The influence of macroalgal mats on seagrass beds in Dungarvan Bay, County Waterford, Ireland

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Abstract. The depletion in the seagrass population in Dungarvan Bay, County Waterford, Ireland, has become more evident. The dense growth of macroalgal mats that cover the existing seagrass beds is an indication that high seawater nutrient levels may be responsible for the proliferation of the macroalgae and consequent depletion of the seagrass beds. This research aimed to determine the impact of macroalgae on the seagrass beds and how local conditions in the environment relate to seagrass growth. Three different sites, comparing a healthy bed in Fenit, Ireland with beds at two sites that have been invaded by macroalgal mats in Dungarvan, were compared with the aim of determining the reason for the seagrass reductions in Dungarvan Bay. The macroalgal cover was estimated, and seawater nutrient levels, granulometry, and organic matter were analyzed. Seawater phosphate was higher at the two Dungarvan sites than at the Fenit site. The results suggested that the higher macroalgal cover, due to higher phosphate levels, may explain the decline of the seagrasses in Dungarvan in contrast to Fenit, where macroalgal cover is absent. In addition to this, the sediment composition was also found to have a potential negative impact on the decline of seagrass growth in one Dungarvan site where a higher proportion of the silt-clay fraction was present in the sediment.
Key Words: environmental impact, macroalgal mats, seagrass bed, sediment composition.

Introduction. Seagrasses represent an essential element in the marine environment. They provide critical ecological services to different marine habitats, such as nutrient cycling, sediment stabilization, improving water quality, and a crucial shelter and feeding area for many aquatic organisms (Orth et al 2006; Robertson & Savage 2021). However, seagrass decline globally has become a concern. Considered to be a result of human activity, the rate of decline has accelerated (Waycott et al 2009; Ambo-Rappe 2022). Many factors threaten the marine ecosystem and cause the loss of seagrasses. The most common factor is the increase in anthropogenic activity, which leads to sedimentation, global warming, nutrient runoff, fishing practices with aquaculture waste, algal blooms, and the increase in macroalgal mats (Waycott et al 2009).

Change in water quality is also considered to be a major cause of seagrass loss. Important organic compounds in the water such as nitrate, phosphorus and salinity must be of specific and in balanced amounts to enable seagrass to thrive (Salomonsen et al 1999; Xu et al 2016; Shields et al 2018). Otherwise, the plants are negatively affected, for instance, one of the significant effects that cause seagrass and other estuarine producers to disappear and be replaced by macroalgal mats is the increase in nitrogen loads (Holmquist 1997; Heck et al 2000; McGlathery 2001; Reyes et al 2022). Another critical factor that causes seagrasses to decline is the existence of marine plants at the sediment-water interface. A high organic matter and nutrient loading near the seagrass area results in accumulating this input into the sediment. In addition, organic matter leads to the presence of macroalgae, which reduce the amount of oxygen and light that reaches deeper sediment surfaces (Terrados et al 1999; Burdige & Zimmerman 2002).

In Ireland, some seagrass beds had a significant decline in the 1930s due to wasting disease (Lynn 1936). The Irish Environmental Protection Agency (EPA) also stated an increase of nutrients along the southeast Irish coast due to human activity, affecting the quality of seawater in many coastal areas. This nutrient enrichment contributes to seagrass reduction and the growth of algae mats along Irish coasts (Jessopp et al 2013). This decline of seagrass continues, though some EPA legislation is in place (Gittings & O'Donoghue 2012). One of the geographic locations that were the subject of the current research is Dungarvan Bay which is located to the east of Cork city. *Zostera marina* and *Zostera noltii* were the most prevalent popular seagrass found in this area (Guiry & Kilty 1972), and the seagrass beds in Dungarvan have decreased since shellfish aquaculture was developed (Gittings & O'Donoghue 2012), though the usual link between aquaculture and the reduction and extinction of *Zostera* beds has been suggested rather than proven, with no tested mechanism to explain the reduction.

The research objectives aimed to determine the impact of macroalgae on the seagrass beds and how local environmental conditions relate to seagrass growth.

Material and Method

Study areas. The study areas were in the southwest of Ireland. The surveys were conducted in three sites: two in Dungarvan, County Waterford on the south coast, and one in Fenit, County Kerry on the west coast. The surveys period was 1 May to 31 July 2017. Currently, the study areas are still available for related research. The location of the sites was: Dungarvan (A) at 52.0820°N - 7.6240°W and Dungarvan (B) at 52.0699°N - 7.6064°W, both in County Waterford, which featured varying amounts of macroalgal mats in the *Zostera* beds. The third site in Fenit, County Kerry, was located at 52°16'37 N 9°51'29 W and was selected as an area with a large *Zostera* bed without algal mats. The *Zostera* beds at both locations were sheltered from the open ocean (Figure 1).

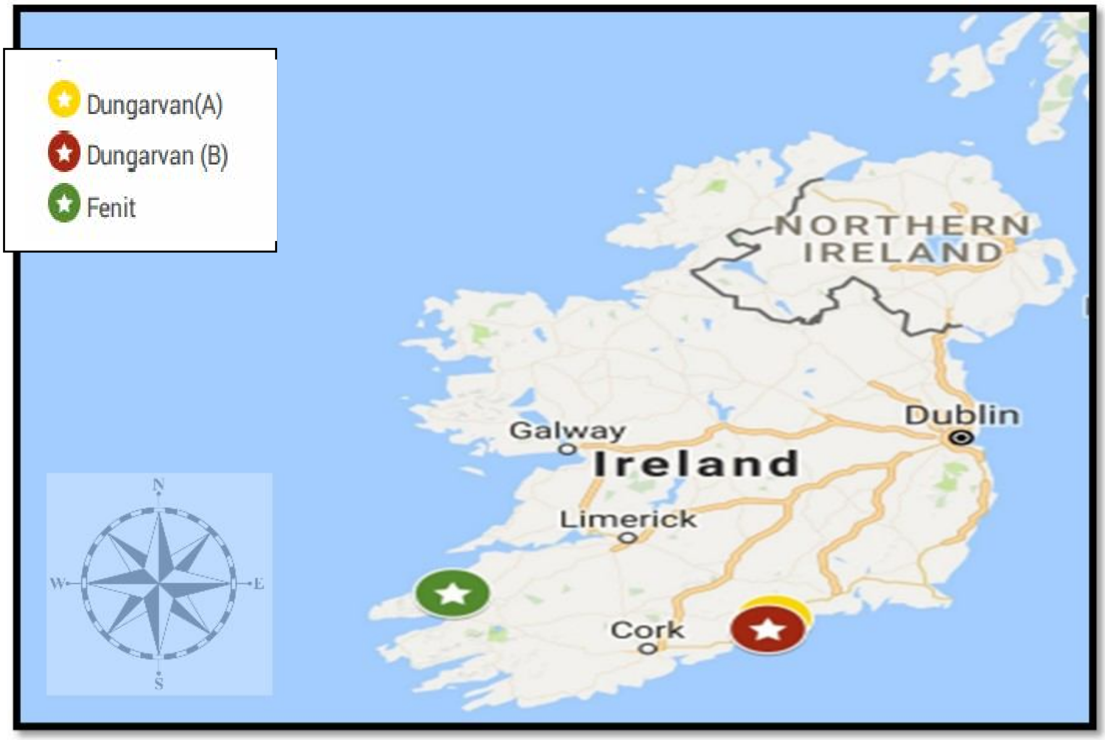


Figure 1. The study area of seagrass habitats in the southwest of Ireland *Zostera marina* in Dungarvan(A); *Z. noltii* in Dungarvan (B), and *Z. marina* and *Z. noltii* in Fenit.

Macroalgae mat cover analyses. The macroalgal surveys were conducted on Dungarvan (A) on 12/July/2017 and Dungarvan (B) on 11/July/2017, and the Fenit site on the 8/June/2017 to measure the percentage of macroalgae that covered seagrasses.

The percentage cover of seagrass, sediment cover, and the macroalgal cover was estimated by using a quadrat (0.5 m x 0.5 m). Four transects were established in each site using the measuring tape across a 60 m distance from just above the upper limit of each *Zostera* bed to the lower level of the *Zostera* bed (or as far as was possible safely) The distances (in meters) between sampling intervals along the tape measure were established by a random number generator function in Excel (Microsoft, USA). The direction of transects was established by a line from the high tide level at right angles to the low tide level.

Water quality analyses. The water samples were collected as the rising tide covered the *Zostera* beds. Furthermore, three samples compared oceanic seawater nutrient levels with those in the *Zostera* beds. The water quality analysis included nitrate (NO_3), phosphate (PO_4^{3-}) and salinity. The concentration of nitrate (NO_3) and phosphate (PO_4^{3-}) in seawater samples were determined following the protocols outlined by the HACH (DR 2008 spectrophotometer). Ascorbic acid digestion was carried out for phosphate detection using the HACH PhosVer 3 reagent powder. Phosphate concentrations were read in mg L^{-1} at 880 nm wavelength on a spectrophotometer (HACH Method 8190). A Cadmium Reduction method was used to detect the nitrate value using the HACH NitraVar5 Nitrate reagent powder. Nitrate concentrations were read in mg L^{-1} at 400 nm on a spectrophotometer (HACH Method 8171). The salinity was sampled by a handheld refractometer (ATAGO ATC-S/MILL-E, Salinity 0~100‰) measuring the liquid's refractive index.

Sediments sample analyses. The core samples were taken with Core Sediment Samplers by pushing them vertically downward into the sediment. A smaller sample (10 cm length, 0.5 cm diameter) was also collected at each transect interval for organic matter analysis in the sediments at a point adjacent to the larger core sediment sample. From the transect, seven cores for granulometry analysis and seven cores for organic matter analysis were collected at 10 m intervals along the transect. Seven sediment core samples were taken from Dungarvan (B) and Fenit while six core samples were taken from Dungarvan (A). The cores samples were numbered sequentially from 0 to 60 m.

Then the dried sediments were separated into silt/clay, fine and very fine sand, medium and coarse sand fractions. The results of all sediments samples were recorded in Microsoft Excel 2015 for the ANOVA test for post hoc comparisons of mean values. $P < 0.05$ was considered to be significant. The grain size and organic matter of sediment were determined by using the Holme & McIntyre (1971) method (Table 1).

Table 1

Grain size classes from silt to coarse

Size class	*Grain size (µm)*
Coarse sand	500-2000
Medium sand	250-500
Silt/clay	< 63

Source: Holme & McIntyre (1971).

Organic matter content of sediments analyses. The sediments collected with the smaller corer (10 cm length and 0.5 cm diameter) were stored in plastic bags in a freezer for two weeks. After removal from the freezer, each sample was placed in the metal container and dried at 60^{o}C for 24 h in the Memmert oven. On the following day, using a METTLER TOLEDO AT201 model, weighing scales with an accuracy of 0.0001 g, approximately one gram of each dried sediment sample was weighed into a ceramic crucible and heated at 450^{o}C for 4 hours in a Carbolite CWF 1300 Muffle Furnace. The same sediment samples were considered again after the organic carbon matter had been combusted to measure the sediment after the organic carbon matter was burned off. The organic carbon content was calculated as the initial weight – final weight/100.

Results. Seawater nutrient analysis indicated that higher levels of phosphate in the Dungarvan Bay *Zostera* beds, by comparison with the Fenit seagrass bed and oceanic seawater, are likely to be responsible for the development of the dense algal mats found in Dungarvan Bay (Table 2). Macroalgae covered the seagrass in Dungarvan (A) with more than 70% cover, while in Dungarvan (B), the algae covered the seagrass with 50% but in Fenit, macroalgae were almost absent. In Dungarvan (A), of 46 quadrats sampled in four transects, 36 were covered by nearly 100% macroalgae. In contrast, in Dungarvan (B), 40 quadrats sampled from all four transects, only 15 quadrats were seen to have more than 50% macroalgae-covered seagrass. In contrast, in Fenit of 29 quadrats sampled in four transects, only 1% of macroalgae covered seagrass in one quadrat (Figure 2). In addition, the sediment at Dungarvan (A) is not suitable for the growth of seagrass because of its high silt-clay content, which forms a visible barrier to rhizome burial within the substrate, whereas the sediments at Dungarvan (B) and Fenit, being sandier, allow roots and rhizomes to grow in the sand and are suitable for the growth of seagrass (Figure 3). Organic matter contents of the sediments were similar in Dungarvan (A) and Fenit and were slightly lower in Dungarvan (B) (Table 3).

Table 2

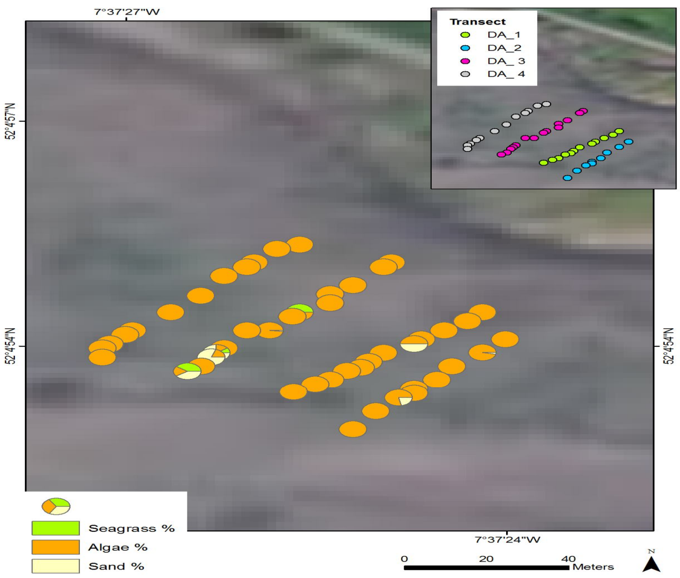
Water nutrient analysis of three samples study areas from the seagrass beds and the ocean water

Site	*PO_4^{3-} (mg L^{-1})*	*NO_3 (mg L^{-1})*	*Salinity (‰)*
Dungarvan (A)	0.63±0.01	0.62±0.2	41±1.7
Dungarvan (B)	0.80±0.18	0.50±0.13	39±2.4
Dungarvan ocean water	0.30±0.08	0.93±0.32	37±0
Fenit	0.04±0.16	1.5±0.16	37±2.2
Fenit ocean water	0.04±0.02	1.5±0.6	35±0

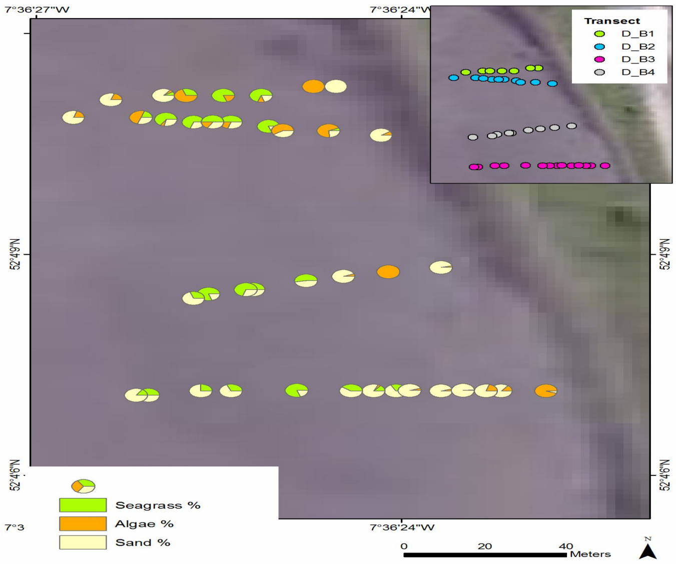
Table 3

The organic matter carbon content of sediments at 10 m intervals along single transects each three study sites

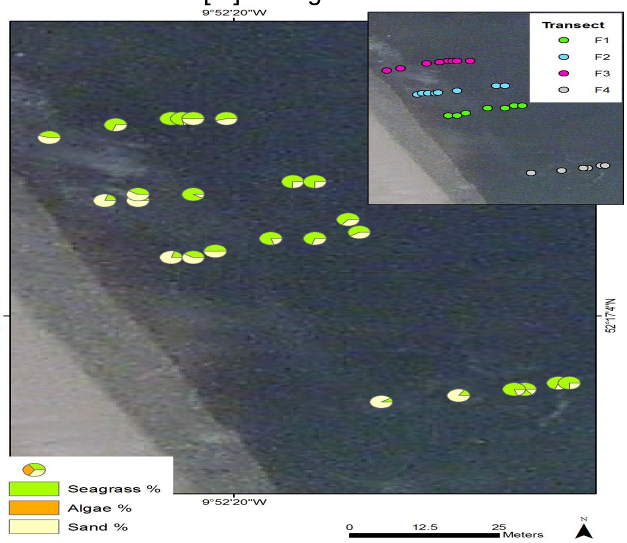
Site	*Organic matter (%)*
Dungarvan (A)	3.25±1.03
Dungarvan (B)	1.99±1.72
Fenit	3.07±1.93



[A] Dungarvan



[B] Dungarvan



[C] Fenit

Figure 2. Estimated percentage cover of seagrass, algal mats, and sediments in [A] Dungarvan, [B] Dungarvan, [C] Fenit in four transect in all sites using 50 x 50 cm quadrats (June-July/2017).

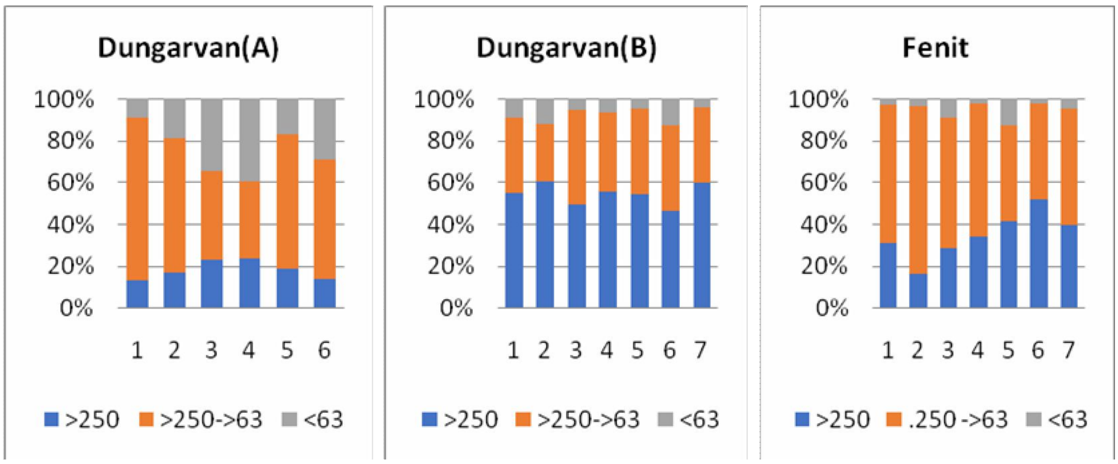


Figure 3. The percentage of sediments composition fractions which were > 250 μm, between 250-63 μm and < 63 μm composition fraction from the three study areas combined.

Discussion. In recent years, two *Zostera* beds in Dungarvan Bay have developed dense floating algal mats that cover much of the *Zostera* beds at low tide and threaten the existence of these seagrass beds. A similar *Zostera* bed in Fenit has not developed such algal mats. There was no significant difference between the seawater nitrate levels at Dungarvan, Fenit, or their related oceanic water sites. The importance of phosphate as opposed to nitrate in the formation of algal mats has not been reported previously. The extent of one of the seagrass beds in Dungarvan, measured in 1970 and 2013, showed a marked reduction. It can also be seen from the Guiry & Kilty (1972) map that there were at least three other beds that have since disappeared (Gittings & O'Donoghue 2012).

In our study, the macroalgal cover was high in the Dungarvan sites (up to 100%) but almost absent in Fenit. The negative influence of high masses of macroalgal covering on seagrass bed distribution has been widely reported (Valiela et al 1997; McGlathery 2001; Thomsen et al 2012). Also, Han & Liu (2014) have described the effect of macroalgae cover in different seagrass species growth, including *Z. marina*, as decreased seagrass function and reduction in shoot density. Compared to Malham et al (2009), which included sampling in Dungarvan, the phosphate and nitrate levels were relatively low, but the exact values of phosphate and nitrate were not given. However, by comparison with our study, the value of phosphate and nitrate in Dungarvan seawater has increased.

In our study, sediment fractions differed in Dungarvan (A) from those in Dungarvan (B) and Fenit. A negative effect of sediments' high organic carbon content has been reported (Hyland et al 2005). In this study, the mean values of organic matter content were varied across sites and ranged from 3.25% in Dungarvan (A) and 1.99% in Dungarvan (B) to 3.07% in Fenit. The absence of macroalgae mats and the high percentage of seagrass bed in Fenit, which had a relatively similar mean of organic content to that in Dungarvan (A), which had a high macroalgal cover and a lower percentage of seagrass cover, indicated that the organic carbon content was not the main responsible factor for the high percentage of macroalgal mats in both Dungarvan sites.

Conclusions. In this study, the results suggested that the higher macroalgal cover, because of higher phosphate levels, may explain the decline of the seagrasses in Dungarvan in contrast to Fenit, where macroalgal cover is absent. In addition to this, the composition of the sediment was also found to have a potential negative impact on the decline of seagrass growth in one Dungarvan site where a higher proportion of the silt-clay fraction was present in the sediment.

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Conflict of interest. The authors declare that there is no conflict of interest.

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