

Seagrass (*Zostera marina*) in the Firth of Forth, Scotland

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1.0. Introduction

Seagrass meadows are a globally significant ecosystem providing a myriad of important ecosystem services such as sequestering carbon, stabilising coastlines and supporting biodiversity¹. However, they are one of the most threatened ecosystems on the planet, declining at a rate of 7% per year². This can be attributed to poor water quality, direct disturbance and widespread disease. Project Seagrass are involved in a pilot project with WWF and Sky Ocean Rescue to restore 2ha of seagrass in Dale, West Wales. This report seeks to expand the restoration of the UK's seagrass meadows by identifying potential restoration sites in the Firth of Forth, Scotland as part of a collaborative seascape project, trialling the restoration of seagrass, oysters, blue mussels and horse mussels. The Firth of Forth stretches for 100km from Stirling to East Lothian and provides a wide range of estuarine habitats. The distribution of seagrass across the globe is largely unknown and understanding the historical and current distribution of seagrass is the first step to a successful restoration project.

Zostera marina may also be known as: seagrass, eelgrass, *Zostera angustifolia* (there is dispute over whether this may be a separate species), wigeon grass, sweet grass, bilearach (Gaelic), sweet seagrass, marlee, sedge or feur-mara (Gaelic). There is some confusion over whether *Zostera angustifolia* is a separate species from *Zostera marina* or is a phenotypic variant. For the purpose of this report, *Zostera angustifolia* will be treated as the same species as *Zostera marina* but the original species name on each record will be retained. *Z. marina* is a subtidal species found on sand, mud or gravel in sheltered waters down to 5m in depth. Leaves are typically up to 50cm in length and up to 10mm wide with rounded tips. The phenotypic variant (*Z. angustifolia*) can be found intertidally, has narrower leaves (~2mm) and is smaller (up to 30cm long)³.

2.0. Methods

To create an understanding of the historical and existing distribution of seagrass (*Zostera marina*), data was mined from a variety of sources. Local stakeholders, such as Scottish Natural Heritage (SNH) Firth of Forth office, SeaSearch Scotland, Royal Botanic Garden Edinburgh (RBGE) and local universities, were contacted to discuss any existing records of seagrass distribution in the Firth of Forth. Literature searches were also performed using key words/phrases including the various historical and current names given to seagrass and *Zostera marina*.

All collected records were divided according to time period (1800s, 1900s or 2000s) and shapefiles created from these records for use within QGIS (Version 3.10.0, 2018)⁴. Three maps of the Firth of Forth were created which represent each of these time periods.

3.0. *Zostera marina* records

3.1. Field Club Flora of the Lothians⁵

The Field Club Flora of the Lothians was produced by the Botanical Committee of the Edinburgh Natural History Society and was published in 1934. It states that the common name of *Zostera marina* is broad-leaved grasswrack and is found below the low water mark.

It may also be known as *Zostera angustifolia*. It was recorded in Aberlady, Leith and Granton.

3.2. Vegetation of Scotland⁶

The Vegetation of Scotland was written by J Burnett and was published in 1964. This book states that extensive seagrass beds were found on the mud flats below many Scottish salt marshes such as Aberlady Bay and Burntisland. However, no recent survey has been made during the time of publication, so the author is unsure if these populations still exist. It is suggested that *Z. angustifolia* is restricted to the extreme south east of Scotland.

3.3. Plant Life of Edinburgh and the Lothians⁷

Plant Life of Edinburgh and the Lothians was written by Smith *et al.* and published in 2002. It contains the findings of an extensive 20 year survey by the Botanical Society of Scotland. It states that the common name of *Zostera marina* is eelgrass and is found below the low water mark but is a rare and likely under-recorded species. It was found west of Blackness and west of Cramond in West Lothian in 2000; in Leith and Granton pre-1934 in Mid Lothian; in East Lothian, it was found in Gosford Bay and Aberlady Bay in 1970, and in Tynninghame Bay. It states that *Zostera angustifolia* is a separate but also rare species with the common name narrow-leaved eelgrass and may be found in intertidal mud. In west Lothian it has been found in the Carriden and Blackness areas but in deeper water than *Zostera noltii* with stream outflows; in Mid Lothian it has been found below low water mark in Leith and Granton pre 1934; in East Lothian, it was found in Craighelaw Bay and Aberlady Bay in 1991 but had declined markedly due to an algal bloom, and had also been found in Tynninghame Bay.

3.4. Wildflowers of Fife and Kinross: a concise checklist⁸

This book was published in 2002 by Fife Nature and is authored by George Ballantyne. Field work for the book started in 1970 and research, including investigating historical records, ceased by 2000. *Zostera* records have no date associated with them and therefore can only be placed at some time between 1970 and 2000. The author reports that it is uncertain whether *Z. marina* occurs in Fife but that *Z. angustifolia* has been found in Burntisland although is uncommon.

3.5. Royal Botanical Gardens of Edinburgh⁹

There are 10 records of *Z. marina* and 16 records of *Z. angustifolia* in the Royal Botanical Gardens of Edinburgh (RBGE) herbarium. The earliest record dates back to 1825 and is a specimen of *Z. marina* taken from Burntisland. The most recent record at RBGE is from 2000 and is a specimen of *Z. marina* from Blackness. These records show that *Z. marina* has been found at Aberlady Bay, Aberdour, Belhaven, Blackness, Burntisland, Craighelaw Point, Cramond, Gosford Bay, Kilspindie, Leith and Tynninghame between 1825 and 2000.

3.6. Marine Scotland

Marine Scotland Information⁹ is a Scottish government website for accessing information on the Scottish marine environment including maps of spatial data, datasets and statistics. The map of the Firth of Forth shows 30 records of *Z. marina/angustifolia*, one from 1994 and 29 from 2014-2018 (Table 1).

Table 1. *Zostera marina/angustifolia* records in the Firth of Forth from Marine Scotland Information. Map of the Firth of Forth shows 30 records of *Z. marina/angustifolia* from 1994-2018. Viewing layer “seagrass beds - *Zostera marina/angustifolia* beds on lower shore clean or muddy sand (SNH WMS)” in Firth of Forth. Survey 1 – 1994 MNCR north and east mainland Scotland lagoon survey; survey 2 - SEPA condition monitoring of intertidal seagrass communities in coastal waters using Water Framework Directive methods.

Location	Date	Determination	Count	Survey name	Data type	Accuracy
Culross	17/08/1994	Certain match/whole record	1	1	Point	OSMapUNK
Culross	13/08/2018	Certain	17	2	Point	GPS
Burntisland	27/08/2014	Certain	4	2	Point	GPS
Burntisland (from Kinghorn to Leith Docks)	27/08/2014	Certain	1.47 hectares of <i>Zostera marina/angustifolia</i>	2	Polygon	Extent interpretation from field survey and aerial imagery
Blackness	15/08/2018	Certain	5	2	Point	GPS
Carriden	13/08/2018	Certain	1	2	Point	GPS
Torry Bay	16/08/2018	Certain	1	2	Point	GPS

A Strategic Environmental Assessment report on Wild Seaweed Harvesting¹⁰ from 2016 was carried about by Marine Scotland. This report states that a small bed of seagrass may be found in the Forth estuary but does not state which species. They state that there is no evidence of seagrass harvesting in Scotland currently. However, the Firth of Forth is a localised area of concern in Scotland as having poorer water quality which can impact upon seagrass beds.

3.7. Scottish Environment Protection Agency

The angiosperm monitoring for the Water Framework Directive¹¹ (WFD) by the Scottish Environment Protection Agency (SEPA) included a seagrass survey for the Forth estuary in August 2014. The report states records of *Zostera* spp. in the Forth date back to 1863 but there is no spatial data. SEPA focused on the Forth estuary rather than the outer Firth and carried out the survey in August 2014. *Z. angustifolia* was only found at one station in Carriden bay. Only *Z. noltii* was found in Brucehaven, Blackness, Culross and Torry Bay.

3.8. Scottish Natural Heritage

Scottish Natural Heritage (SNH) review no. 22¹² was an investigation into the status of *Zostera* in Scottish coastal waters by Cleator in 1993. He noted that the distributions of *Z. angustifolia* and *Z. noltii* are similar. In the Firth of Forth, the most significant populations

were found along the southern shore of the Firth of Forth, near Dunbar, Aberlady and east of Bo'ness; north east Fife in the Eden estuary and at Tayport. The north shore only possess *Z. marina/angustifolia* records pre-1940 and no post-1940 records whilst the south shore contains both pre- and post-1940 records (Figure 1).

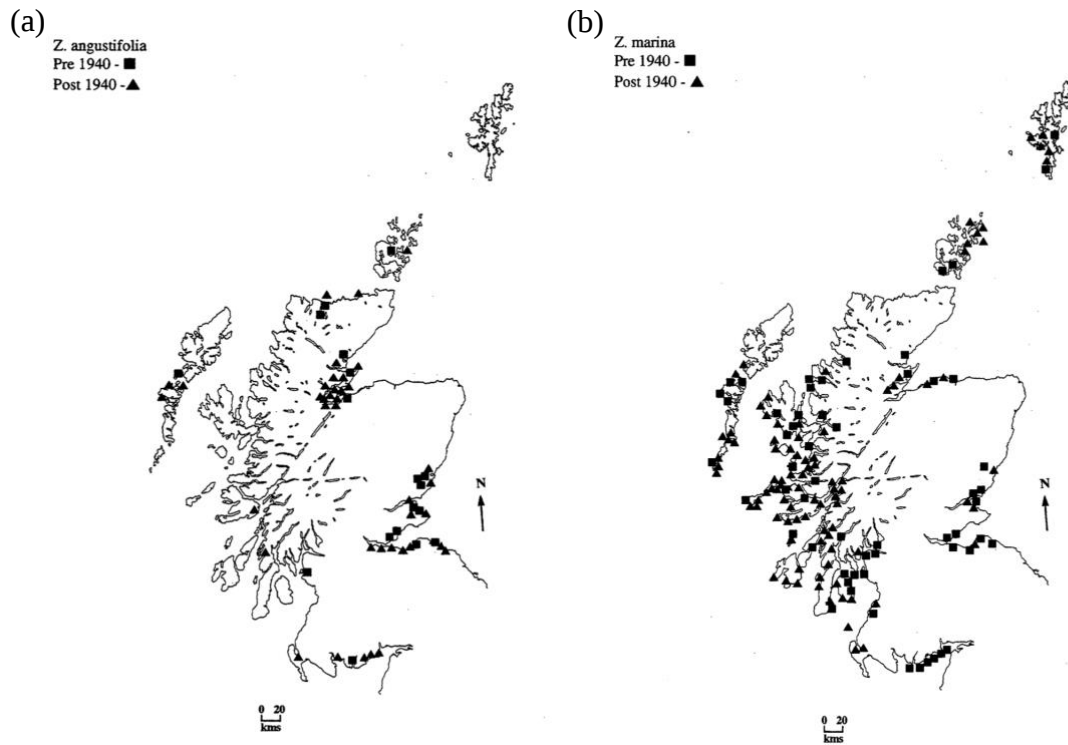


Figure 1. (a) Distribution of *Zostera angustifolia* and (b) *Zostera marina* in Scotland pre- and post-1940. Figure taken from Cleator (1993).

Cleator investigated records from Botanic Garden Edinburgh and other literature to assess the distribution of seagrass in Scotland. Findings for the Firth of Forth are depicted in Table 2.

Table 2. Records of *Zostera marina/angustifolia* in the Firth of Forth. Table adapted from Cleator (1993). SNH: Scottish Natural Heritage; BGE: Botanic Gardens Edinburgh.

Location	Species	Date	Comments	Source
Tynninghame (Belhaven Bay) NT6380	<i>Z. angustifolia</i>	1993	<i>Z. angustifolia</i> recorded from 1869	SNH BGE
Dunbar NT6278	<i>Z. angustifolia</i>	Recent	BGE record from 1966	SNH BGE
Aberlady	<i>Z. marina</i> <i>Z. angustifolia</i>	1939	A number of records from 1884	SNH BGE
Kilspindie	<i>Z. angustifolia</i>	1966	Records from 1884	BGE
Craigielaw point	<i>Z. angustifolia</i>	1977		BGE
Gosford Bay	<i>Z. marina</i>	1971	On mud	BGE
Black Rocks	<i>Z. marina</i>	1863	Almost certainly not there anymore	BGE
Leith, Edinburgh				
Blackness Bay NT0679	<i>Z. angustifolia</i>	Recent	Beds have expanded during the last 10 years	SNH
Carriden Bay NT0281	<i>Z. angustifolia</i>	Recent	There may be other species present	SNH
Burnt Island	<i>Z. angustifolia</i>	1874		BGE

3.9. SeagrassSpotter¹³

There is one record of *Zostera marina* from SeagrassSpotter in Fife from 2014.

3.10. Maria Potouroglou¹⁴

Maria Potouroglou conducted a PhD which included surveying the Firth of Forth for seagrass records. She found *Z. marina* at Hopetoun House and Blackness in 2014. Her project also included data from SNH where *Z. marina* was found in the upper midshore of Tyne Sands in 1992, in Dunbar (east of St. Baldreds Cradle) in 1992 and in the muddy bottom of an enclosed lagoon and the lower shore at Culross (Pond Cottage Pool) in 1994. Marias work was supported by the Natural Environment Research Council NE/K501207/1.

3.11. Heriot Watt University student papers

Students from the Heriot Watt University have been conducting surveys on seagrass in the Firth of Forth since 2011. This has amounted to more than 300 GPS coordinates, many of which correspond to the edges of a seagrass bed.

3.11.1. Zoutenbier (2011)¹⁵

Zoutenbier MSc report (2011) found *Z. angustifolia* in Blackness, Carriden, Burntisland, Aberlady and Kilspindie. A 2016 poster by Zoutenbier *et al.* presented at the 12th International Seagrass Biology Workshop estimated that there is <0.5ha of *Z. angustifolia* in the Firth, with beds at Burntisland and Tynninghame Bay, the latter found in rock pools. They state that the species is rare and should be a conservation priority.

3.11.2. Box (2013)¹⁶

Another MSc report by Box (2013) recorded *Z. angustifolia* in the Firth of Forth at Tynningham, Tynemouth and Carriden. It was noted that *Z. angustifolia* was more commonly found in standing water or drainage channels in sheltered areas such as bays or behind spits/raised sediment. This study mapped 32,636 m² of *Z. angustifolia* in the Firth of Forth, considerably more than Zoutenbier (2011), speculated to be a result of mapping methodology.

3.11.3. Fraser (2014)¹⁷

Fraser MSc report (2014) focused on the genetic analysis of *Z. marina* and *Z. angustifolia* and seagrass susceptibility to wasting disease. Specimens of *Z. angustifolia* were collected from Carriden and Belhaven Bay, Tynningham for this study. Additionally, RBGE herbarium Zosteraceae collection specimens were investigated by Fraser and Lyndon.

3.11.4. Finlay (2014)¹⁸

Another MSc report in 2014 by Finlay surveyed Kincardine Bridge, Culross, Torry Bay, Ironmill Bay, Brucehaven, Dalgety Bay, Burntisland, Carriden, Blackness, Cramond, Aberlady and Tynningham. Several small patches of *Z. angustifolia* (0.5m x 0.5m) were found at Culross on the shore edge of the most easterly bed. This presence was last recorded in 2004 and had been recorded as absent at this site in 2002, 2003, 2011 and 2013 by previous Heriot-Watt or SNH surveys. A 2003 SNH survey found *Z. angustifolia* in Torry Bay but has not been found there since. Five individual plants of *Z. angustifolia* was found at Burntisland in close proximity to each other. Four individual plants and three small scattered patches were found here in 2011 (sizes: 8m², 2.25m², 1.5m² respectively) between the middle of the beach and the headland on the west side of the bay. This indicates a loss of *Z. angustifolia* in this area between 2011 and 2014. Small patches were recorded in Burntisland in 2002 by SNH. Historical records imply a continuous presence of *Z. angustifolia* in Burntisland between 1825 (the earliest *Zostera* record in the Firth of Forth) and 1903, after which there is an absence until 2002. Finlay also recorded *Z. angustifolia* in channels in Carriden, the area of which appeared to increase between 2011 and 2014. Additionally, *Z. angustifolia* was found in rock pools at the east edge of Cramond, the first record since 2000. The highest abundance of *Z. angustifolia* was found on the back shore of Blackness Bay (approximately 79m²). Small channels running through a *Z. noltii* bed in Blackness Bay between the pier and the sandy area to the west contained individual *Z. angustifolia* plants. Six individual *Z. angustifolia* plants were also found in Aberlady. Furthermore, this report cited a number of unpublished records from the East Lothian Council in Aberlady (Figure 2). These show a total of 77 patches of *Z. angustifolia* in Aberlady Bay, 26 of which are considered to be large. The council surveyed *Z. angustifolia* in 2000 and found 129 plants in Kilspindie Bay, near the Peffer Burn, at the same location as those found in 1991. In 2014, the patches in Craigeilaw, Kings Kist, and south of the Peffer Burn were absent. Only six *Z. angustifolia* plants were found in Aberlady in 2014. *Z. angustifolia* was present in Craigeilaw in 1970, 1991 and 2002 but was absent in 2014.

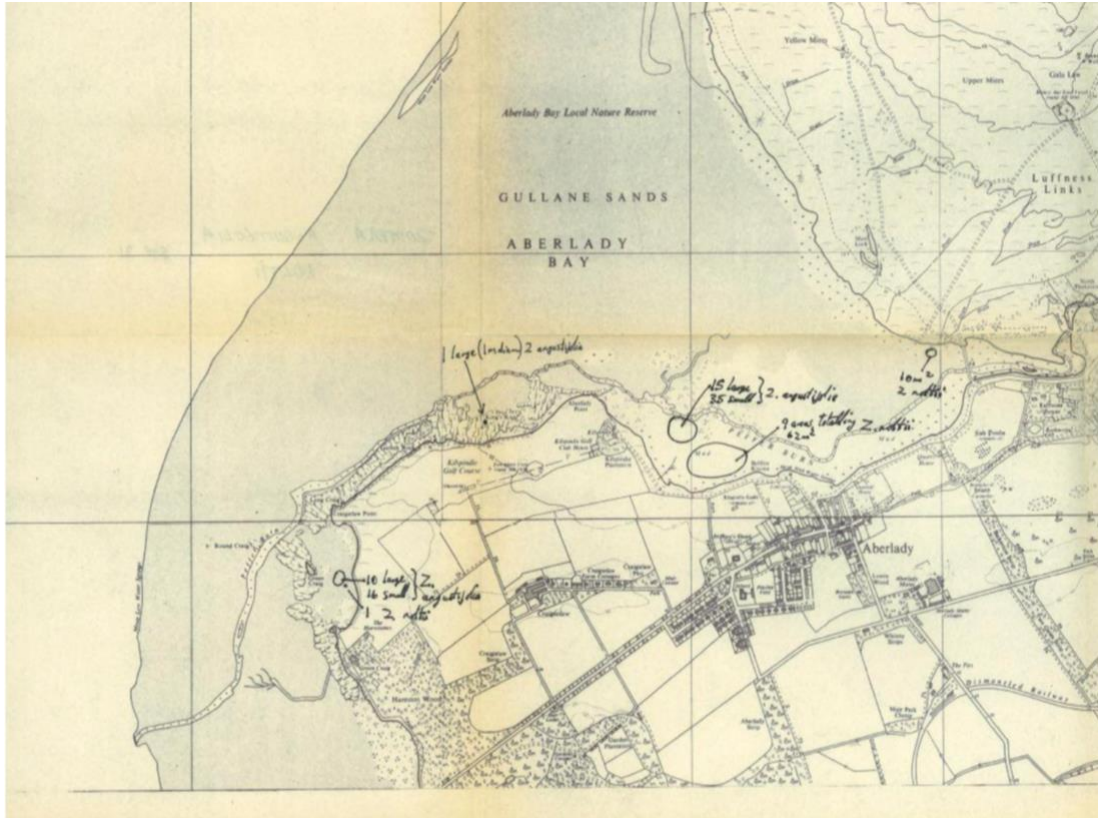


Figure 2. Distribution of *Zostera angustifolia* and *Z. noltii* in Aberlady 1991. There were 26 large and 51 small patches of *Z. angustifolia* found. Figure taken from Finlay (2014), referencing East Lothian Council (2000).

In Tynninghame, a mixed bed of *Z. noltii* and *Z. angustifolia* can be found on the north-east side of Sandy Hirst. *Z. angustifolia* can be found scattered in rock pools around the north shoreline and in shallow channels and pools at the edge of the main bed. In 1993, the East Lothian Council also recorded a single plant of *Z. angustifolia* in the southwest of Tynninghame and in 1998 a follow up survey found several patches. Finlay found that the highest abundance of *Z. angustifolia* in the Firth of Forth is at Carriden, Blackness and Tynninghame.

3.11.5. Wilson (2015)¹⁹

A BSc project by Wilson (2015) observed *Z. angustifolia* in channels throughout the shore of Carriden near the high-water mark. This study only focused on the density of *Z. noltii* beds but noted that *Z. angustifolia* was observed among these beds, although only noted its presence in Carriden.

3.11.6. Padron (2019)²⁰

A BSc project by Padron (2019) stated that the occurrence of *Z. angustifolia* in 2018 was found in similar areas to previous records but was found higher than its usual water margin in waterlogged areas.

3.12. National Biodiversity Network²¹

The National Biodiversity Network (NBN) Atlas is the UK's largest collection of freely available biodiversity data. In the Firth of Forth, they have aggregated 79 *Zostera marina* records dating back to 1825 and as recently as 2014. The Botanical Society of Britain and Ireland have provided 75 of these records whilst the Joint Nature Conservation Committee (JNCC) has provided four. Seven of these records have no date.

4.0. Seabirds of the Firth of Forth

It has been estimated that the Firth of Forth supports over 20,000 seabird breeding colonies¹⁰. Many of these will be reliant on seagrass either as a direct food source (for example, Wigeon, *Anas penelope*) or feed on prey species that utilise seagrass as a nursery ground or habitat, such as mussels and herring. This includes both breeding and non-breeding populations of seabird that may be sensitive to the harvesting of seaweed or seagrass (Table 3).

Table 3. Seabird species in the Firth of Forth which are sensitive to the harvesting of seagrass or seaweed and their association with seagrass. There are 16 species of seabird, seven of which are breeding colonies, in the Firth of Forth that rely either directly or indirectly on seagrass meadows. Species of seabird sensitive to seaweed/seagrass harvesting taken from Marine Scotland¹⁰.

Species	Breeding/non-breeding colony	Seagrass association	Source
Cormorant (<i>Phalacrocorax carbo</i>)	Breeding	There is a close relationship between the presence of swimming and roosting beds of <i>P. carbo</i> and the presence of seagrass. Cormorants are more likely to visit estuarine habitats with seagrass present likely due to the abundant species of prey that seagrass beds support.	Dorfman and Kingsford (2001) ²⁵
Eider (<i>Somateria mollissima</i>)	Non-breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰
Guillemot (<i>Uria aalge</i>)	Breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰
Herring gull (<i>Larus argentatus</i>)	Breeding	Feeds almost exclusively on large shore crabs, high densities of which are found among seagrass beds.	Thiel and Dervedde (1994) ²⁶
Lesser black-backed gull (<i>Larus fuscus</i>)	Breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰
Long-tailed duck (<i>Clangula hyemalis</i>)	Non-breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰
Mallard (<i>Anas platyrhynchos</i>)	Non-breeding	Wintering area and direct grazing of seagrass beds	Borum <i>et al.</i> (2004) ²⁷
Puffin (<i>Fratercula arctica</i>)	Breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰
Razorbill (<i>Alca torda</i>)	Breeding	Feeds on pipefish which live within seagrass habitats	Kleiber <i>et al.</i> (2011) ²⁸
Red breasted merganser (<i>Mergus serrator</i>)	Non-breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰
Red-throated diver (<i>Gavia stellata</i>)	Non-breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰
Scaup (<i>Aythya marila</i>)	Non-breeding	Forage in seagrass	Menning <i>et al.</i> (2020)
Shag (<i>Phalacrocorax aristotelis</i>)	Breeding	Prefer to fish above or within seagrass meadows and presence of seagrass contributes to breeding success	Morat <i>et al.</i> (2014) ²⁹ Cardona <i>et al.</i> (2007) ³⁰
Velvet scoter (<i>Melanitta fusca</i>)	Non-breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰
Wigeon (<i>Anas penelope</i>)	Non-breeding	Wintering area, direct grazing of seagrass beds and main winter food source	Borum <i>et al.</i> (2004) ²⁷
Common scoter (<i>Melanitta nigra</i>)	Non-breeding	Indirectly benefit from seagrass meadows due to prey species utilising seagrass as a habitat	Marine Scotland (2016) ¹⁰

5.0. Threats

The Firth of Forth is a heavily developed area, with sewage works, residential areas, farmland and railways all situated on the coast. By the 1990s, more than 50% of the intertidal region had been claimed for agriculture, harbours and industrial development²³. This damages existing seagrass habitat and further reduces the potential sites for seagrass beds. In the late 1990s, algal blooms were cited to have caused large declines in seagrass cover⁷. The construction of the Forth bridges in 1890, 1964, 2008 and 2017 and the regular dredging of the Forth entrance to allow for vessel access is estimated to have caused considerable disturbance to coastal habitats, including seagrass beds¹⁸. Furthermore, deforestation in the uplands which increases soil erosion causing increased turbidity is speculated to be considerably more acute in the Firth of Forth¹² and high turbidity has restricted the distribution of *Z. marina* to intertidal regions¹⁵. The tributaries of the Forth estuary transport agricultural pollutants into the Firth of Forth, increasing nutrient concentrations and the potential for algal blooms²². The discharge of industrial effluents is known to occur in areas of the Firth of Forth which has been cited as an area of concern for poor water quality¹⁰. Additionally, bait digging is a significant threat to seagrass²⁴ and occurs at a commercial scale in Burntisland¹⁸. The Firth of Forth now contains many protected areas such as Special Protection Area (SPAs), Special Area of Conservation (SAC), Site of Special Scientific Interest (SSSIs) and a Ramsar site which has aided in reducing the rate of loss.

6.0. Timeline of *Zostera marina* in the Firth of Forth

The top three most common reported sites of *Zostera marina* in the Firth of Forth are Aberlady, Tynninghame and Burntisland. The most common area reported to contain *Z. marina* is Aberlady, which has been recorded in 20 out of a reported 50 individual years from 1823 to 2018 (Figure 6). Aberlady is one of the earliest reported records in 1832 and was last recorded in 2014. The earliest record of *Z. marina* is from 1823 at Burntisland and was also recorded most recently in 2018. The earliest records of *Zostera* in the Firth of Forth are of *Z. marina* in 1825, suggesting that this species colonised the Firth of Forth before *Z. noltii*, the earliest record of which appears to be 1884 (RBGE herbarium).

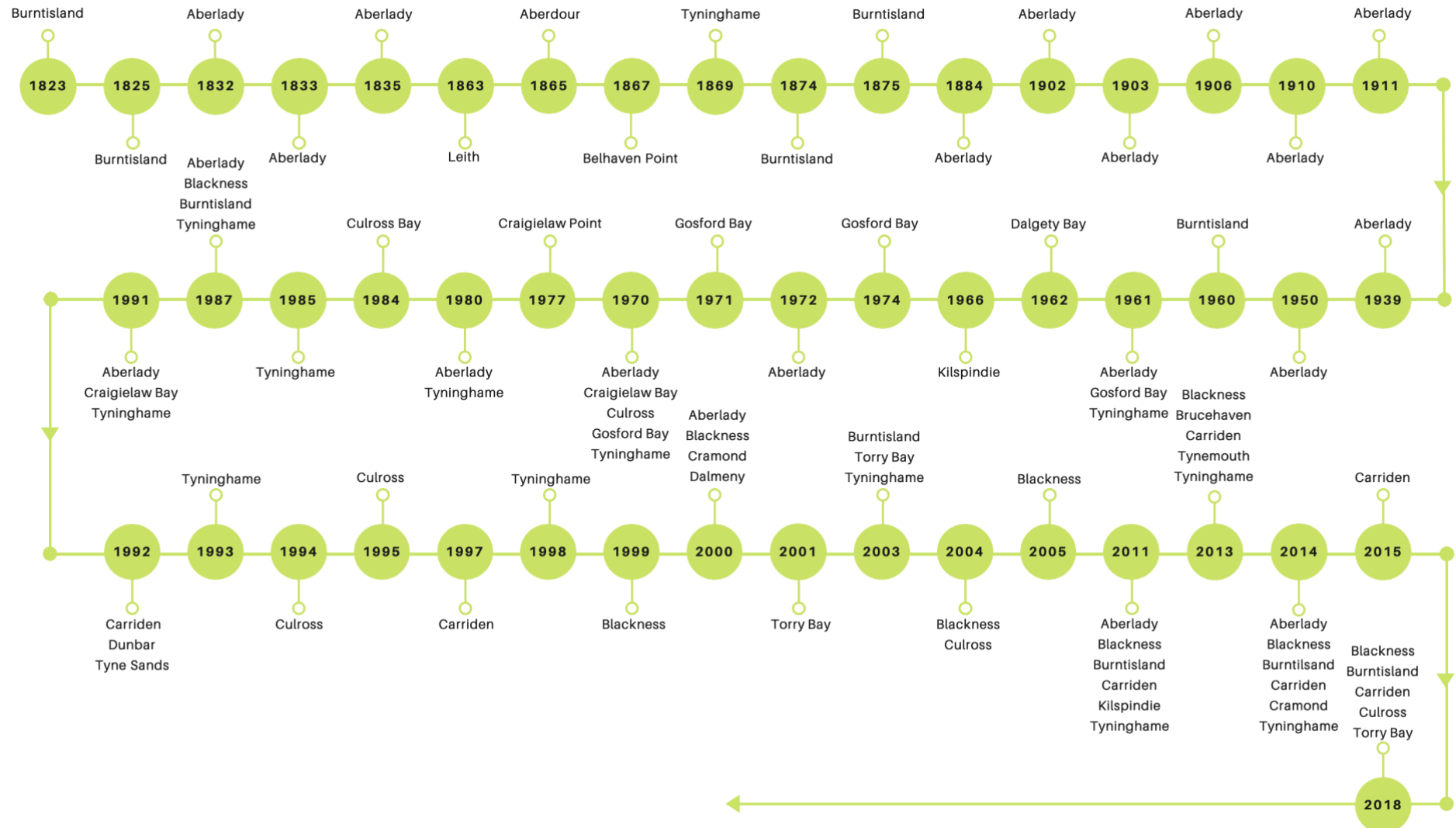


Figure 6. Timeline of *Zostera marina* records in the Firth of Forth. Between 1823 and 2018, there are 50 individual years which contain *Z. marina* records. Only records which had an exact year, rather than an estimated year, recorded are included.

6.1. 1800s records

There are few records from the 1800s on the presence of *Zostera marina* (Figure 3). There are 8 records on the north shore (Burntisland and Aberdour) and 9 on the south shore (Leith, Aberlady and Tynninghame). The earliest record is from 1823 at Burntisland (Royal Botanic Gardens Edinburgh record).

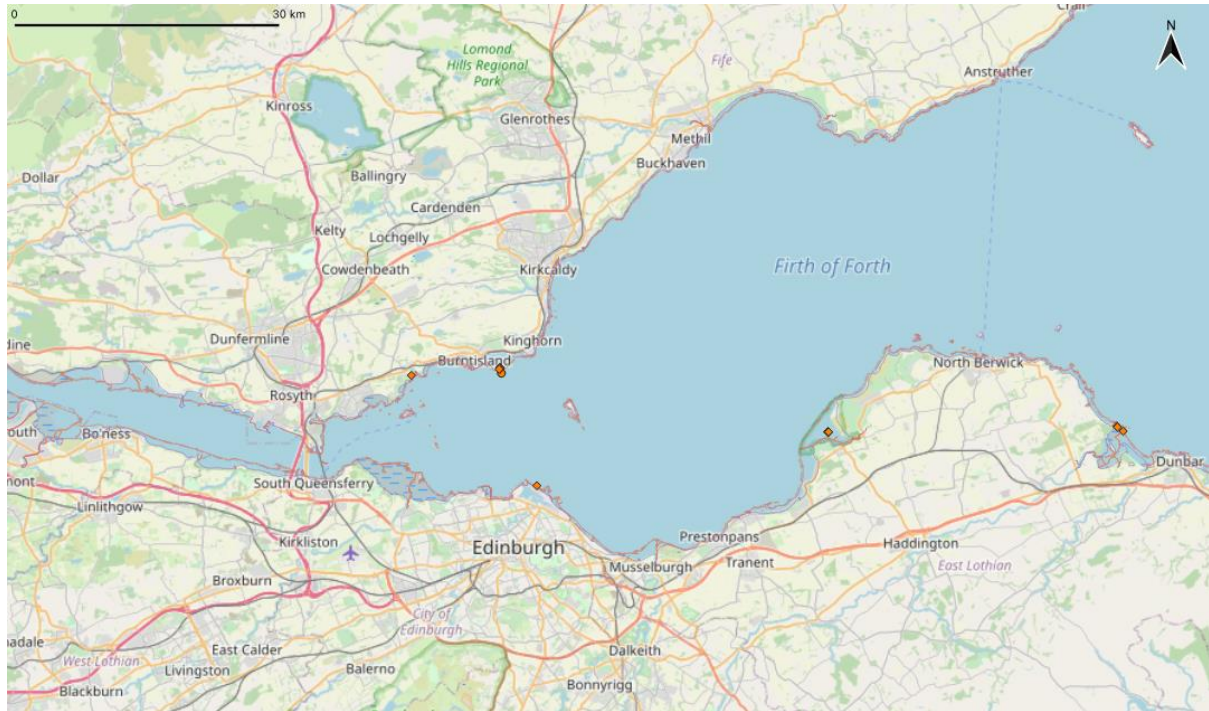


Figure 3. Recorded distribution of *Zostera marina* in the Firth of Forth in 1800s. There are 17 records in the 1800s. Circular points represent exact location (GPS coordinates were provided); triangular points represent estimated location (GPS coordinates were not provided).

6.2. 1900s records

There are 92 records of *Z. marina* in the 1900s. In this time period, *Z. marina* was found at Aberlady, Blackness, Burntisland, Carriden, Craigielaw, Culross, Dunbar, Gosford Bay, Granton, Kilspindie, Leith, Tyne Sands and Tynninghame (Figure 4).

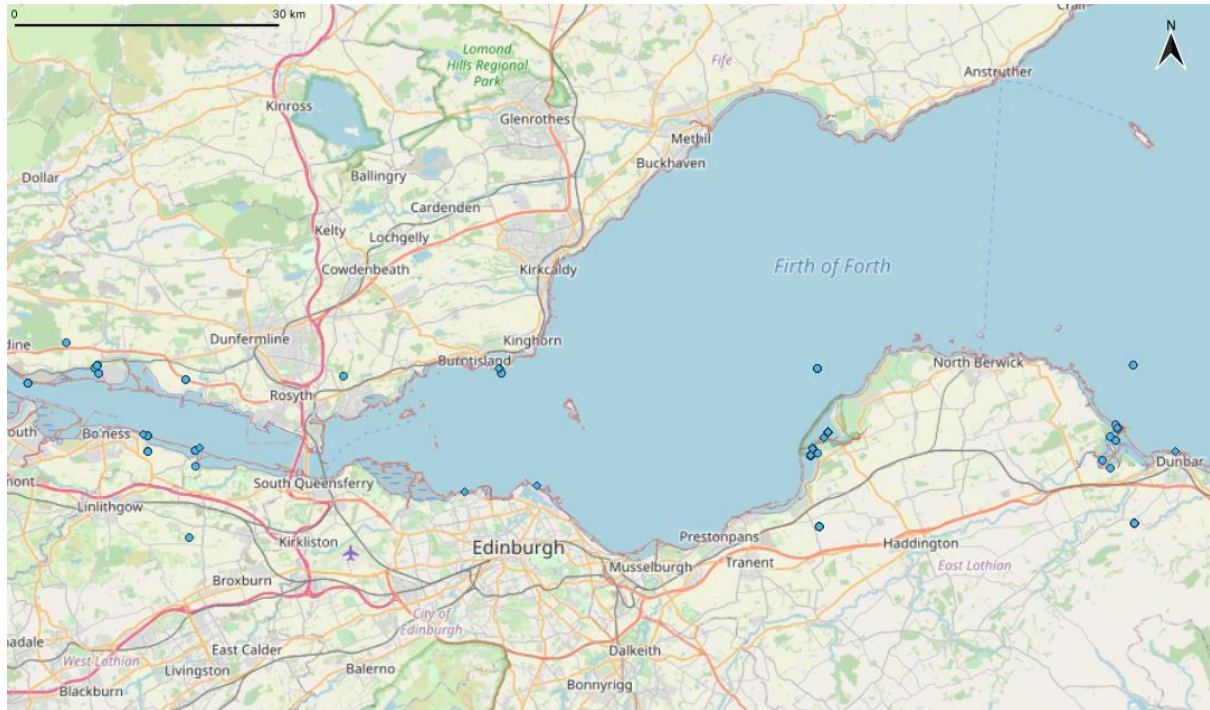


Figure 4. Recorded distribution of *Zostera marina* in the Firth of Forth in 1900s. There are 92 records in the 1900s. Circular points represent exact location (GPS coordinates were provided); triangular points represent estimated location (GPS coordinates were not provided).

6.3. 2000s records

Between 2000-2018, there have been 402 records of *Z. marina* in the Firth of Forth. However, many of these points correspond to the edge of a seagrass bed. For example, approximately 200 of these records correspond to the edge of a bed in Tynninghame, recorded by MSc student Finlay (2014). In this time period, *Z. marina* was found in Aberlady, Blackness, Brucehaven, Burntisland, Carriden, Cramond, Culross, Dalmeny, Fife, Torry Bay and Tynninghame (Figure 5).

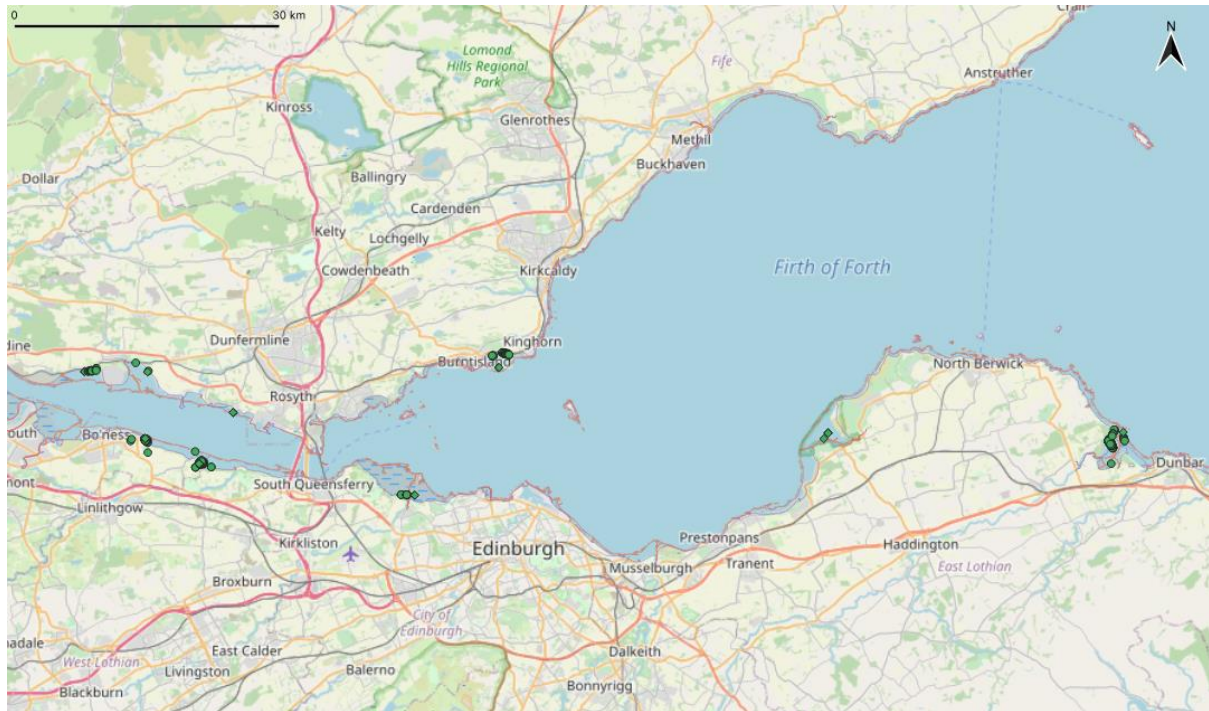


Figure 5. Recorded distribution of *Zostera marina* in the Firth of Forth in 2000s. There are 402 records in the 2000s, however, many points correspond to the edge of a seagrass bed and not to the location of a single bed. Circular points represent exact location (GPS coordinates were provided); triangular points represent estimated location (GPS coordinates were not provided).

All records mentioned in this report depicting the distribution of *Z. marina* in the Firth of Forth over time are available as supplementary data.

7.0. References

- ¹ Cullen-Unsworth, L. and Unsworth, R. (2013). Seagrass Meadows, Ecosystem Services, and Sustainability. *Environment: Science and Policy for Sustainable Development*, 55(3):14-28.
- ² Waycott, M., Duarte, C., Carruthers, T., Orth, R., Dennison, W., Olyarnik, S., ... Williams, S. (2009). Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences*, 106(30):12377-12381.
- ³ D'Avack, E., Tyler-Walters, H., Wilding, C., Garrard, S.M. (2019). [*Zostera (Zostera) marina*] beds on lower shore or infralittoral clean or muddy sand. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. Available from: <https://www.marlin.ac.uk/habitat/detail/257>
- ⁴ QGIS Development Team (2018). QGIS Geographic Information System. Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>
- ⁵ Martin, I., 1934. *Field-Club Flora Of The Lothians*. Edinburgh: W. Blackwood.
- ⁶ Burnett, J. (1964). The vegetation of Scotland (p. 114). Edinburgh: Oliver & Boyd.
- ⁷ Smith, P., Dixon, R., Cochrane, M. and Jeffree, C., 2002. *Plant Life Of Edinburgh And The Lothians*. Edinburgh: Edinburgh University Press.
- ⁸ RBGE Herbarium. *Zostera marina* / *angustifolia* specimen collection. Edinburgh: Royal Botanic Garden Edinburgh.
- ⁹ Marine Scotland Information (2020). Seagrass Beds - Intertidal sediments and Inshore and shelf subtidal sediments. Available at: <http://marine.gov.scot/information/seagrass-beds-intertidal-sediments-and-inshore-and-shelf-subtidal-sediments>
- ¹⁰ Marine Scotland (2016). Wild seaweed harvesting: strategic environmental assessment environmental report. Available at: <https://www.gov.scot/publications/wild-seaweed-harvesting-strategic-environmental-assessment-environmental-report/pages/20/>
- ¹¹ Scottish Environmental Protection Agency (2018). Angiosperm Monitoring for the EU Water Framework Directive 2013 – 2015: Baseline seagrass surveys of the Montrose Basin, Eden Estuary, Forth Estuary and Loch Ryan. Available at: https://www.sepa.org.uk/media/365890/angiosperm_baseline_seagrass_survey.pdf
- ¹² Cleator, B. (1993). The status of the genus *Zostera* in Scottish coastal waters. *SNH Review No. 22*. Edinburgh, Scottish Natural Heritage. ISSN: 1350 3111.
- ¹³ Seagrass Spotter sighting 166 by RFoster (2014). Available at: <https://seagrassspotter.org/sighting/166>
- ¹⁴ Potouroglou, M. (2014). Assessing the role of intertidal seagrasses as coastal carbon sinks in Scotland. (Thesis). Edinburgh Napier University. Available at: <http://researchrepository.napier.ac.uk/Output/975386>

- ¹⁵ Zoutenbier, R. (2011). Mapping the distribution of seagrass in the Firth of Forth, Assessing the sediment composition on a micro habitat scale and analysing the impact of climate change on seagrass distribution, *Msc Thesis, Heriot-Watt University Honours project*
- ¹⁶ Box, T.A. (2013). Mapping intertidal seagrass in the Forth and Eden and create an environmental envelope to aid monitoring efforts and assess sea level rise impacts. MSc Thesis. Heriot-Watt University, Edinburgh
- ¹⁷ Fraser, K, A (2014) An investigation of the taxonomic status of *Zostera angustifolia* Horn. (*Zosteraceae*) and its potential susceptibility to wasting disease pathogen *Labyrinthula* spp. (*Labyrinthulomycota*) in comparison to *Z. marina* L.: environmental variation or genetic differentiation? MSc Thesis. Heriot-Watt University, Edinburgh
- ¹⁸ Finlay, S. (2014). Mapping seagrass distribution in the Firth of Forth. MSc Thesis. Heriot-Watt University, Edinburgh.
- ¹⁹ Wilson, F. (2015). Winter changes in bed extent and density of the seagrass *Zostera noltei* in the Forth estuary. BSc Thesis. Heriot-Watt University, Edinburgh.
- ²⁰ Padron, D. (2019). Resurvey of Seagrass Density at the Carriden Bed in the Forth Estuary. BSc thesis. Heriot-Watt University, Edinburgh.
- ²¹ NBN Atlas (2020). UK's largest collection of biodiversity information. Available at: <https://nbnatlas.org/>
- ²² Scottish Environmental Protection Agency (2005). Eutrophication Assessment of Scottish Coastal, Estuarine and Inland Waters. Available at: http://www.sepa.org.uk/pdf/publications/technical/eutrophication_assessment_2005.pdf
- ²³ McLusky, D.S., Bryant, D.M., Elliott, M. (1992). The impact of land-claim on macrobenthos, fish and shorebirds on the Forth Estuary, eastern Scotland. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 2:211-222.
- ²⁴ Davison, D. and Hughes, D. (1998). *Zostera* Biotopes (Volume I): An overview of dynamics and sensitivity characteristics for conservation management of marine SAC's. Scottish Association for marine Science (SAMS).
- ²⁵ Dorfman, E. and Kingsford, M. (2001). Environmental determinants of distribution and foraging behaviour of cormorants (*Phalacrocorax* spp.) in temperate estuarine habitats. *Marine Biology*, **138**(1):1-10.
- ²⁶ Thiel, M. and Dornedde, T. (1994). Recruitment of shore crabs *Carcinus maenas* on tidal flats: Mussel clumps as an important refuge for juveniles. *Helgoländer Meeresuntersuchungen*, **48**(2-3):321-332.
- ²⁷ Borum, J., Duarte, C., Krause-Jensen, D. and Greve, T. (2004). *European seagrasses: an introduction to monitoring and management*. M & MS Project.

- ²⁸ Kleiber, D., Blight, L., Caldwell, I. and Vincent, A., 2010. The importance of seahorses and pipefishes in the diet of marine animals. *Reviews in Fish Biology and Fisheries*, **21**(2), pp.205-223.
- ²⁹ Morat, F., Mante, A., Drunat, E., Dabat, J., Bonhomme, P., Harmelin-Vivien, M. and Letourneur Y. (2014). Diet of Mediterranean European shag, *Phalacrocorax aristotelis desmarestii*, in a northwestern Mediterranean area: a competitor for local fisheries? *Scientific reports of the Port-Cros national park*. **28**:113-132
- ³⁰ Cardona, L., Revelles, M., Sales, M., Aguilar, A. and Borrell, A. (2007). Meadows of the seagrass *Posidonia oceanica* are a significant source of organic matter for adjoining ecosystems. *Marine Ecology Progress Series*, **335**:123-131

8.0. Supplementary information

Supplementary data accompanies this report and can be found alongside the online version.