Skomer MCZ Distribution & Abundance of *Zostera marina* in North Haven, Skomer, 2023

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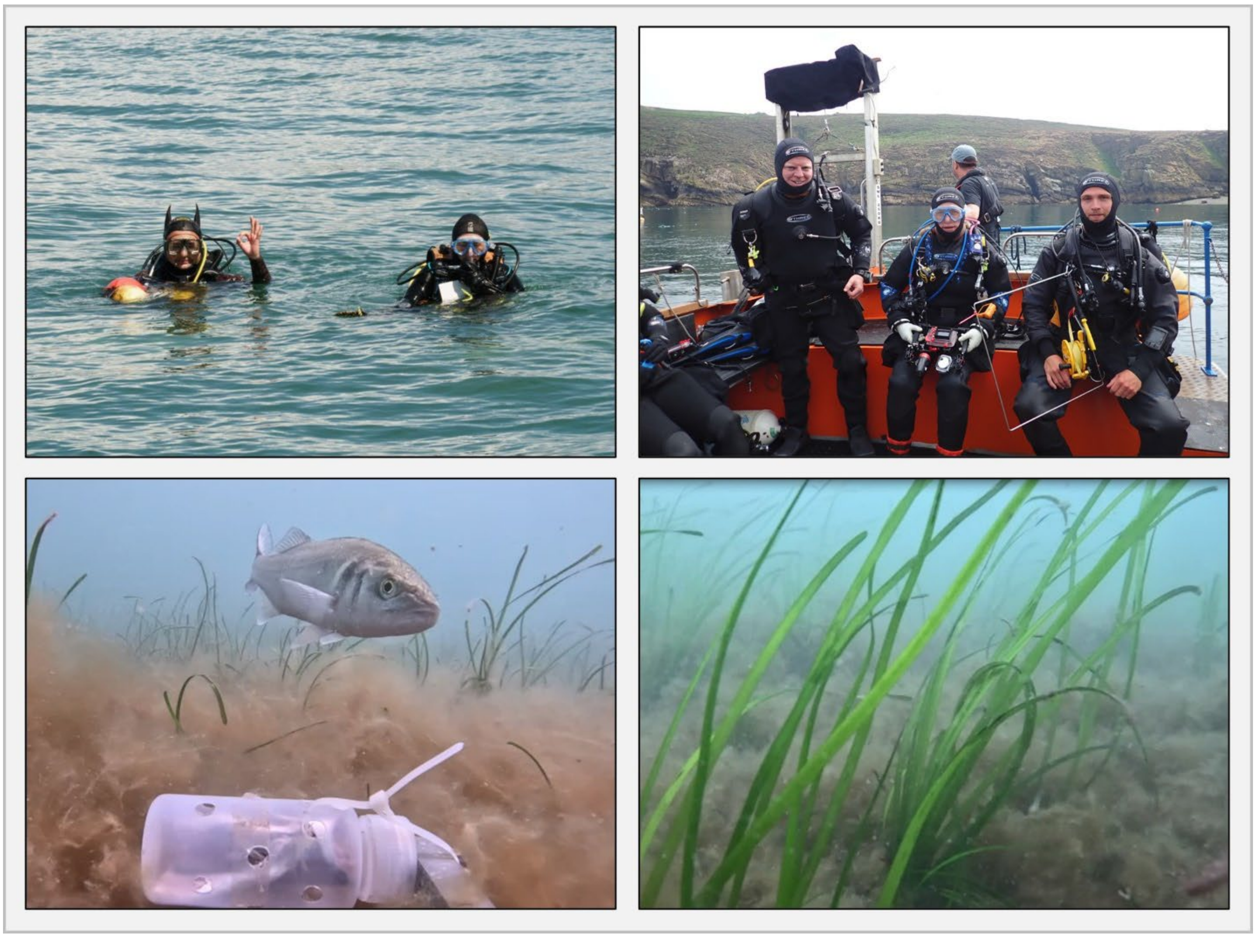

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Contents

List of Figures

List of Tables

Crynodeb Gweithredol

Arolygwyd y gwely o forwellt *Zostera marina* yn North Haven (sydd o fewn Parth Cadwraeth Morol Sgomer) gan grŵp o ddeifwyr gwirfoddol dros ddau benwythnos ym mis Mehefin a mis Gorffennaf 2023. Bu’r arolwg hwn yn ailadrodd dulliau arolygon blaenorol i amcangyfrif maint yr arwynebedd a dwysedd egin y gwely morwellt.

Cynhaliodd Tîm Asesu Pysgodfeydd CNC ail-arolygon gan ddefnyddio seinydd adlais ‘Biosonics DT-X split beam’ yn 2019, 2021 a 2022. Er nad oes modd eu cymharu'n uniongyrchol, mae canlyniadau arolwg y plymwyr yn rhoi canlyniadau tebyg i arolygon acwstig Biosonics. Mae'r dull acwstig o bell yn darparu dewis amgen effeithlon i'r arolwg deifwyr er mwyn cael canlyniadau blynyddol ar gyfer yr arwynebedd.

Mae canlyniadau 2023 yn dangos gostyngiad o 2.3% yn yr arwynebedd a gofnodwyd ers yr arolwg blaenorol (8367m^2 o gymharu â 8567.6m^2 yn 2018). Bu cynnydd bychan o ran dwysedd yr egin ar draws y gwely (mae nifer yr egin fesul m^2 wedi cynyddu o 42.4 egin / m^2 yn 2018 i 47.4 egin / m^2 yn 2023). Mae dwysedd yr egin yn dal i gynyddu ers y cyfraddau isel yn 2014, ac mae 2023 yn dangos y cofnodion uchaf hyd yma o ran dwysedd cyfartalog yr egin.

Roedd twf helaeth o algâu brown ffilamentaidd ar draws y gwely morwellt yn amharu ar y gwaith arolygu ond mae’n ymddangos nad yw wedi cael effaith negyddol ar ddwysedd yr egin.

Gosodwyd system camera fideo tanddwr o bell yn y gwely *Zostera* ar 16 achlysur, rhwng mis Mai 2023 a mis Ionawr 2024, er mwyn asesu cyflwr y gwely morwellt a chofnodi ffawna symudol.

Mae targedau cynllun rheoli Parth Cadwraeth Morol Sgomer ar gyfer y boblogaeth *Z. marina* yn North Haven wedi'u cyrraedd o ran maint a dwysedd yr egin. Mae'r nodwedd mewn cyflwr ffafriol.

Executive summary

The *Zostera marina* (seagrass) bed in North Haven (situated within the Skomer MCZ) was surveyed by a group of volunteer divers over two weekends in June and July 2023. This survey repeated the methods of previous surveys to estimate the area of extent and average shoot density of the seagrass bed.

NRW Fisheries Assessment Team conducted repeat surveys using a Biosonics DT-X split beam echo sounder in 2019, 2021 and 2022. The diver survey results, whilst not directly comparable, give similar results to the Biosonics acoustic surveys. The remote acoustic method provides an efficient alternative to the diver survey for obtaining annual results for area of extent.

The 2023 results show a 2.3% decrease in area of extent recorded since the previous survey (8367m^2 compared to 8567.6 m^2 in 2018). There has been a slight increase in shoot density across the bed (number of shoots per m^2 has increased from 42.4 shoots / m^2 in 2018 to 47.4 shoots / m^2 in 2023). The shoot density continues to increase from the low counts in 2014, with 2023 having the highest average shoot density recorded so far.

Extensive growth of filamentous brown algae across the seagrass bed hampered surveying but does not appear to have had a negative effect on shoot density.

A remote underwater video camera system was deployed within the *Zostera* bed on 16 occasions, between May 2023 and January 2024, to assess the condition of the seagrass bed and record mobile fauna.

The Skomer MCZ management plan targets for the population of *Z. marina* in North Haven have been met for both extent and shoot density. The feature is in favourable condition.

1 Introduction

1.1 Seagrass beds

There are two species of true seagrass in the UK; *Zostera marina* (eelgrass), found typically on sandy bottoms in the subtidal to approximately 4m depth and *Zostera noltei* (dwarf eelgrass), an intertidal species. The optimal growth conditions for *Zostera* are found in relatively shallow, sheltered, and stable environments. Both species are listed as nationally scarce (BRIG, 2011).

In 1994 the UK government published the UK Biodiversity Action Plan (BAP) for species and habitats identified as threatened; seagrass beds were included as threatened habitats. BAP was superseded by the NERC Act (2008) and further by the Environment (Wales) Act, 2016, where seagrass beds are listed as a Section 7 habitat due to the declines and level of threat to this habitat. Section 7 states that 'Welsh ministers must take all reasonable steps to maintain and enhance the living organisms and types of habitat included in any list published under this section and encourage others to take such steps.'

Seagrass beds are recognised by the European Union as a 'sub-feature' within Special Areas of Conservation (SACs) under the EU Habitats Directive 1992 (Council Directive 92/43/EEC). The Habitats Directive states that habitats, e.g. estuaries, shallow inlets and bays, 'must be maintained in their present state, or where possible, restored to a more favourable condition'.

Zostera beds are on the OSPAR list of 'Threatened and/or Declining Species and Habitats' in the most recent assessment (OSPAR, 2022) *Zostera* beds are classified as having poor overall status in Arctic Waters (Region I); North Sea (Region II); Celtic Seas (Region III) and Bay of Biscay & Iberian Coast (Region IV).

1.2 Ecosystem services provided by seagrass

Seagrass beds are highly productive habitats which influence the physical, chemical, and biological environments in shallow coastal waters (Orth et al. 2006). Seagrass beds support a high biodiversity of species, providing nursery areas for commercially important fish and crustaceans (Davidson & Hughes 1998, Nordlund et al. 2018a; Unsworth et al. 2018 a & b). When present in large areas and in good condition, seagrass meadows form vast filters for the coastal environment (both landward and seaward), recycling nutrients and reducing pathogens (Flindt et al. 1999; Lamb et al. 2017).

Seagrass beds provide powerful nature-based climate solutions. The plant's dense and complex root structure encourages sedimentation and helps to stabilise the underlying substrate. This allows seagrass beds to function as natural coastal defence systems and assist in the reduction of coastal erosion (Boyes et al. 2008). Capturing disproportionately high levels of carbon in relation to other habitat types (they store 10-18% of the world's oceanic carbon despite covering less than 0.1% of the seafloor) makes seagrass beds extremely valuable in mitigating climate change (Crooks et al. 2011; Mcleod et al. 2011; Duarte et al. 2013; UNEP. 2020).

The carbon sequestration importance of seagrass is due to its ability to encourage sedimentation. 'Blue Carbon' is the term given to organic carbon held in the marine system; this is held in the sediments and thus stored in the seagrass bed. If there are few stresses on the seagrass bed and sediments the organic carbon may be stored and preserved for decades or millennial time scales (Hemminga and Duarte 2000).

1.3 Threats to seagrass beds

Seagrasses are important but also threatened on a global scale with an estimated decline rate of 7% per year globally (Waycott et al. 2009; UNEP. 2020). Human influences affecting the abundance *of Zostera marina* include:

- Land reclamation,
- Nutrient and sediment run-off,
- Physical disturbance (e.g. dredging, bait digging, construction, moorings and anchoring),
- Invasive species e.g. *Sargassum muticum*,
- Pollution

(Davidson & Hughes 1998, Nordlund et al, 2018b).

Nutrient input e.g. effluent and fertiliser run-off is one of the largest threats (Jones et al., 2018). Increased nutrients create more favourable conditions for opportunistic and faster growing macroalgae and epiphytic algae which can out compete or smother seagrass meadows (Jones, 2014). Increases in epiphytic algae and increased water turbidity can also reduce the light absorbed by the seagrass leading to degradation of the seagrass and in turn reduced resilience of the meadow (Jones, 2014).

The population of *Zostera spp.* across the whole of the North Atlantic seaboard was decimated by a wasting disease in the 1930s resulting in the loss of over 90% of seagrass beds by 1932 (see Muehlstein, 1989 for a comprehensive review). Butcher (1934 and 1941) reported two distinct periods of deterioration in the UK, one in the early 1920s and the other in the early 1930s. The initial destruction went unnoticed until investigations into massive declines in wildfowl populations (Brent geese) in the US. The loss of the seagrass beds had effects across the whole coastal ecosystem, not just on wildfowl. Cottam (1934) reported declines in clams, lobster, scallops, crab, cod, and flounder. The loss of seagrass as an effective breakwater and sediment stabiliser resulted in coastal erosion, an increase in water turbidity and pollution (Cottam and Munro 1954). The cause of this wasting disease was a marine slime mould of the *Labyrinthula* genus (Muehlstein 1989) with possible links to pollution and eutrophication (Hughes et al. 2018). Interestingly the seagrass beds in brackish, low salinity environments were less susceptible to the disease. This event highlighted just how important seagrass beds are to the coastal ecosystem, a lesson that seems to have been forgotten in recent times.

1.4 Review of *Zostera marina* mapping studies in North Haven

The occurrence of *Z. marina* in North Haven, Skomer was first recorded by Bassindale (1946 and 1950) and subsequently by Hunnam (1976). The extent and density of the *Z. marina* bed in North Haven was unknown at this time. The first mapping studies were completed in 1979, 1980 (Jones and Hodgson, 1980) and 1981 (Jones et al., 1983), however the surveys were less intensive than subsequent surveys and so comparison between these years is difficult. In 1982 a more detailed method was devised based on a fixed grid area and used a defined abundance scale (Jones et al., 1983), this method formed the basis of the Skomer Marine Nature Reserve (MNR) survey completed in 1997 (Lock, 1998).

The method used in 1997 to map the distribution and abundance of *Z. marina* closely followed that used in 1982, which allowed for comparisons to be made. The main change in method was that counts of *Z. marina* shoots in a quadrat were made instead of using an abundance scale. This avoided discrepancies between recorders and had the advantage of providing numbers for comparison in future surveys (Lock, 1998). The 1997 survey also established fixed corner markers for the survey plot. This method was successfully repeated in 2002. The method was expanded in 2006 (Lock et al., 2006) and repeated in 2010, 2014, 2018 and 2023.

In 1997 a basic map of the *Z. marina* bed boundary was produced using shore-based surveyors taking bearings on the divers' surface marker buoys using digital hand-held compasses. In 2000 a GPS (Global Positioning System) unit was used to electronically record the position of the divers and the boundary of the *Z. marina* bed. This was repeated in 2002 and 2004. In 2013 a Biosonics DT-X echo sounder was used to acoustically estimate the coverage of *Z. marina* in North Haven. This method was repeated in 2014, 2018, 2021 and 2022. In 2018 the *in situ* diver survey was repeated alongside a Biosonics acoustic survey. Unfortunately, it was not possible to run the Biosonics survey in 2023 due to our survey vessel *Skalmey* being out of action for several months.

1.5 Current management of *Zostera marina* in North Haven, Skomer

1.5.1 Zostera marina population

In 1990, due to its conservation importance, *Z.marina* was selected as a management plan feature of the Skomer MNR (now Skomer Marine Conservation Zone [MCZ]). It is ascribed "specified limits" which contribute to "performance indicators" used to assess its conservation status (Alexander, 2004).

The 1982 seagrass bed area of extent is used to establish "limits of acceptable change" for the Skomer MCZ Management Plan (referred to as upper and lower specified limits) for the extent of the *Z. marina* population at North Haven.

Until 2018 the lower specified limit for *Z. marina* mean shoot density was set from the 1997 survey. In order to obtain a comparative value for the shoot density a subset of survey points was used which matched the 1997 survey (Figure 10). These survey points are mainly in the densest part of the seagrass bed and therefore give artificially high shoot density results when compared with density values that encompass the whole area of suitable habitat. In 2006 the survey methods changed to incorporate more of the outer bed. The survey now has a more comprehensive coverage of the whole area of suitable habitat. Therefore, from 2023, the lower limit for *Z.marina* shoot density shall be based on comparable survey data points used across the entire bed since 2006 and the lower limit set from the 2014 survey (lowest recorded density since 2006).

Extent of the *Z. marina* bed:

Upper Specified limit: No limit set
Lower Specified limit: 3788 m^2 (from estimated 1982 level; see Table 5).

Mean shoot density of the *Z. marina* bed:

Upper Specified limit: No limits set
Lower Specified limit: mean density $^{>}/_{=}$ 23.1 shoots/m^2 (from 2014 level as calculated from comparable survey stations; see Table 4).

1.5.2 The North Haven *Zostera* site

North Haven is marked as an anchorage on Admiralty Charts and gives access to the Skomer Island landing. Many boats use the area especially during the summer months; these include yachts, motorboats, dive boats and fishing vessels.

From 1992 onwards "No Anchoring" marker buoys, clearly defining the northern edge of the *Z. marina* bed, have been installed as part of management measures designed to protect the bed from damage from anchoring. Several visitor moorings were established at the same time to the north side of the *Z. marina* bed and their use is encouraged. Visiting vessels are asked to refrain from anchoring southwards of the marker buoys. This information is included in the Skomer MCZ User Regulation leaflet which is distributed by the Skomer MCZ Officers during on-water patrol and is available on the NRW website (https://www.naturalresources.wales/skomer?lang=en).

1.6 Survey objectives

The key objectives of this survey are to:

- Determine the distribution, abundance, and extent of *Z. marina* in North Haven.
- Map the boundaries of the *Z. marina* bed with *in situ* diver survey and acoustic sonar methods.
- Ground-truth acoustic survey methods against *in situ* diver surveys.
- Determine if the *Z. marina* bed meets the minimum specified limits for conservation assessment.
- Provide a visual record of the condition of the *Z. marina* bed throughout the year.
- Provide data on species recorded within the *Z. marina* bed throughout the year.
- Compare results with previous surveys.

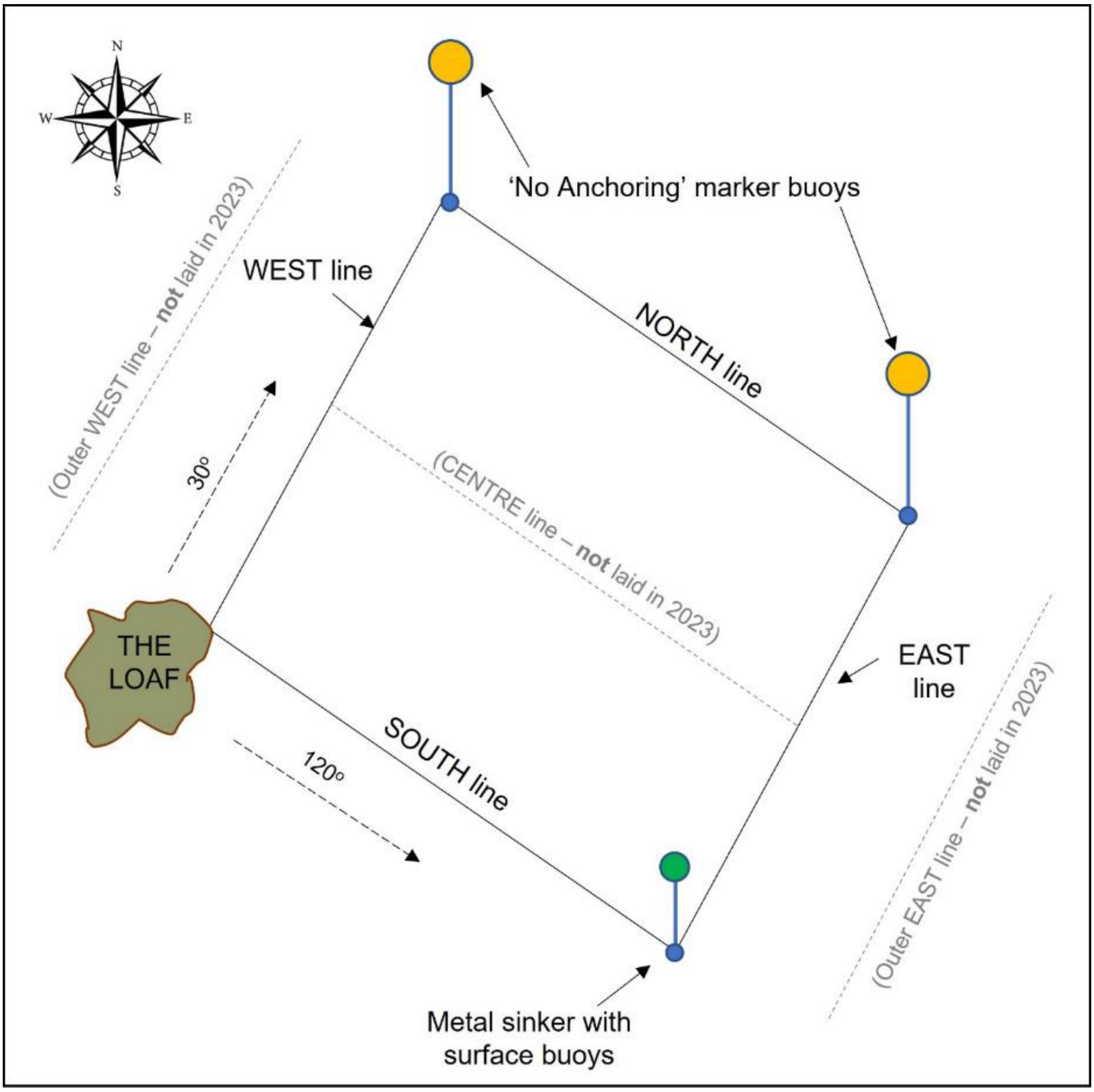
2 Methods

2.1 Establishment of survey plot

The survey plot used from 2006 onwards was re-established (Figures 1 and 2). The fixed locations of the two “No Anchoring” marker buoy moorings, a ring-bolt secured to ‘The Loaf’ rock and a metal sinker with a sub-surface buoy were relocated. Divers laid lead lines marking the four outer edges of the main bed (Figure 2). The lead lines are marked at 5m intervals with labelled tags showing the distance along the rope.

Figure 1. Location of survey grid in North Haven (green dots represent established survey points which are spaced 5m apart).

Figure 2. Layout of fixed markers and ropes deployed to mark the *Z.marina* survey site 'main bed' in North Haven, Skomer.



In previous surveys three additional lines have been laid; one centre line (running west to east) and two lines parallel to the east and west lines, 20m out from the inner lines (Figure 2 and Burton *et al.*, 2019). In 2023 a dense mat of filamentous brown algae smothered the *Z.marina* bed (Figures 3 and 4), lines were not visible on the seabed and were challenging to lay. It was therefore decided not to lay these additional lines (which, in years clear of algae, would aid the surveyors with laying transects).

On completion of the survey, divers retrieved the lead lines and secured the four corner markers as permanent markers for future surveys.

Some points were not surveyed in 2023 for the following reasons:

- Seabed topography prevented survey (immediately adjacent to the loaf rock: west transect, 0m).
- Survey was stopped at outer extent of seagrass (outer limits of north and south transects).
- The west lead line only extended to 55m before meeting the north line (therefore west transect, 60m could not be completed). It is expected that there has been a slight shift in the' No Anchoring' marker buoy on the north-west corner. Due to the extended time required to lay the lines (the algae mats made this task extremely challenging) there was not time to adjust this corner prior to the survey.

Non-surveyed points appear as an 'x' on the 2023 shoot density maps (Figure 10).

In 2018 some of these areas contained seagrass, it is therefore likely that these omissions will have had an impact the '2023 area of extent result', giving a slightly lower area in 2023 as a result.

Figure 3. Appearance of filamentous brown algae over the North Haven *Zostera marina* bed.

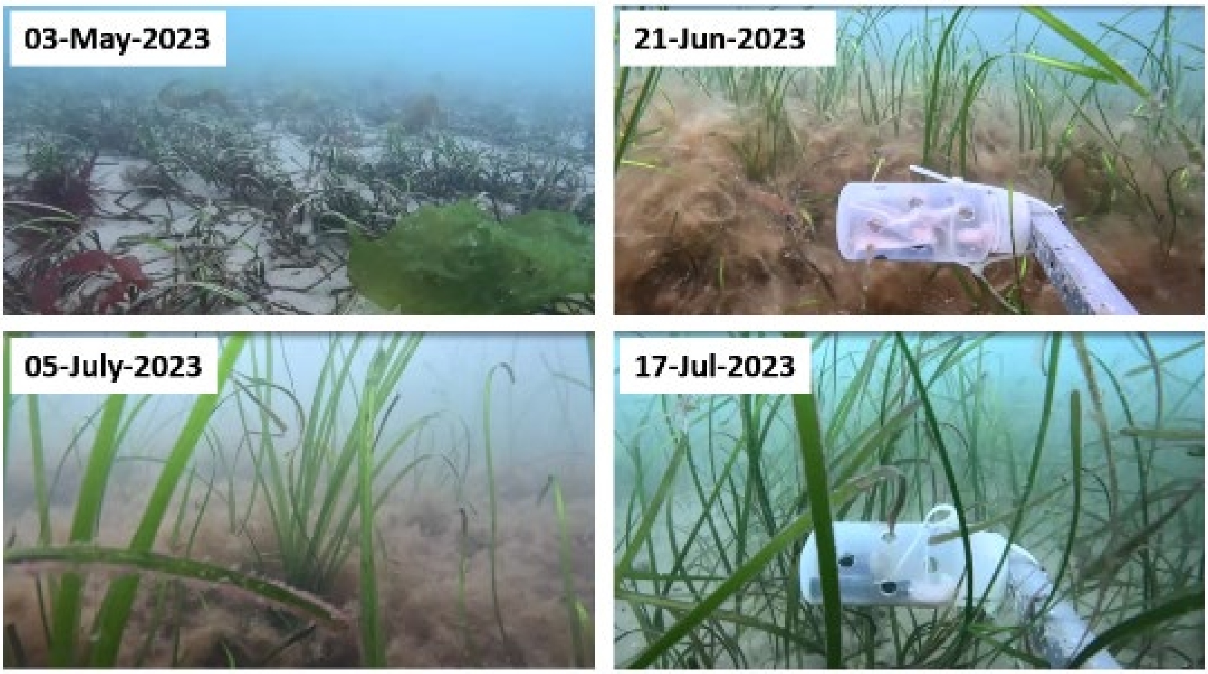
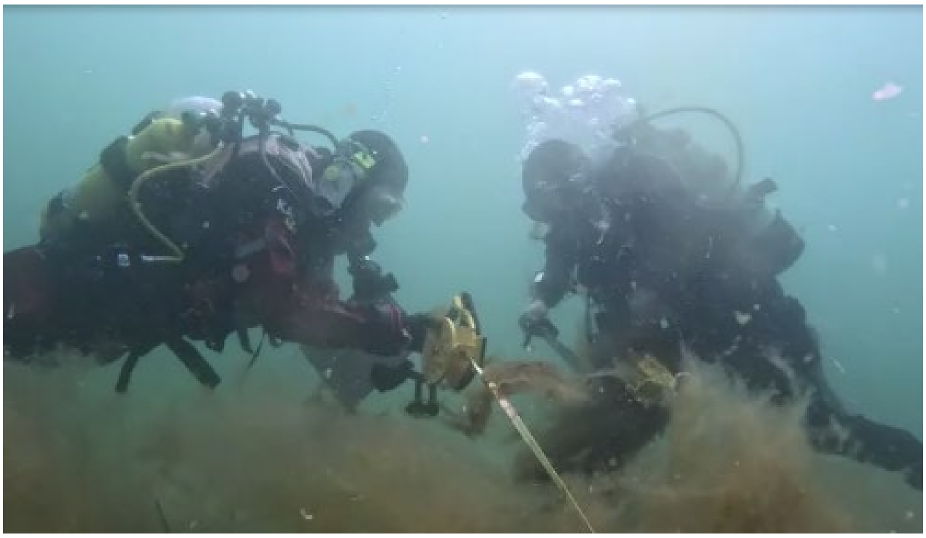


Figure 4. Divers laying transect tapes across *Zostera* bed amidst filamentous brown algae growth.



2.2 Distribution and abundance of *Zostera marina*

The survey method established in 2006 was repeated, the recording procedure was as follows.

Example for survey of the main bed 0m transect line:

1. Diver pair secures the end of a 30m tape measure (using a diving weight) to the 0m mark on the north line. Divers lay the 30m tape from the north line heading towards the south line following a bearing of 210°. A second 30m tape is attached, and divers continue to the south line securing the end of the second tape at the 0m mark on the south line. The tapes form the 0m transect line, 60m in length, shown in Figure 5.

2. Divers swim back along the tapes checking that they have been correctly laid and secured.

3. The diver pair works either side of the tape commencing on the north line at ‘0m’ on the transect tape (called station 0). Each diver lays a $0.25m^2$ quadrat ‘randomly’ next to the station (note: in previous reports this has been referred to as a ‘7m x 0.25m’ quadrat; the correct dimensions are 0.5m x 0.5m, the same quadrat size has been used for this and all previous surveys). The diver counts and records the total number of *Z. marina* shoots within the quadrat. Repeat so that each diver completes 3 quadrats (total of 6 quadrats completed by the diving pair) as shown in Figure 5.

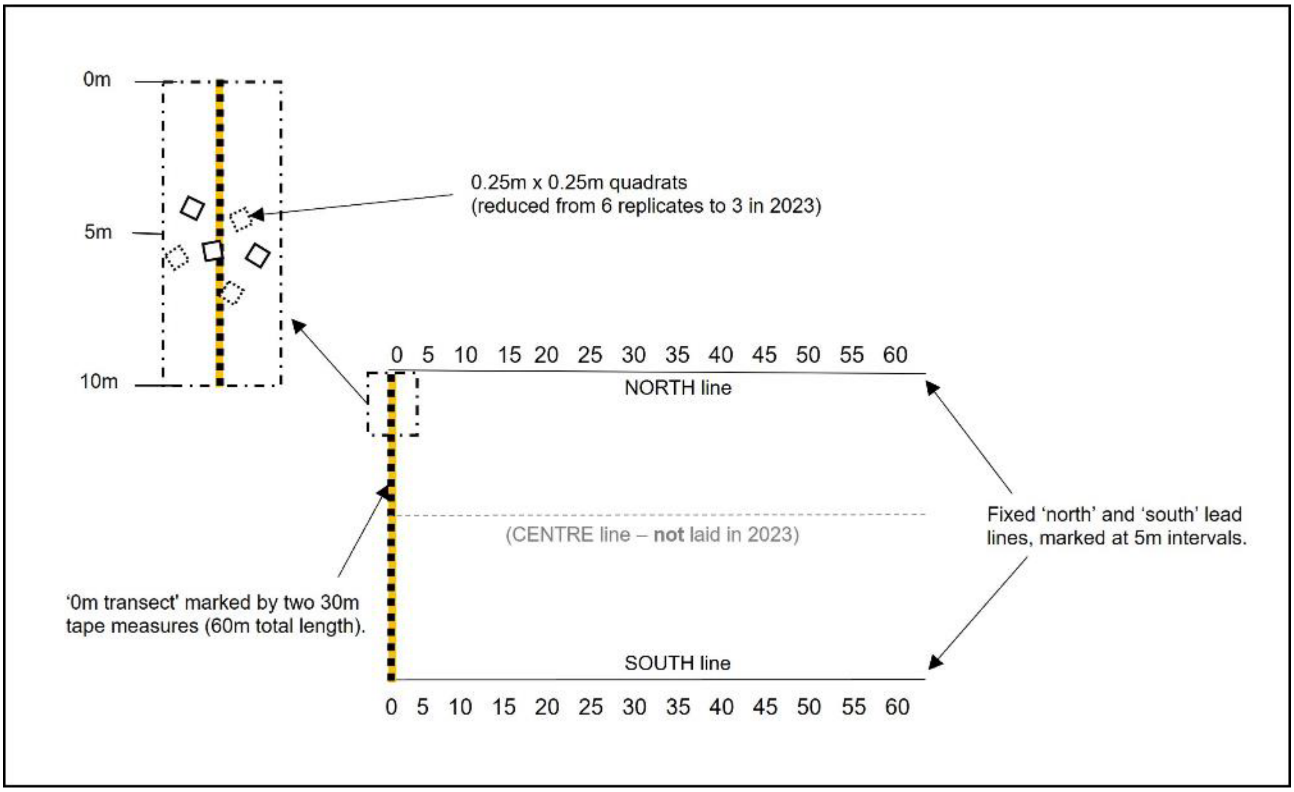
Note: The dense filamentous brown algae seen in 2023 (Figures 3 and 4) severely hampered survey work; it was therefore decided to reduce the number of quadrats to 3 quadrat counts per station.

4. On completion of ‘station 0’, divers move along the transect tape to ‘5m’ (‘station 5’) and complete quadrat counts. Divers repeat the process at 5m intervals finishing the 60m-long transect at the southern line.

5. On completion of the transect, divers retrieve the transect tapes and re-lay for the subsequent transect starting at the 5m mark on the north line for the 5m transect line.

6. The method is repeated for each transect, working at 5m intervals along the north line and finishing with the ‘60m transect’ completing the main bed survey area.

Figure 5. Survey method measuring the abundance of *Z.marina* in the fixed plot area, showing the 0m transect on the Main Bed.



On completion of the survey within the main bed area, the distribution and abundance of *Z. marina* outside the main bed is surveyed:

7. Starting on the south line, two 30m tapes on reels are laid by divers in place of the ‘0m transect’ forming the west line (this is the same as ‘0m transect’ on the main bed).

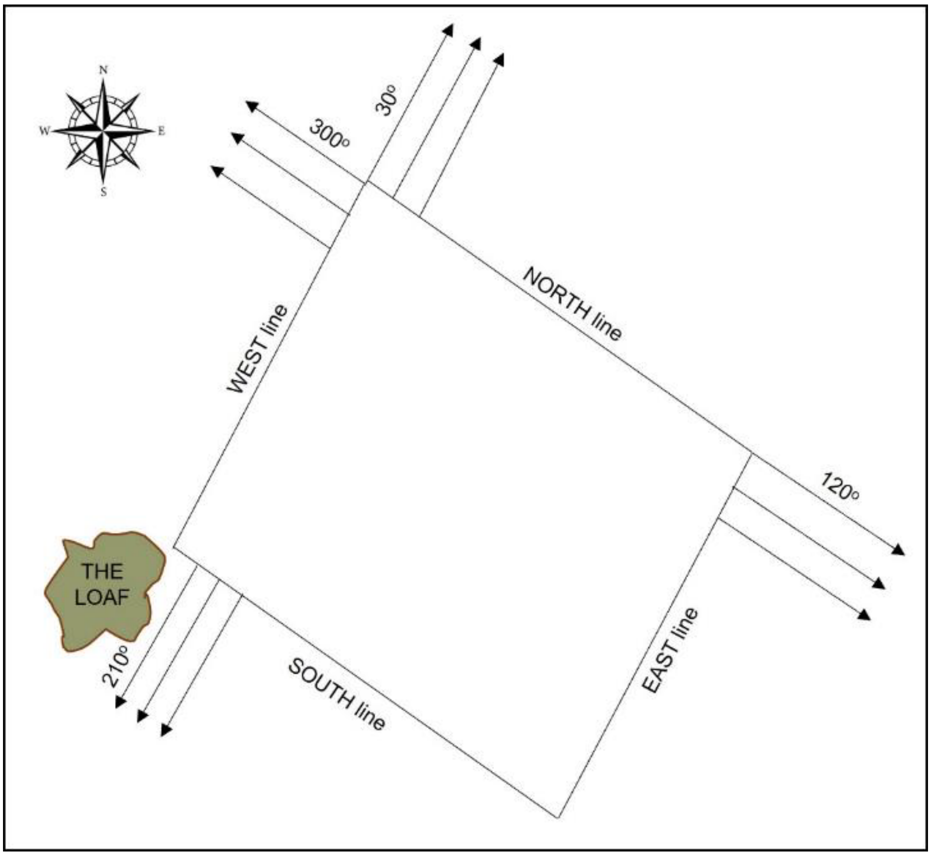
8. Divers attach the end of another 30m tape to the 0m mark at the corner of the south/west lines and lay the tape out on a bearing of 300° westwards, joining a second 30m tape to lay a full 60m transect. The full 60m west is surveyed for each transect.

9. Divers work either side of the tape completing quadrat counts every 5m along the tape (as described in steps 3 and 4 above) until 60m is reached.

10. On completion, divers retrieve the tape, re-lay it, and repeat the method at 5m intervals until all transects from the west line are complete. Note: in 1997 and 2002 tapes were laid at 10m intervals this was reduced to 5m intervals from 2006 onwards.

11. Divers repeat the method steps 7-9 for each direction out from the study plot; the north line working 30° northwards; the east line 120° eastwards; and the south line working 210° southwards, as shown in Figure 6.

Figure 6. Laying transects for surveying the north, south, east and west sides of the Zostera bed



2.3 Remote Underwater Video Survey

A Baited Remote Underwater Video System (BRUVS) was deployed within the North Haven seagrass bed on 16 occasions for 1-2 hours at a time (between May-2023 and January-2024). The BRUVS system comprises a heavy metal framer; a GoPro11 in an underwater housing; a bait arm and tube; a length of rope and a marker buoy (Figure 7). 40-50g of mackerel was used in the bait tube to attract mobile predators into view.

Figure 7. Skomer MCZ's Baited Remote Underwater Video System (BRUVS).

The purpose of the BRUVS deployment was to record the presence of mobile species within the bed and to obtain a visual condition assessment of the seagrass throughout the year. The benefits of using BRUVS over survey by SCUBA-divers are:

- Longer deployments / survey times are possible.
- BRUVS can run concurrently with other tasks (as the system is left for 1-2 hours and does not require on-site monitoring).
- The bait attracts mobile species into the camera's field of view.
- Mobile species (e.g. fish) are likely to be more visible and not hiding (i.e. not being disturbed by diver's movements and bubbles).
- The SCUBA-diving program is seasonal (April-Oct); with the right weather conditions it is possible for BRUVS to be deployed year-round.
- Deployments can be combined with routine monitoring and water-sampling activities thus requiring minimal additional time and effort.

3 Results

The survey plot lines were set up by the Skomer MCZ team, and survey transects were completed by a team of volunteer divers over two weekends in June and July 2023.

3.1 *Zostera marina* shoot density, *in situ* diver survey.

There are 781 sample stations in total (Figure 1). In any one year it is likely that some stations will not have been surveyed. For a direct and fair comparison between different years it is therefore essential to compare only data from the same sample stations. For this reason, when running different comparisons, different values may be reported for the same survey year (this is due to the differing number of sample points being compared).

The density of *Z.marina* shoots recorded in 2023 are shown in Table 1, and for comparison those recorded in 2018 are shown in Table 2. Standard deviation, error and variance have been calculated using the mean density counts from each station (3 quadrats per station).

Table 1. 2023 Density of *Z.marina* (shoots / m^2) [using data from stations also surveyed in 2018].

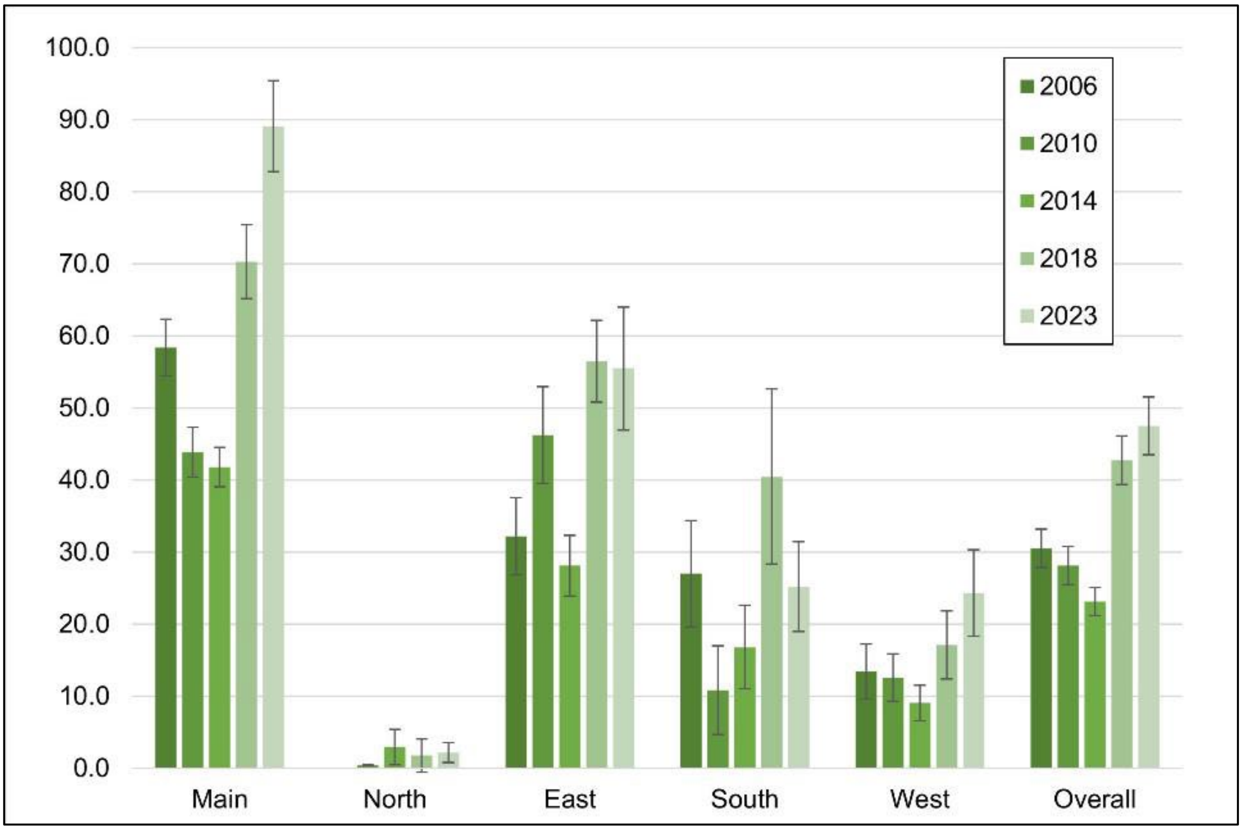
2023	Main	North	East	South	West	Overall
Mean	89.0	2.2	55.5	25.7	24.3	47.4
Standard deviation	41.3	6.4	54.4	27.8	35.1	50.1
Variance	1707.2	40.9	2956.4	774.7	1234.9	2514.1
Number of stations	168	78	156	78	132	612
Standard error 95%	6.25	1.42	8.53	6.18	5.99	3.97
Min	0.0	0.0	0.0	0.0	0.0	0.0
Max	181.3	36.0	202.7	88.0	137.3	202.7

Table 2. 2018 Density of *Z.marina* (shoots / m^2) [using data from stations also surveyed in 2023].

2018	Main	North	East	South	West	Overall
Mean	70.4	1.7	56.5	37.4	17.1	42.4
Standard deviation	33.7	10.3	36.1	51.6	27.7	42.1
Variance	1136.4	107.0	1301.7	2660.2	767.3	1773.0
Number of stations	168	78	156	78	132	612
Standard error 95%	5.10	2.30	5.66	11.45	4.73	3.34
Min	0.0	0.0	0.0	0.0	0.0	0.0
Max	162.0	74.0	148.0	232.7	101.3	232.7

Compared to 2018, increases in shoot density were recorded in the main, north and west beds. Overall shoot density in 2023 was higher than in the previous four surveys (Figure 8).

Figure 8. Comparison of shoot densities 2006-2023 (95% S.E. bars) [using data from survey stations sampled in every survey year].

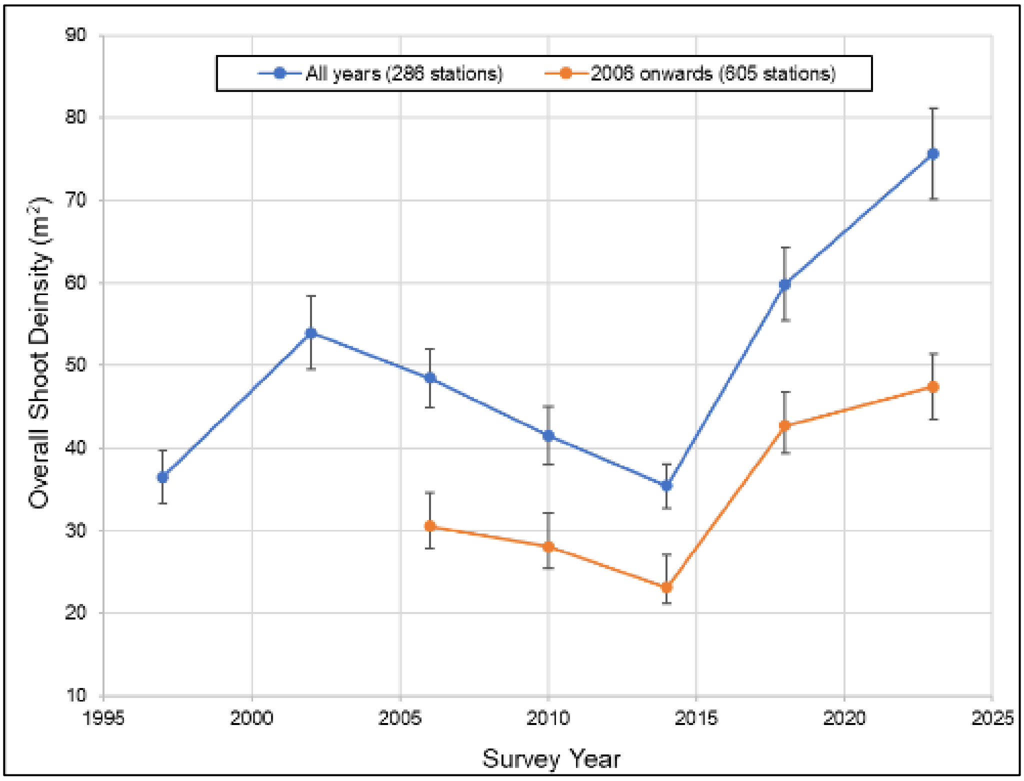


The number of sample stations was increased in 2006 (see Figure 10). By comparing only the same sample stations used in 1997 and 2002 across all years it is possible to make direct comparisons between all results since 1997 (Table 3 and Figure 9). Comparing all data sets (1997 to 2023), 2023 has the highest overall shoot density recorded to date.

Table 3. Comparison of overall shoot density (per m^2) for all years 1997-2023 [using only data from selected sample stations with replicates in every sampling year].

	1997	**2002**	**2006**	**2010**	**2014**	**2018**	**2023**
Mean	36.5	54.0	48.5	41.5	35.4	59.9	75.7
Standard deviation	27.2	38.3	31.2	30.4	23.2	38.4	47.6
Variance	739.9	1468.5	973.7	925.9	537.5	1477.1	2262.9
Count	286	286	286	286	286	286	286
Standard error 95%	3.15	4.44	3.62	3.53	2.69	4.45	5.51
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Max	104.0	156.0	128.7	182.7	104.7	162.0	202.7

Figure 9. Comparison of shoot densities 1997-2023 and 2006-2023 (95% S.E. bars) [using data from survey stations sampled in every survey year].



The results from all years highlight the decline in overall shoot density from 2002 to 2014 followed by increases in 2018 and 2023.

A one-way ANOVA test between years on (logx+1) transformed data showed a significant difference in shoot density between years ($P<0.01\%$). A Tukey test showed shoot density to be significantly higher in 2023 than in 1997 and 2014.

As described in Section 1.5: **data from 2006 onwards is compared when making the condition assessment for the *Zostera marina* feature 'shoot density'.** The average shoot density in 2023 (when compared with stations sampled in all years 2006-2023) is 47.46 shoots per m^2 (Table 4). This is well above of the lower specified limit of 23.1 shoots per m^2.

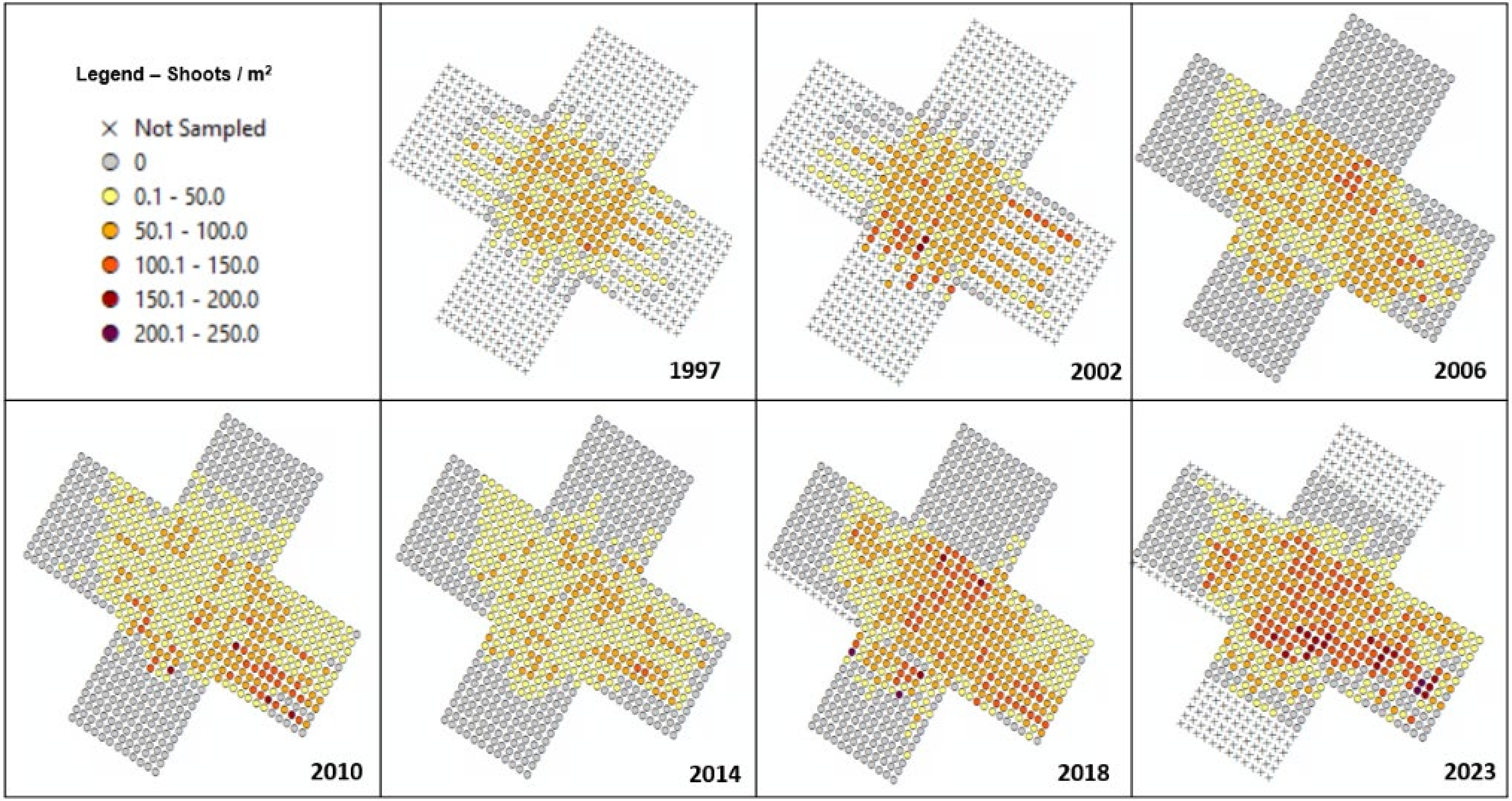
Table 4. Comparison of overall shoot density (per m^2) 2006-2023 [using only data from selected sample stations with replicates in every sampling year].

	2006	2010	2014	2018	2023
Mean	30.52	28.09	23.10	42.71	47.46
Standard deviation	33.34	33.44	24.79	42.09	50.27
Variance	1111.42	1118.04	614.69	1771.53	2526.86
Count	605	605	605	605	605
Standard error 95%	2.66	2.66	1.98	3.35	4.01
Min	0.00	0.00	0.00	0.00	0.00
Max	128.67	182.67	104.67	232.67	202.67

3.2 Spatial analysis of shoot density using GIS

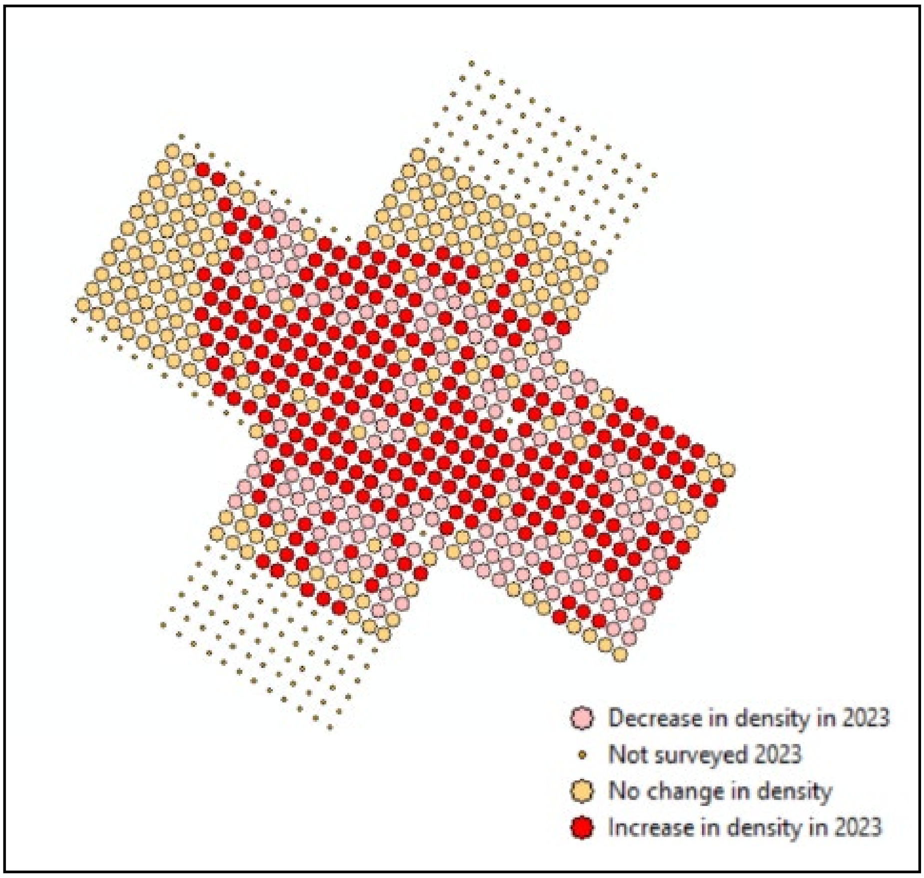
Position data and mean shoot density from all the sampling stations in every survey year were entered into ArcMap (v10.2.2). Thematic maps were produced showing the variation in shoot density across the whole seagrass bed for each year (Figure 10).

Figure 10. Shoot density maps 1997-2023



Differences in shoot densities between the 2018 and 2023 surveys have been mapped in ArcGIS by plotting a function of; difference = 2023 density - 2018 density. A negative value means a decrease in density in 2023 compared to 2014 (see Figure 11).

Figure 11. Differences in shoot density between 2018 and 2023 surveys.



3.3 Extent of the *Z.marina* bed

Since 1997 there have been 3 methods used to estimate the area of extent of the North Haven *Z. marina* bed:

- **Diver swims of the boundary**: giving a series of GPS waypoints around the edge of the bed which were used to estimate extent [2000, 2002 and 2004].

- **Polygons drawn in GIS software using the survey grid data:** From 1997 to 2010 “MapInfo” was used to plot GIS polygons, with positions recorded using the WGS84 projection. In 2014 the software was changed to “ArcMap 10.2” and British National Grid was used as the coordinate system. “ArcMap v10.2” was used (with positions recorded using the British National Grid projection) to complete maps for all dive survey years.

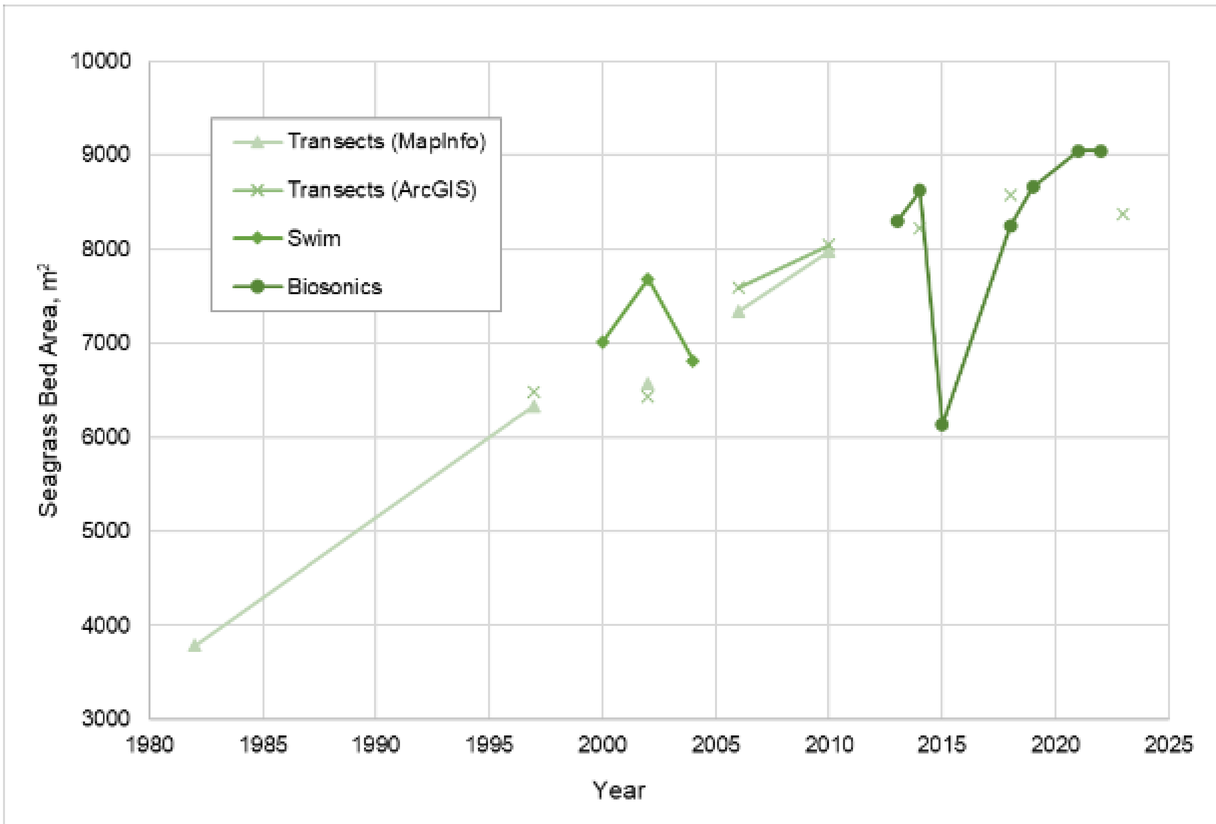
- **Biosonics acoustic survey:** produces an estimate of area covered based on various values of Percent Area Inhabited (PAI). Biosonics surveys started in 2013 and were repeated in 2014, 2015, 2018, 2019, 2021 and 2022. It was not possible to complete a survey in 2023 due to the survey boat being offline for engine repairs.

The area of extent for each year (as calculated using the methods described above) is shown in Table 5 and Figure 12.

Table 5. Estimated coverage (area in m^2) of *Z.marina* in North Haven. 1982-2023, all survey methods.

Year	Polygon drawn from survey transects (MapInfo)	Polygon drawn from survey transects (ArcGIS)	Diver boundary swim	Biosonics acoustic survey (60-70 PAI)
1982	3788	n/a	n/a	n/a
1997	6333.4	6484.2	n/a	n/a
2000	n/a	n/a	7007.8	n/a
2002	6569.5	6439.6	7683.20	n/a
2004	n/a	n/a	6817.5	n/a
2006	7336.6	7587.2	n/a	n/a
2010	7980.6	8044.0	n/a	n/a
2013	n/a	n/a	n/a	8290
2014	n/a	8224.6	n/a	8621
2015	n/a	n/a	n/a	6133
2018	n/a	8567.6	n/a	8244
2019	n/a	n/a	n/a	8659
2021	n/a	n/a	n/a	9040
2022	n/a	n/a	n/a	9039
2023	n/a	8367.1	n/a	n/a

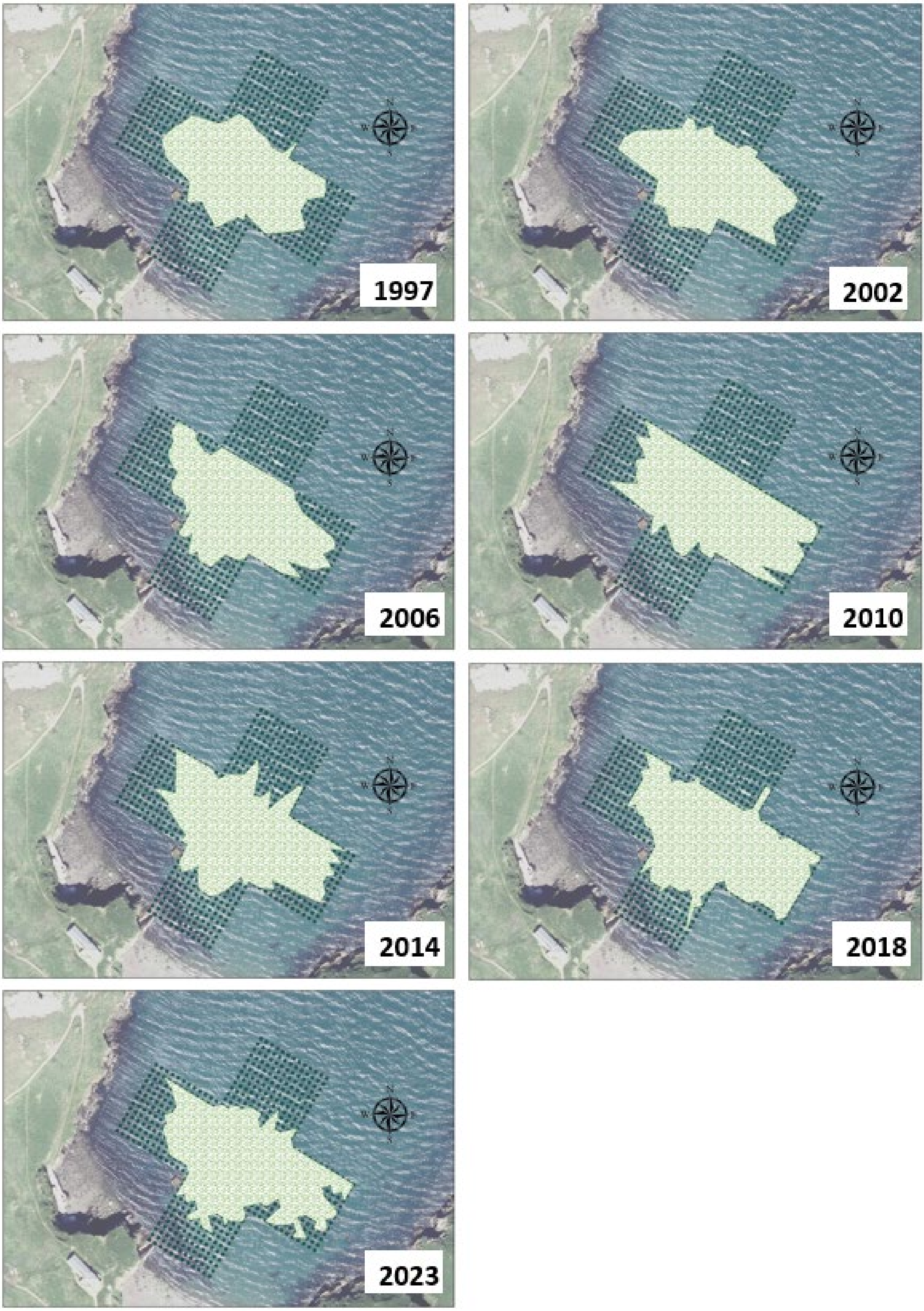
Figure 12. Graph of seagrass extent in (m^2) 1982 - 2023, estimated by different methods.



The two GIS methods (MapInfo and ArcMap) using two different projections (WGS 84 & British National Grid) give similar results (Table 5 and Figure 12). The area of extent has gradually increased over the survey period, but in recent years is showing signs of having reached a plateau with little change seen. In 2023 the area estimate of 8367.1 m^2 remains well above the lower specified limit of 3788 m^2 (1982 value).

The *Z.marina* bed extent for each survey year is mapped in Figure 13 using the diver-survey data. Whilst there is little variation in the overall extent, the boundaries of the bed do change between survey years with most variation been seen in the east and west transects.

Figure 13. Area of *Z.marina* extent 1997-2023 from diver survey transect data



3.4 Extent of the *Z.marina* bed: Bioacoustics survey results

The NRW Fisheries assessment team surveyed the North Haven *Z. marina* bed in 2013, 2014, 2015, 2018, 2019, 2021 and 2022 using the same Biosonics DT-X sonar equipment (see Clabburn *et al.* 2014 for methods). The results are shown in Table 6, and the 2022 maps for area extent are shown in Figures 14 and 15.

Different cut off (contour) values can be used to set the edge of the *Z. marina* bed, the 60% contour appears to match up best with the *in situ* diver area estimate. In 2015 the area estimate was very low (Table 6), no *in situ* data was available to confirm this.

The Biosonics survey area incorporates areas of seagrass outside of the diver-survey grid (e.g to the north-east and north-west of the main bed) therefore the values for area of extent, whilst similar, cannot be directly compared between survey methods (diver and bio acoustic) and are generally a little higher than the diver-survey results.

It was not possible to repeat the Biosonics acoustic survey in 2023 due to issues with our survey vessel 'Skalmey'.

Table 6. Estimated area of North Haven seagrass bed (m^2) 2013-2022, as mapped by Biosonics Survey.

% Area Inhabited Contour	2013	2014	2015	2018	2019	2021	2022
90	6140.2	6282.1	3833	6086	n/a	n/a	n/a
80	7126.0	7329.4	4910	7004	n/a	n/a	n/a
70	7742.1	8041.8	5572	7589	n/a	n/a	n/a
60	8290.1	8621.1	6133	8244	8659	9040	9039

Figure 14. Bosonic plot of seagrass bed area extent in 2022 (using 60% Area Inhabited contour values).

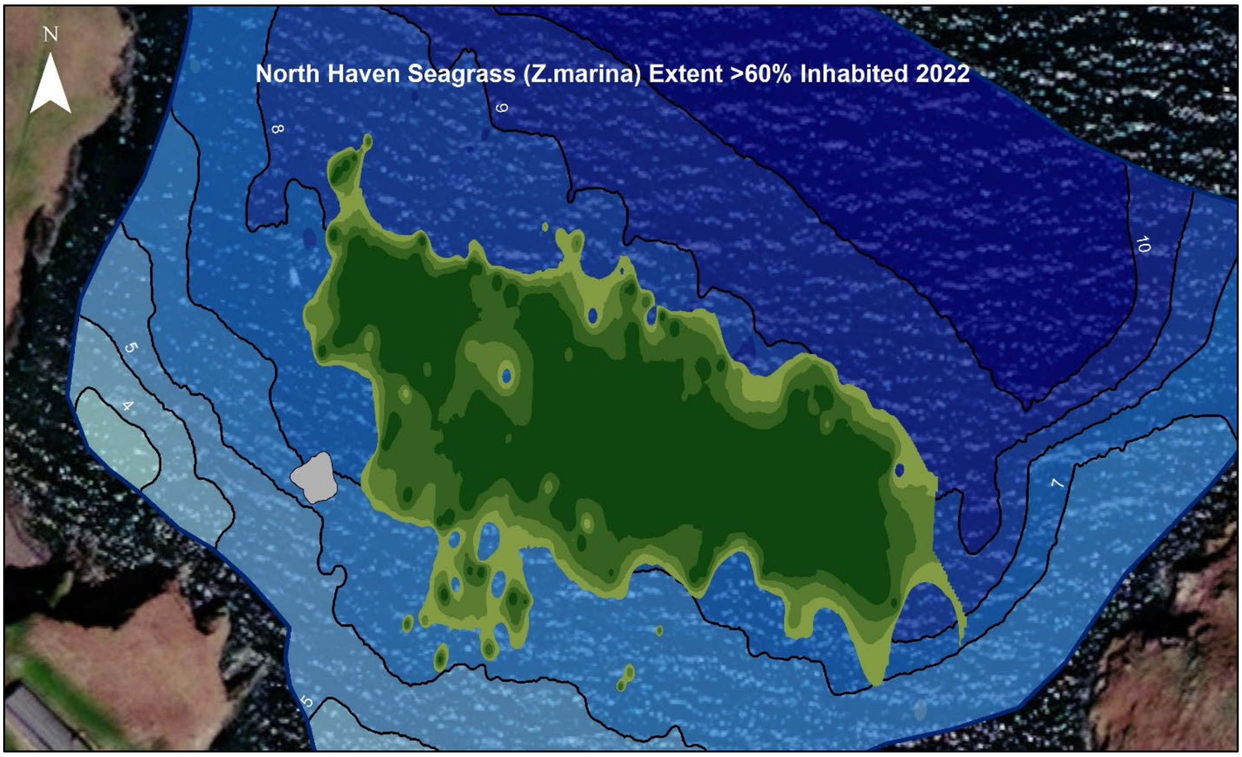
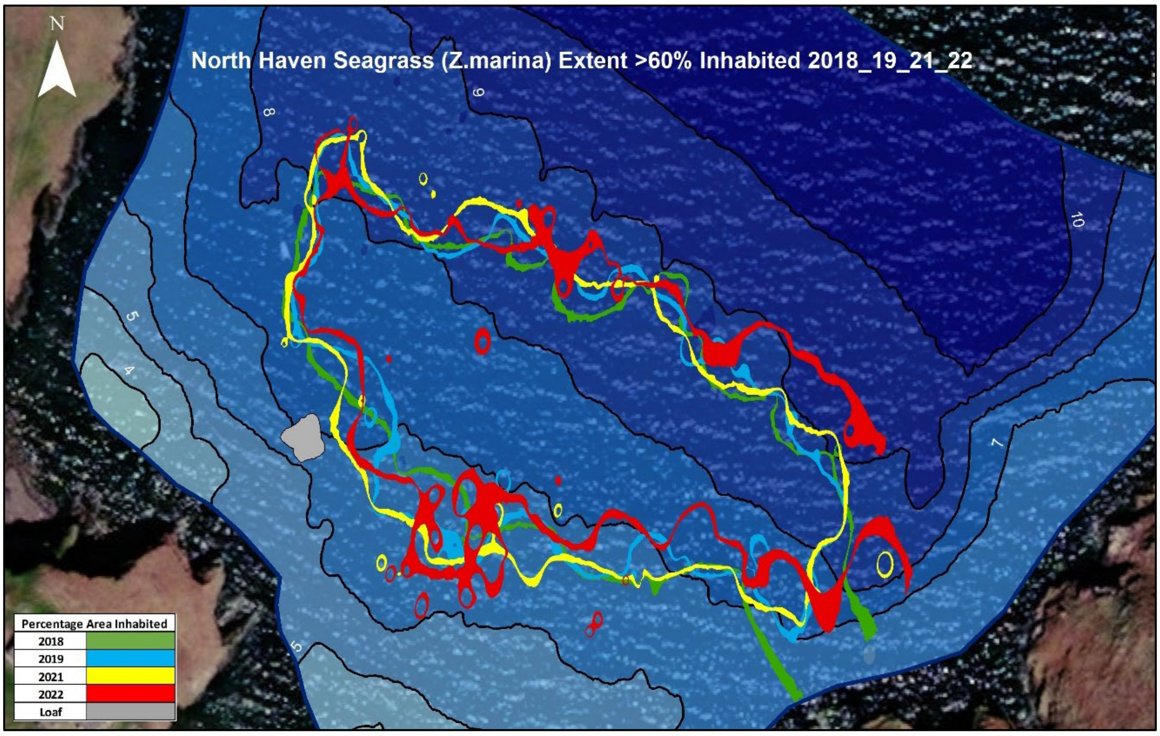


Figure 15. Biosonics plot of seagrass bed area extent (using 60% Area Inhabited contour values) for years 2018, 2019, 2021 & 2022.



3.5 BRUVS and diver observations

3.5.1 Species observations

The Baited Remote Underwater Video System (BRUVS) was deployed on 16 occasions between May 2023 and January 2024 at locations across the North Haven seagrass bed (Figure 16).

Figure 16. Location of BRUVS deployments in North Haven, shown in relation to the seagrass bed survey area.

The analysis of video footage is ongoing; to date footage from 8 of the deployments has been reviewed. A selection of BRUVS video frame stills is shown in Figure 17.

Figure 17. A selection of species captured by the BRUVS: (a) bib; (b) sea bass; (c) spider crab (stealing the initial bait tube!) and (d) netted dog whelk and dragonet.

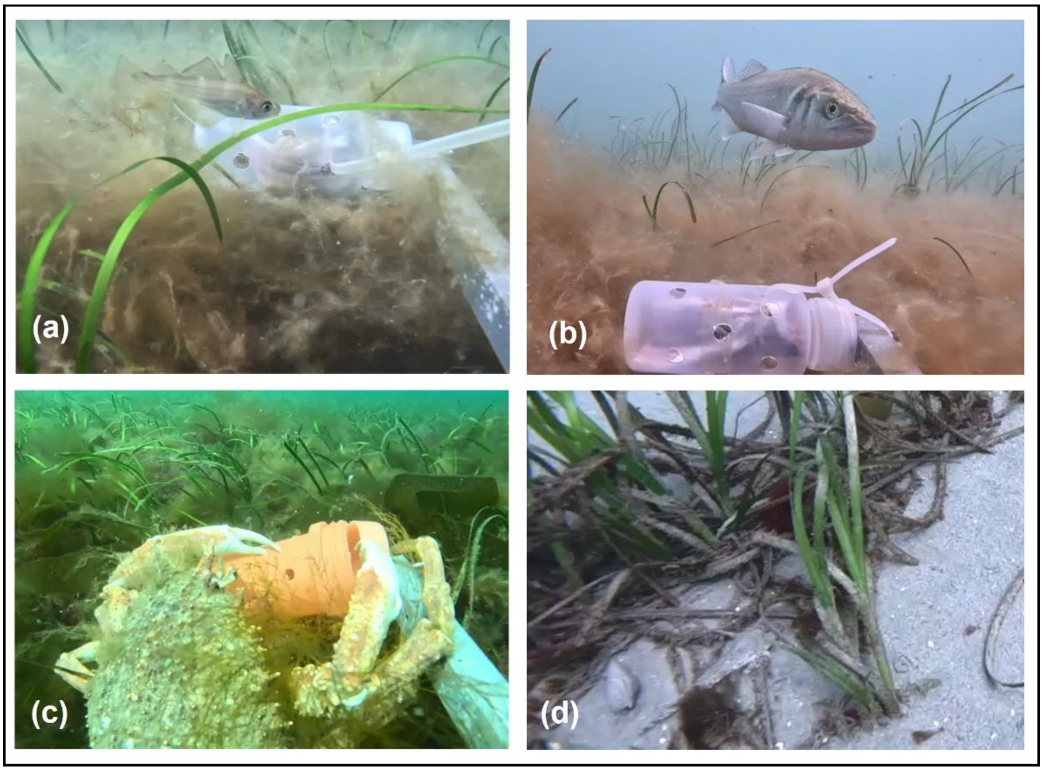


Table 7 lists the 20 species identified so far from a combination of BRUVS footage and notable species observed by SCUBA divers during their seagrass survey dives (note that the SCUBA diver species records were not collected as part of a formalised species survey).

Table 7. Species recorded in the North Haven seagrass bed (by BRUVS and SCUBA divers).

Species	**Recorded by diver / BRUVS**
Aurelia aurita (moon jellyfish)	BRUVS
Pleurobrachia pileus (sea gooseberry)	BRUVS
Beroe cucumis (comb jelly)	BRUVS
Cerianthus lloydi (tube-dwelling anemone)	Diver
Callionymus sp. (dragonet)	BRUVS
Pomatoschistus flavescens (two spotted goby)	BRUVS
Juvenille *Trisopterus luscus* (pouting / bib)	BRUVS
Juvenille *Limanda limanda* (dab)	BRUVS
Juvenille flatfish	BRUVS
Symphodus melops (corkwing wrasse)	BRUVS
Dicentrarchus labrax (seabass)	BRUVS
Atherina presbyter (sand smelt)	BRUVS
Ensis sp. (razor clam)	Diver
Pecten maximus (king scallop)	Diver
Tritia reticulata (netted dog whelk)	BRUVS & Diver
Maja squinado (spider crab)	BRUVS
Pagurus bernhadus (hermit crab)	BRUVS
Echinocardium sp. (sea potato)	Diver
Polycera quadraliniata (nudibranch)	Diver
Polycera lapitala (nudibranch)	Diver
Aplysia punctata (sea hare)	Diver
Halichoerus grypus (grey seal)	BRUVS & Diver

Divers observed the presence of epiphytic red filamentous algae growing on some seagrass blades (Figure 18). Collections by diver Francis Bunker were sent to Ignacio Bárbara (University of A Coruña) who identified it as *Colaconema daviesii* (formerly *Audouinella daviesii*). Previous records exist for *Audouinella* sp in the North Haven seagrass bed in 2005 (Johnson et al, 2005).

Figure 18. Red epiphytic algae *Colaconema daviesii* growing on *Zostera marina* [Photo credit: F.Bunker].

3.5.2 Seagrass bed condition observations

Images from the BRUVS video footage, showing the general condition of the North Haven *Zostera* bed between May-23 and January-24, are shown in Figure 19.

The dense mat of filamentous brown algae was not present on the first deployment on 3rd May but appears well established by the next deployment on 30th May. It was still present on 5th July but had all but gone by the 17th July.

On 3rd May epiphytic algae can be seen on many *Zostera* leaves, however on all following deployments the presence of epiphytic algae appears greatly reduced.

Figure 19. Images of *Z.marina* bed taken by BRUVS between May 2023 and Jan 2024.

4. Discussion

4.1 Survey conditions

The presence of a dense covering of filamentous brown algae across the entire *Zostera* bed impeded divers. The algae had to be carefully cleared from each quadrat to access the base of the seagrass shoots for counting, this significantly increased the time required for each quadrat count. For this reason, the number of quadrats per sample station was reduced from 6 to 3. Once divers had cleared the algae the counting of seagrass shoots was a simple task, therefore the presence of the algae should not have affected the accuracy of the counting.

4.2 Shoot density

The overall mean shoot density has continued to increase since the lowest shoot density recorded in 2014 (23.10 shoots / m^2). In 2023 the comparable overall mean shoot density was 47.46 shoots / m^2 and the average density within the main bed was 89 shoots / m^2 (using data points which are comparable across years 2014-2023); this is the highest density recorded in this survey thus far and double that recorded in 2014.

When compared with results from seagrass beds in other areas of the UK the shoot densities at Skomer appear at the lower end of the range. However, caution must be taken when making comparisons between sites as the range of factors limiting seagrass growth (e.g the availability of light, nutrients and suitable substrate) will vary immensely.

Table 8. Shoot densities of *Zostera marina* in UK seagrass beds.

Site	Area	Year	Mean density (shoots per m^2)	Data Source
Porth Dinllaen	North Wales	2012	115	Stamp & Morris, 2012
Porth Dinllaen, North outer harbour	North Wales	2012	128	Stamp & Morris, 2012
Porth Dinllaen, South Outer harbour.	North Wales	2012	83	Stamp & Morris, 2012
Gelliswick Bay, (middle of bed)	South Wales	2008	129	Morris, Goudge & Irving, 2008
Gelliswick Bay, (outer edge of bed)	South Wales	2008	81	Morris, Goudge & Irving, 2008
Angle Bay	South Wales	2008	91	Morris, Goudge & Irving, 2008
Drakes Island, Plymouth	Devon	2018	64	Bunker & Green, 2019
Cawsand Bay, Plymouth	Devon	2018	86	Bunker & Green, 2019
Cellar’s Cove, Plymouth	Devon	2018	112	Bunker & Green, 2019
Red Cove South, Plymouth	Devon	2018	119	Bunker & Green, 2019

Factors affecting shoot density:

- **Light availability -** High turbidity in the water column above the bed will reduce photosynthetic activity and growth (Olesen *et al*., 1993 and Unsworth *et al*., 2014). Turbidity is regularly recorded using a Secchi disk at two sites within the Skomer MCZ during June-September each year (Figure 20).This data shows that the period from 1997 to 2002 was relatively clear. Since 2002 water turbidity has been variable with poor turbidity in 2004 to 2009, 2012, 2014, 2017 and 2022 -2023. This may have contributed to the declining trend from 2002 - 2014. In 2018 visibility was above average, especially in the period leading up to the survey. 2022 and 2023 have shown increased turbidity, however the increase in turbidity does not seem to have had a negative impact on shoot density which has increased since the previous survey in 2018.

- **Photosynthetically Active Radiation (PAR):** Since 2015 a PAR sensor has been used on a weekly basis (June-September) to record light levels through the water column in North Haven. The results so far show the attenuation of light through the water column is relatively constant; with, on average, 15.8% of available light reaching 5m depth (shallow areas of the bed) and 7.6% of available light reaching down to 8m (seabed) depth. Cloudy days and those with a high tide in the middle of the day will further limit the light available to the seagrass for photosynthesis.

- **Net radiation and sunshine hours:** The amount of available light can be estimated using data from a local weather station situated 1 km away from North Haven (on Wooltack Point, Marloes peninsula). The data is consistent back to 2006 and does not show much inter-annual variation (Figure 20). Only having shoot density records every 4 years makes it difficult to correlate to these types of environmental factors.

- **Physical damage:** This would tend to produce a localised effect. There have been very few instances of anchoring within the bed since the instalment of the 'no anchoring' buoys and none recorded over the last 5 years. The "no anchoring" buoys and the visitor moorings appear to be working.

- **Water quality and health of the seagrass:** Jones et al. (2018) suggest that high nitrogen and phosphorus loading could limit growth. Burkholder *et al*. (1992) demonstrated that high nitrogen loads cause a decline in seagrass health, especially in spring. To date, only one set of tissue samples have been taken to look at C:N:P ratios in Skomer seagrass (Jones & Unsworth, 2016), this showed Skomer seagrass contained high levels of nitrogen and phosphorus when compared to other UK seagrass beds.

  An MSc project (Sleight, 2019) on nitrogen and phosphorous content in the soils of Skomer Island showed that the nitrogen levels were up to 4 times higher in Skomer soils compared to the mainland and phosphorous levels were over 10 times higher. The land around North Haven has some of the highest densities of Manx shearwater burrows so high levels of nitrogen and phosphorous runoff would be expected.

- **Temperature:** Davison & Hughes (1998) give the optimum temperature range for growth and germination of *Z.marina* as approximately 10 - 15°C, but note that plants can tolerate sea temperatures from 5 to 30°C. Den Hartog (1970) states that *Z.marina* generally tolerates temperatures up to 20° C without showing signs of stress.

  In May 2023 an Onset Hobo Water Temperature Pro v2 logger (set to log temperature at intervals of 15 minutes) was deployed on the loaf rock in North Haven at a depth of 2m below chart datum (bcd). The daily average seawater temperature, May-October 2023, is shown in Figure 22. A maximum temperature of 17.9°C was recorded on 9th September. It is unlikely that the water temperature over this period will have affected shoot density or extent in the current survey year. However, continuation of temperature logging at this site will provide valuable data for future *Zostera* surveys. The logger was replaced in October-2023 and will be downloaded again in spring 2024.

Figure 20. Secchi disc data (turbidity) for two sites within the Skomer MCZ (OMS - north side of Skomer & TRK - south side). Annual difference from grand overall mean (negative results = cloudy water). Routine monitoring runs Jun-Sept each year.

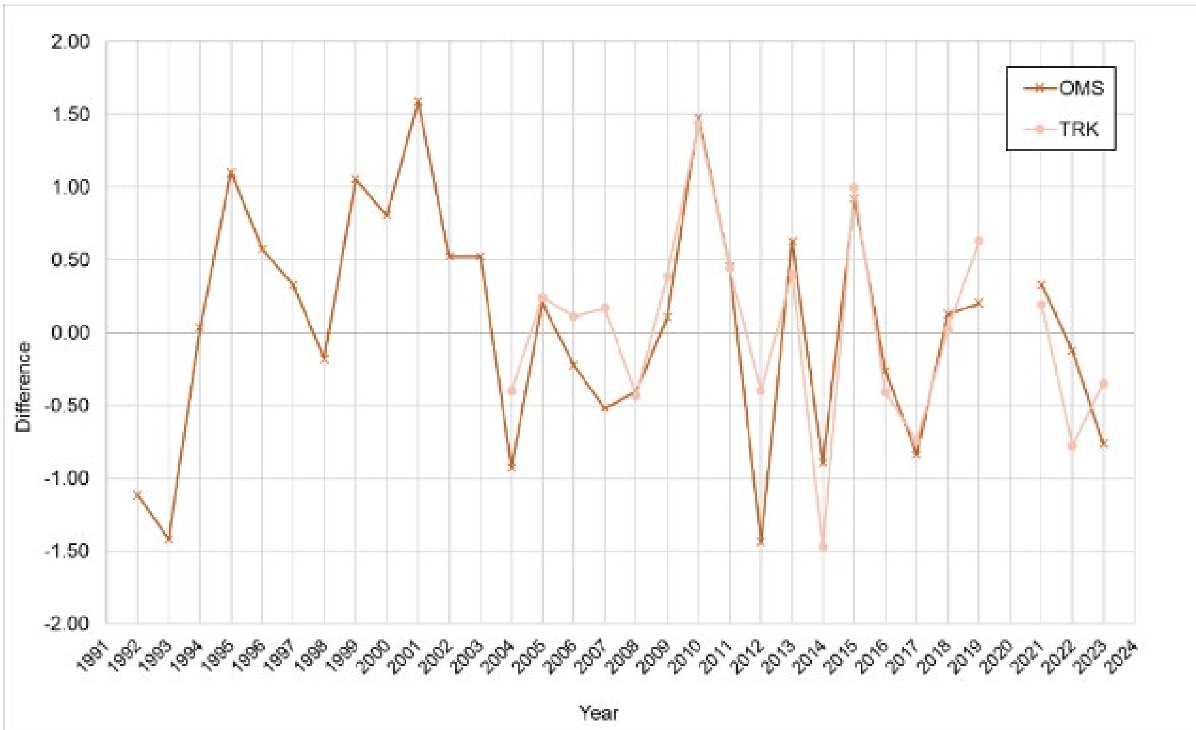


Figure 21. Monthly solar radiation and sunshine hours (2006-2023), Wooltack Point.

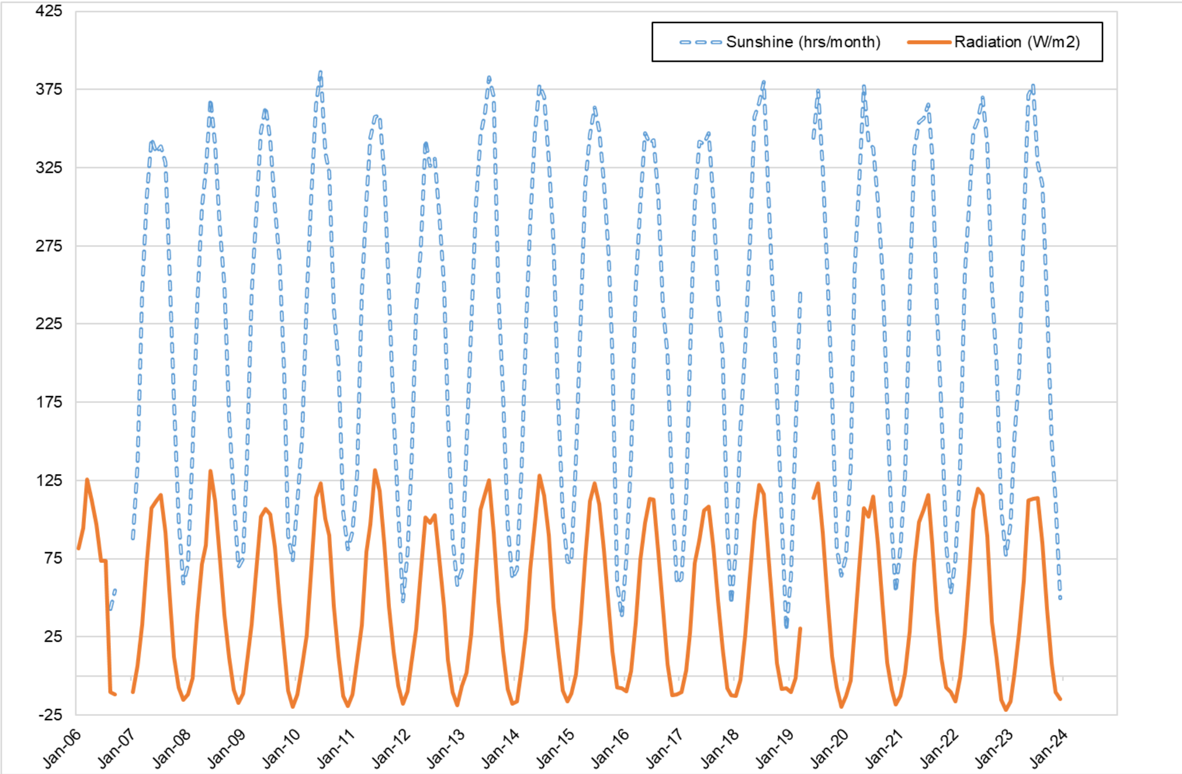
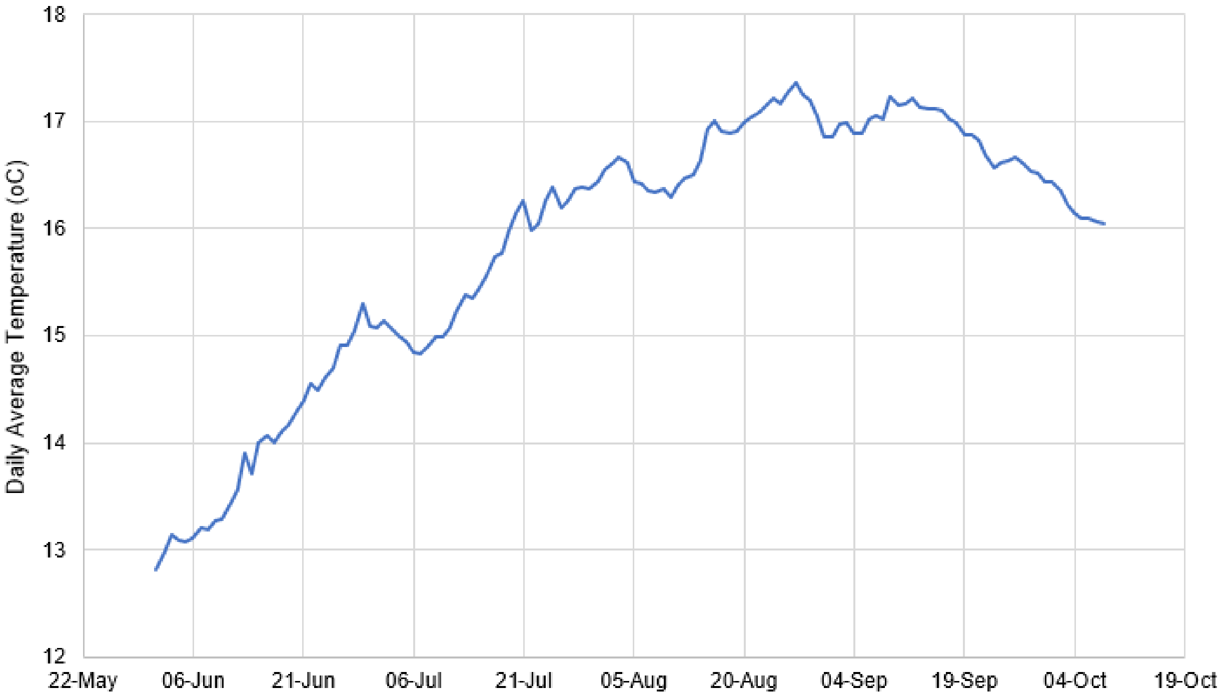


Figure 22. Daily average seawater temperature at 2m (bcd), North Haven. May-Oct 2023.



4.3 Area of extent

The 2023 area of extent (estimated as 8367.1m^2 by diver survey) is comparable to the 2022 BioSonics acoustic survey (9039m^2) and the 2018 diver survey (8567.6m^2). These are the highest areas of extent recorded in the survey history. In the 2018 report (Burton *et al*., 2019) the assumption was made that the seagrass bed was occupying most of the suitable habitat in North Haven, with its extent limited by the availability of physical space to the south, east, west, and limited by increasing water depth to the north. The 2022 and 2023 results concur with this assumption.

The Biosonics acoustic method of surveying the estimated area of extent has worked very well. This method is very quick and provides a practical way to get an annual estimate of area of extent. It can also pick up areas outside of the normal survey grid (e.g. to the northeast and northwest) which would not normally be surveyed.

The only area which is consistently different from the diver survey is the southeast corner. More diver survey time is needed to confirm if this is an artefact of the interpolation method (e.g. a change in substrate type or algal cover which mimics the acoustic signal of seagrass) or an area of seagrass that has been consistently missed by the diver survey.

4.4 Further work and ecosystem services

4.4.1. BRUVS and diver observations

BRUVS deployments in conjunction with diver records captured a wide range of species within the seagrass bed (Table 7). BRUVS is particularly useful for monitoring highly mobile species, such as fish, which can be easily disturbed by SCUBA divers.

The presence of the red epiphytic algae *Colaconema daviesii* and the dense carpet of brown filamentous algae can likely be attributed to the high levels of nutrients known to be present around Skomer (because of the dense seabird colonies). In 2005 a study of seagrass epiphytes (Johnson *et al*., 2005) reported that of their 4 study sites (Porth Dinllaen, Criccieth, Milford Haven and Skomer) *Zostera* at Skomer had the highest number of epiphyte species and the largest percentage of leaves fouled.

Samples taken in 2014 showed seagrass at Skomer to contain some of the highest concentrations of phosphorus and nitrogen when compared to other UK seagrasses (Jones *et al.*, 2018). An MSc project (Sleight, 2019) on nitrogen and phosphorous content in the soils of Skomer Island showed that the nitrogen levels were up to 4 times higher in Skomer soils compared to the mainland and phosphorous levels were over 10 times higher; surface water run-off with high levels of nitrogen and phosphorus would therefore be expected. The study also investigated the ^{15}N ratio of the soils and found that the Skomer soils had a high (9-16%) ^{15}N ratio which corresponded well to the bird species feathers and prey species. This contradicts the findings of Jones et al. (2018) which found the ^{15}N ratio of the seagrass tissue to be low (~6%). So, it remains unclear where the nitrogen enrichment is coming from.

The BRUVS is a useful tool for condition assessment monitoring of the *Zostera* bed; picking up the occurrence of macro and epiphytic algal growth and the presence of drift algae. The North Haven *Zostera* survey occurs every 4-years; in the intervening years limited diving occurs on the seagrass bed (aside from the checking of buoys at the perimeter of the bed). BRUVS provides a simple yet effective method of observing the seagrass condition on a more frequent basis. It is expected that summer deployments should be achievable alongside routine operations. Whilst winter deployments are highly weather dependant, deployments could be made during routine monthly water-sampling activities.

4.5 Current management of the *Zostera marina* bed in North Haven, Skomer

The Skomer MCZ management plan objective for the population of *Z. marina* in North Haven (as outlined in Section 1.5) is to maintain it in favourable condition where:

Extent of the *Z. marina* bed:

> Upper Specified limit: No limit set
> Lower Specified limit: 5500 m^2 (from original 1982 level)

In 2023 the extent is **8367.1m^2** and is therefore in <u>favourable condition</u>.

Mean shoot density within the *Z. marina* bed:

> Upper Specified limit: No limits set
> Lower Specified limit: mean density $\geq$ 23.10 shoots/m^2 (from 2014 level as calculated from comparable survey stations; see Table 4).

In 2023 the comparable mean density is **47.46 shoots/m^2** and is therefore in <u>favourable condition</u>.

5.Conclusions

The Skomer MCZ management plan targets for the population of *Z. marina* in North Haven for both extent and shoot density have been met and the feature is in favourable condition.

The four-yearly *Z. marina* distribution and abundance survey using volunteer divers has provided valuable and cost-effective data for the Skomer MCZ.

NRW Fisheries Assessment Team conducted four repeat surveys using a Biosonics DT-X split beam echo sounder between 2018 and 2022. The diver survey results compare well against the Biosonics acoustic surveys. The remote acoustic method provides an efficient alternative to the diver survey for obtaining annual results for area of extent.

Both the 2018 and 2023 results are very encouraging but other studies (Jones *et al*., 2018) show evidence that the health of the seagrass at Skomer may be limiting growth. Further work is needed to investigate the impacts and causes of nutrient inputs on the Skomer seagrass.

The Skomer MCZ is within the Pembrokeshire Marine Special Area of Conservation (SAC), data collected here is used to help assess the condition of features of the SAC. The North Haven *Zostera marina* bed data is applicable to some of the attributes of Favourable Conservation Status of the Large Shallow Inlet and Bay’s (LSI&B) feature. Examples are shown in Table 9.

Table 9. Pembrokeshire Marine SAC attributes of 'Favourable Conservation Status of the Large Shallow Inlet and Bay's' (LSI&B).

Component of habitat feature assessed	Favourable conservation status statement	Attibute	Measure	Target
Range	Distribution of Large Shallow Inlets and Bays within the site is stable or increasing	**Distribution** of encompassed features	Conservation status of distribution attributes of encompassed habitats and habitat features within the LSI&B feature (i.e. the distribution attributes of features within LSI& B need to be met for this attribute to be favourable)	Favourable
Range	Extent of Large Shallow Inlets and Bays within the site is stable or increasing	**Extent** of encompassed features	Conservation status of extent attributes of encompassed habitats and habitat features within the LSI&B feature (i.e. the distribution attributes of features within LSI& B need to be met for this attribute to be favourable)	Favourable.
Function	**Nutrients** in the water column and sediments to be: - at or below existing statutory guideline concentrations, - within range that are not potentially detrimental to the long term maintenance of Large Shallow Inlets and Bays species populations, their abundance and range	Community composition (from biological monitoring)	Evidence of community composition indicative of elevated levels of Dissolved Available Inorganic Nitrogen (DAIN) &/or Dissolved Available Inorganic Phosphorus (DAIP) (*i.e.* hypertrophic / eutrophic); indicated by univariate and multivariate analytical techniques.	No evidence that community composition indicates elevated levels of nutrients.
Typical species	The physiological health, reproductive capacity and recruitment of typical species of Large Shallow Inlets and Bays are determined by natural biotic and abiotic factors that are not degraded	Detrimental physiological stress	For seagrass: - epibiota burden - shoot density	*No target – surveillance (pending development of suitable monitoring targets)*

6. Recommendations

- Continue the 4 yearly *in situ* volunteer diver survey and maintain the continuity of data.

- Continue with an annual acoustic survey of the seagrass bed for area of extent and check the boundary areas of the bed with a drop-down video to confirm acoustic results.

- Continue with the BRUVS survey of the seagrass bed to provide monitoring of annual algal growth and presence of mobile fauna within the seagrass bed.

- Continue to log seawater temperature in North Haven.

- Developing a project to monitor shoot density & length, plant health, and surveillance of environmental factors would allow some conclusions to be drawn about changes in shoot density. Ideally this would be an annual survey.

- Encourage and support research into C: N, ^{15}N and C:P ratios measurements of leaf biometrics.

- Link in with other research and monitoring projects for eelgrass around Wales and the UK (see Unsworth *et al.*, 2014).

Acknowledgements

Thank you to all the volunteer divers who did a superb job of surveying the seagrass in challenging conditions and to Pembrokeshire Boat Charters with skipper David Stolwell.

Photo credits: Becky Tooby [cover image of divers in water]; Francis Bunker [epiphytes on *Zostera* - Figure 18]. All other photos were taken by the authors.

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