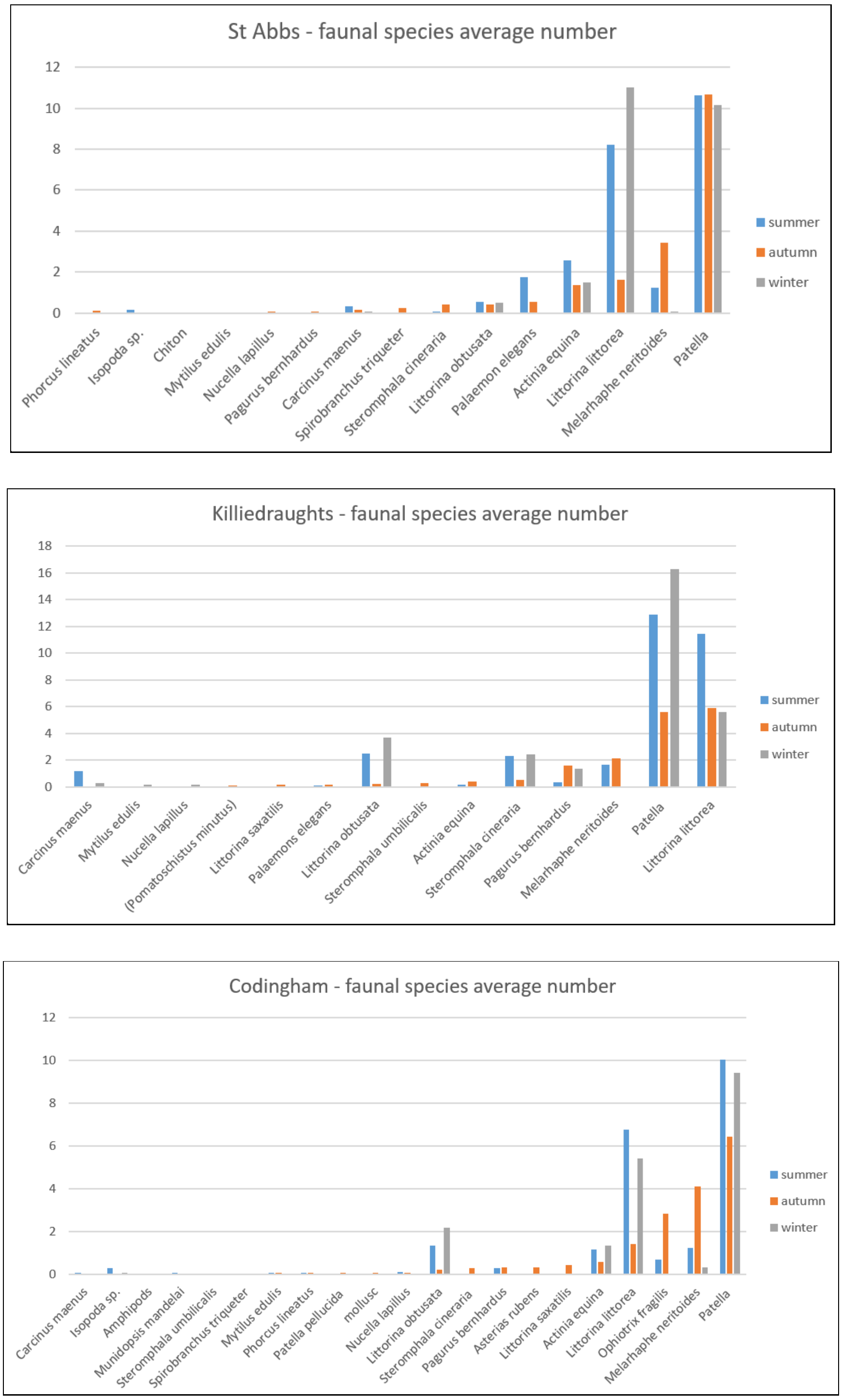

Figure 5. The seasonal changes of faunal species

The Figure 5 shows that there is variability in the dominant species (i.e. the species with relatively higher average numbers) in each season in the different areas. Summarising the top five species in terms of average numbers at the three sites, it can be seen that the species common to all three areas are Limpets (*Genus Patella sp.*) and Common or edible periwinkle (*Littorina littorea*), and the dominant species common to both sites St Abbs and Coldingham are Blue mussel (*Mytilus edulis*) and Beadlet anemone (*Actinia equina*).

Within the same area, different species show very different seasonal variations, for example within the Coldingham area Limpets (*Genus Patella sp.*) and Beadlet anemone (*Actinia equina*) species show a trend from a higher average number, go down, and then up again during the summer to winter period, while Small periwinkle (*Melarhaphe neritoides*) shows an opposite, rising and then falling trend. For the seasonal variation of the same species in different areas, it can be seen that some maintain the same pattern of variation (Flat periwinkle (*Littorina obtusata*) and Small periwinkle (*Melarhaphe neritoides*)), but several species like Common or edible periwinkle (*Littorina littorea*) show a different trend.

5. The seasonal changes of seaweed species average coverage

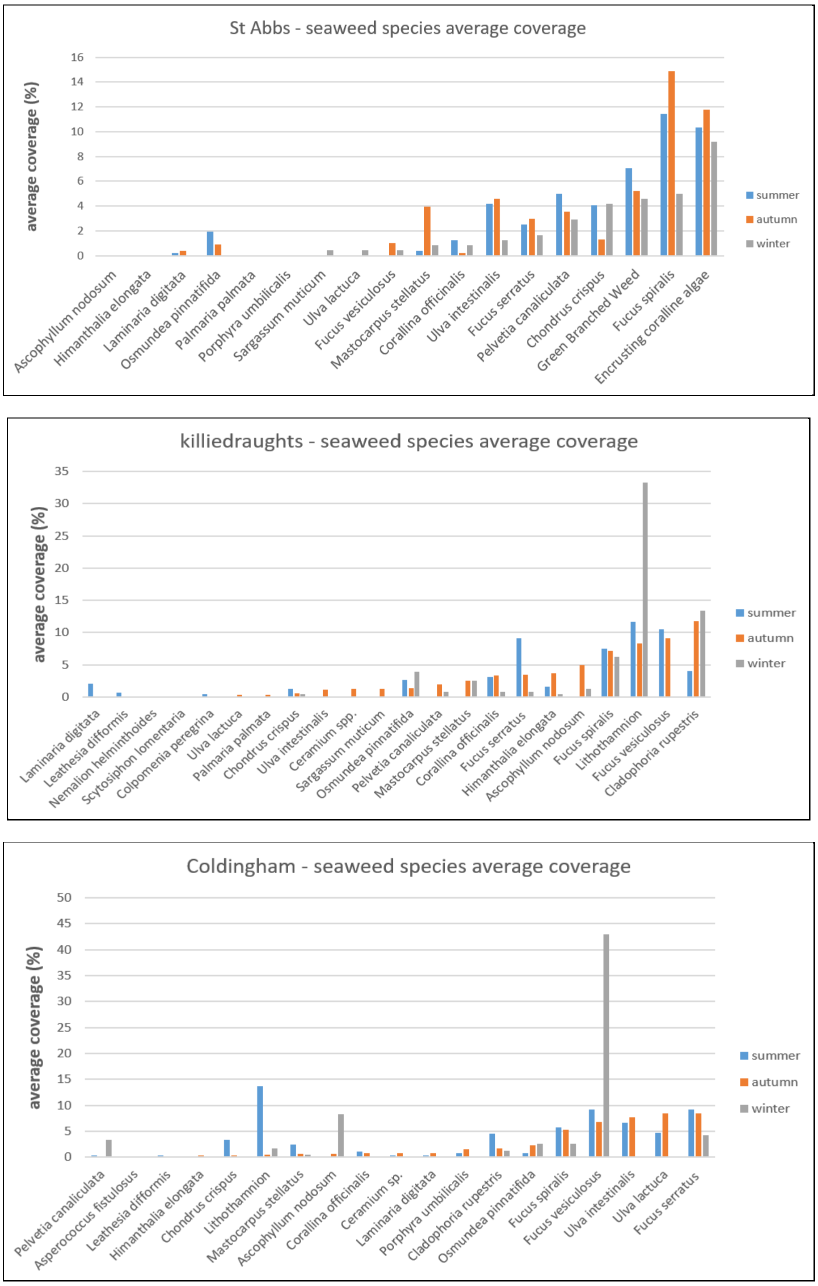

Figure 6. The seasonal changes of seaweed species

An analysis of the proportions of seaweed species in the different regions and their variation in Figure 6 shows that the top five dominant species of seaweed differ significantly between regions. The three areas share only spiral wrack (*Fucus spiralis*) as the dominant species, and Coldingham and Killiedraughts shares toothed wrack (*Fucus serratus*) with both sites. The five dominant species in Killiedraughts do not include green algae, while St Abbs and Coldingham have one (Green Branched Weed (*Cladophoria rupestris*)) and two (gutweed (*Ulva intestinalis*) *and* sea lettuce (*Ulva lactuca*)) species respectively. Coldingham and Killiedraughts both have species with an average cover of more than 30% in winter, which is encrusting coralline algae (*Lithothamnion*) and bladder wrack (*Fucus vesiculosus*) respectively.

Different species in the same area also have different variations in cover with seasonal changes. For example, both spiral wrack (*Fucus spiralis*) and toothed wrack (*Fucus serratus*) species in Killiedraughts region show a decreasing trend in average coverage, but Green Branched Weed (*Cladophoria rupestris*) has an increasing trend. For bladder wrack (*Fucus vesiculosus*), there is very little (less than 2%) or even no coverage in the St Abbs and Killiedraughts sites during the winter, but up to nearly 43% in Coldingham in the same period.

Discussion:

1. Drivers for differences in species richness in three sites

From the result 1, 2, 3 about the species richness, it can be assumed that in general the species of Coldingham and Killiedraughts is slightly richer than that of St Abbs. A possible reason for this is anthropogenic, as it has been shown in many countries and regions that boosted tourism can lead to a loss of biodiversity [19, 20]. Thus, an attempt is made to compare the tourism influx in these three sites. St Abbs has always attracted people as a diving and tourist destination for a long period. And after the film *Avengers: Endgame* (2019), both in the press [21] and in our interviews with staff at the visitor centre in St Abbs, it is clear that the St Abbs being as the New Asgard filming location, has brought more tourism flowing into the area. By comparison, the Coldingham and Killiedraughts area is relatively less well known. Generally, the more frequent number of tourism visits may have contributed to the overall lower species richness of the St Abbs than the other two sites.

On the other hand, species richness in a certain region is also related to many other natural and anthropogenic factors. For example, it has been shown that butterfly species richness in the north-western Mediterranean basin is related to factors such as climate and topography, vegetation structure and farmland and urban development. [22] For the three sites located within the BMR, differences in climate factors (temperature, precipitation etc.) and intertidal substrates (sandy or rocky), as well as the storms [23] are all likely to have influenced species richness.

2. Is there a seasonal change pattern of species richness?

According to results 1 and 2, both total species richness and faunal species richness show a pattern of increasing and then decreasing from summer to winter in all three regions. The report assumes that autumn provides more favourable conditions for the emergence of various faunal species and seaweeds than the other two seasons. However, this does not allow for a definite inference that there is a seasonal pattern of species richness. Some studies show that seasonal fluctuations in richness need to be supported by a large amount of data, preferably surveyed and analysed over several consecutive months of the year [24, 25]. The data used to analyse the BMR region are only available for three seasons in 2021 (lacking spring data) and only one transect was placed during the winter period, which would be less accurate compared to the other two seasons of data. Only by conducting more transect and quadrat surveys in the BMR area will more precise and credible seasonal change patterns be produced, which will consume more time and human resources.

3. Drivers for changes of species abundance

According to result 4 and 5, seasonal variation in the average number of faunal species and the average coverage of seaweed, which can be used to indicate species abundance (i.e. how many individuals of a single species), are analysed respectively. Unique abundance fluctuations can be found for various species within BMR, and the same species can have different abundance fluctuations in different areas. This can be related to a number of factors, such as whether the local climatic environment is favourable to the growth of opportunistic species of seaweeds, the effect of storms on the structure of species communities, rising sea temperatures, etc. As each species responds differently to specific environmental variables, if there is a need to investigate the patterns of species as they change seasonally, it is best to conduct correlation analyses of factors and species populations under controlled variables. [26] The study of species in the nature reserve can contribute to the further development of the implementation of the nature reserve.

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