Cyfoeth Naturiol Cymru
Natural Resources Wales

Intertidal SAC monitoring of *Zostera marina* at Porth Dinllaen, Pen Llŷn a'r Sarnau SAC 2016

J. Davies, B. Wray & D.P. Brazier

NRW Evidence Report No: 064
2017

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Published by: Natural Resources Wales
Maes y Ffynnon
Penrhosgarnedd
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Report series:	NRW Evidence Report
Report number:	064
Publication date:	July 2017
Title:	Intertidal SAC monitoring of *Zostera marina* at Porth Dinllaen, Pen Llŷn a’r Sarnau SAC, 2016
Author(s):	Jake Davies, Ben Wray and Paul Brazier
Approved By:	Mike Camplin
Restrictions:	None

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Recommended citation for this volume:

Davies, J., Wray, B. & Brazier, D.P. 2017. Intertidal SAC monitoring of *Zostera marina* at Porth Dinllaen, Pen Llŷn a’r Sarnau SAC, 2016. Pp 51 + xii. Natural Resources Wales Evidence Report No. 064, Bangor.

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Yn Ardal Cadwraeth Arbennig Pen Llŷn a'r Sarnau, mae'r nodweddion cynefin rhynglanwol perthnasol yn Atodiad I yn cynnwys gwastadeddau llaid a gwastadeddau tywod nad ydynt yn cael eu gorchuddio gan ddŵr y môr ar lanw isel. O fewn nodweddion gwastadeddau llai a gwastadeddau tywod rhynglanwol, yr is-nodwedd benodol sydd o ddiddordeb yn yr adroddiad hwn yw'r gwely o wellt y gamlas Zostera marina ym Mhorth Dinllaen. Mae'r adroddiad hwn yn disgrifio ac yn cyflwyno canlyniadau'r astudiaethau monitro a gynhaliwyd ar y gwely hwn o wellt y gamlas yn 2016. Mae'r adroddiad hefyd yn edrych yn ôl at ddata monitro/arolwg blaenorol, ac yn asesu'r agweddau perthnasol ar y data hwn mewn perthynas â'r data a gasglwyd yn 2016. Defnyddiwyd delweddau awyrol i gasglu data ynglŷn â chyrhaeddiad y gwely rhynglanwol o wellt y gamlas yn 2000, 2006, 2009 a 2013, blynyddoedd pan na chynhaliwyd gwaith monitro maes yn yr Ardal Cadwraeth Arbennig.

Roedd data o'r arolygon maes yn dangos bod gostyngiad bach i gyrhaeddiad cyffredinol Zostera marina ym Mhorth Dinllaen. Roedd hyn yn bennaf oherwydd amrywiant rhwng arddull mapio syrfewyr, gan ei bod yn bosibl rhannu Z. marina rhwng dau ranbarth amlwg (y gwely dwys di-dor gogleddol a'r gwely gwasgarog deheuol). Gwnaeth tynnu'r gwely deheuol o'r dadansoddiad ddangos bod cynnydd o dros 0.5 hectar yn y gwely di-dor gogleddol.

Yn y blynyddoedd pan na chynhaliwyd unrhyw arolygon rhynglanwol yn yr Ardal Cadwraeth Arbennig, defnyddiwyd delweddau awyrol i nodi cyrhaeddiad gwellt y gamlas yn yr ardal rynglanwol. Roedd ffin y cyrhaeddiad tua'r môr wedi'i osod ar uchder penodol i dynnu'r amrywiant a achosir gan y llanw. Defnyddiwyd ffin 2010 gan mai dyna oedd y ffin uchaf (tua'r môr) a gofnodwyd yn ystod yr arolygon maes. Oherwydd bod y gwely deheuol yn wasgarog ac yn llai dwys, crëwyd polygonau cyrhaeddiad ar gyfer y gwely gogleddol yn unig. Wedyn, crëwyd polygonau cyrhaeddiad ar gyfer delweddau awyrol y blynyddoedd 2000, 2006, 2009 a 2013. Cafodd ffiniau cyrhaeddiad arolygon maes eu haddasu hefyd i sicrhau y gellid cymharu'r cyraeddiadau (trwy fasgio ar hyd traethlin isel gyffredin). Dangosodd canlyniadau o bolygonau fod cynnydd o 0.89 hectar (62%) o Z. marina yn y gwely gogleddol rhwng 2000 a 2016.

Roedd defnyddio delweddau awyrol yn lle arolygon maes yn ddefnyddiol ar gyfer casglu data ynglŷn â chyrhaeddiad, ond roedd nifer o newidynnau'n lleihau dibynadwyedd y canlyniadau. Dylid cynnal treialu cymharu gan edrych ar y cyrhaeddiad o ddelweddau awyrol ac arolygon maes pan fydd y delweddau awyrol yn cael eu casglu, i nodi camgymeriadau mapio.

Mae data a gasglwyd o'r arolwg o effeithiau a difrod yn ystod arolwg monitro Ardal Cadwraeth Arbennig PLAS yn 2016 yn dangos yr un tueddiad ag arolygon monitro Ardal

Cadwraeth Arbennig blaenorol, lle roedd y rhan ogleddol o'r gwely gogleddol yn llai dwys ac wedi cael ei heffeithio rhagor gan weithgareddau anthropogenig. Ni nodwyd data meintiol ynglŷn â’r difrod o gwmpas yr angorfeydd, gan nad oedd yn cyd-fynd yn gyson â hyd llinellau'r angorfeydd ar eu pennau eu hunain, ac mae'n bosibl bod ffactorau eraill yn cyfrannu at yr ardal yr effeithir arni. Roedd arolygon effaith hefyd yn nodi erydiad gwaddodion yn y gwely gogleddol a phresenoldeb Sargassum muticum, a allai arwain at ddifrod pellach i'r gwely.

Mae angen monitro tymor hir i barhau i wella'r wybodaeth ac i nodi'r newidiadau yn y gwely o wellt y gamlas. Byddai nodi pa mor gyflym mae Z. marina yn gwella yn dilyn effaith gorfforol, h.y. angorfa neu gerbyd, yn werthfawr i'r sail dystiolaeth, gan wella'r wybodaeth ynglŷn â pha mor gydnerth yw'r gwely yn erbyn effeithiau ac, o ganlyniad, ein helpu ni i ddeall beth fyddai'r camau nesaf er mwyn lleihau effeithiau. Mae angen rhagor o ddata ynglŷn â’r amodau amgylcheddol ym Mhorth Dinllaen hefyd, i nodi cyflwr Z. marina. Byddai dadansoddi ansawdd y dŵr o fewn y bae'n caniatáu gwybodaeth well am yr amodau dŵr, ac o bosibl yn nodi unrhyw straenachoswyr ychwanegol sy'n effeithio ar y gwely. Mae sail dystiolaeth well ynglŷn â chyflwr ac effeithiau Z. marina yn bwysig, gan ei bod yn helpu i sicrhau y gellir rhoi mesurau effeithiol ar waith i leihau effeithiau.

Executive Summary

The Habitats Directive establishes that the management of Special Areas of Conservation (SACs) should aim to achieve the **favourable conservation status** of habitat and species features listed within its Annex I and Annex II. For SACs in Wales, Natural Resources Wales (NRW), is required to report on a regular basis on whether features are in favourable conservation status. To do this NRW has developed a programme of **feature condition monitoring.** Aquatic Survey and Monitoring Ltd. (ASML) have been contracted by NRW to develop and manage the monitoring programme for the intertidal features in marine SAC's for the period 2006 to 2016; working as a team with NRW staff.

In the Pen Llŷn a'r Sarnau Special Area of Conservation (PLAS SAC), the relevant Annex I intertidal habitat features include mudflats and sandflats not covered by seawater at low tide. Within the intertidal mudflat and sandflat feature the specific sub-feature of interest covered in this report is the bed of seagrass/eelgrass *Zostera* (*Zostera*) *marina* Linnaeus, 1753 in Porth Dinllaen bay. This report describes and presents the results of the monitoring studies carried out on this seagrass bed in 2016. The report also looks back at previous monitoring/survey data and assesses the relevant aspects of this in relation to the data collected in 2016. Aerial imagery was used to obtain extent data for the intertidal seagrass bed in 2000, 2006, 2009 and 2013, years where no SAC field monitoring were undertaken.

Data from the field surveys revealed that there was a small decrease in the overall extent of *Zostera marina* in Porth Dinllaen. This was primarily due to the variability of mapping *style* between surveyors, as the *Z*. *marina* can be split into two distinct regions (continuous dense north bed and the sparse south bed). The removal of the south bed from the analysis, revealed that there was an increase of over 0.5 ha in the continuous north bed.

Years where no SAC monitoring intertidal surveys were undertaken, aerial imagery was used to determine the extent of the intertidal seagrass. The seaward boundary of the extent was set to a specific height to remove variability caused by the tide. The 2010 boundary was used as it was the highest (seaward) boundary recorded during the field surveys. Due to the south bed being sparse and less dense, only extent polygons for the north bed were created. Extent polygons were then created for years 2000, 2006, 2009, 2013 aerial images. Field survey extent boundaries were also altered to ensure that the extents were comparable (by masking along a common low shore line). Results from polygons revealed that there was an increase of 0.89 ha (61%) of *Z. marina* in the north bed from 2000 to 2016.

Using aerial imagery as a proxy to field survey was useful to obtain data on extent, but numerous variables decreased the reliability of the results. Comparison trials should be carried out looking at extent from aerial imagery and field survey when the aerial imagery is collected to determine mapping errors.

Data gathered from the impacts and damage survey during the 2016 PLAS SAC monitoring survey displayed the same trend as previous SAC monitoring surveys. Where the northerly region of the north bed was less dense and more impacted by anthropogenic activities. No quantitative data on the damage surrounding moorings was determined as it didn't relate consistently with the length of the mooring lines alone and other factors could be contributing to the impacted area. Impact surveys also noted sediment erosion in the north bed and the presence of *Sargassum muticum* which may lead to further damage of the bed.

Further long-term monitoring is required to continue to improve the knowledge and changes in the seagrass bed. Determining the recovery rate of the *Z. marina* following a physical impact i.e. mooring or vehicle would be valuable to the evidence base, improving the knowledge on how resilient the bed is to impact and therefore help in understanding what the next steps would be to reduce impacts. More data on the environmental conditions in Porth Dinllaen are also required, to determine the condition of the *Z. marina*. Analysing the water quality within the bay would allow for improved knowledge of the water conditions and potentially pick up any additional environmental stressors affecting the bed. An increased evidence base on the condition and impacts of the *Z. marina* is important as it helps to ensure that effective measures can be put in place to reduce impacts.

1 Introduction

1.1 Biology and Ecology

Seagrass beds are amongst the most widespread and productive ecosystems on earth and are present over a wide geographic range from the tropics to the boreal margins of every ocean (Boyes *et al.* 2008). Seagrasses are a unique group of flowering plants that have adapted to survive fully submerged in marine water (Orth *et al.* 2006). Often growing in dense and extensive beds or meadows, they are typically found in shallow coastal areas on sheltered sandy or muddy substrata up to a maximum depth of approximately 10m (depending on water clarity and light penetration) (Boyes *et al.* 2008). Within the British Isles there are two species *Zostera* (eelgrass) (Borum *et al.* 2004).

- ***Zostera* (*Zostera*) *marina* (common eelgrass):** This is the largest of the two species, with leaves up to 1 m in length (although usually 20-50 cm). It typically occurs from the sublittoral (down to a depth of approximately 4 m) to lower littoral zone, in fully marine conditions and on relatively coarse sediments.
- ***Zostera* (*Zosterella*) *noltei* (dwarf eelgrass):** *Z. noltei* Hornemann is the smallest and hardiest of the species. It occurs higher on the shore than *Z*. *marina*, typically on mixtures of sand and mud, and is often found adjacent to saltmarsh communities. Maximum leaf length is approximately 22 cm.

The distribution, extent, and density of *Zostera* spp*.* is highly variable, with the beds being spatially dynamic and often expanding or receding at their edges. Such dynamics are dependent on several naturally occurring factors, including extreme weather conditions (i.e. storms, floods, frost), increases in turbidity that prevent or reduce photosynthesis, overgrazing by wildfowl, and excessive algal/epiphytic growth in the absence of sufficient grazing species (Boyes *et al.* 2008).

1.1.1 Ecosystem Services provided by seagrass

Seagrass habitats influence the physical, chemical and biological environments in coastal waters, acting as important ecological engineers and providing numerous important ecosystem services to the marine environment (Orth *et al*. 2006). They are an important food source for some wildfowl (e.g. Brent geese), and a critical habitat for many species including epiphytes, algae (which grow amongst the sea grass or as mats on the sediment), invertebrates, and fish (Beck *et al.* 2001). Seagrass beds are known to support a high diversity of juvenile organisms including commercially and recreationally important fish and crustacean species, thus acting as important nursery grounds (Davison & Hughes 1998; Bertelli & Unsworth 2014). It is thought that the high abundance and variety of life in seagrass beds is in part due to the shelter from predators afforded by the dense vegetation of the meadows. The abundance of food enables a variety of species to thrive in these habitats (Davison & Hughes 1998).

Seagrass plants have a dense and complex root structure and this, together with wave attenuation across seagrass beds, encourages sedimentation. Thus, seagrass beds help to stabilise the underlying substratum. This enables seagrass beds to function as natural coastal defence systems, and to assist in the reduction of coastal erosion (Boyes *et al.* 2008).

Encouraging sedimentation has an important role in the carbon sequestration ability of seagrasses. `Blue Carbon’ is the term given to organic carbon held in natural marine systems, including in seagrass sediment. Blue carbon accumulates through the sedimentation of particulate carbon from the water column and through *in situ* production from seagrasses (Greiner *et al.* 2013). The amount of carbon accumulated by seagrass meadows depends on the species, sediment characteristics, depth and extent of the habitats (Greiner *et al.* 2013). Much of the organic carbon stored by seagrasses is in the sediment (in comparison with terrestrial systems where carbon tends to be stored within living biomass and soil organic matter (Greiner *et al.* 2013). Carbon stored within the marine sediment has another advantage as it tends to be anoxic with high sediment accumulation rates (Greiner *et al.* 2013). If there are minimal stresses on the seagrass bed and seabed sediment this can enable long term storage of organic carbon within the sediment, where it can be preserved for decades or millennial time scales (Hemminga & Duarte 2000)

In addition to their biological function and conservation importance, seagrass beds have considerable economic importance. As examples of coastal marine habitats, they are amongst the most biologically and economically important on earth (Constanza *et al.* 1997).

1.1.2 Threats to seagrass and seagrass beds

Seagrass habitats are currently under threat from a variety of anthropogenic activities which threaten the longevity of the multiple biological and economic services that they provide (Davison & Hughes 1998). Human influences affecting the abundance of *Zostera marina* include land claim, nutrient and sediment run-off, physical disturbance (i.e. dredging, bait digging, construction of harbours and marinas, vehicle tracks and boat moorings) and invasive species such as *Sargassum muticum*. These threats, along with pollution, have contributed to the alteration of the local hydrographic regime and sediment balance within some seagrass habitats (Mazik & Boyes 2009).

Increased nutrient input e.g. fertilizer run-off is one of the biggest threats to seagrasses (Jones & Unsworth 2014). Increased nutrient loads create more favourable conditions for more opportunistic and faster growing macroalgae, epiphytic algae and phytoplankton species which in turn can outcompete or smother seagrass meadows (Jones 2014). Increased loading of epiphytic algae on seagrass blades can reduce the light absorbed by the seagrass due to smothering. Reduction in light can lead to the degradation of the seagrass meadow and in turn reduce the resilience of the meadow (Jones & Unsworth, 2014; Unsworth *et al.* 2015).

Annually, the average loss rate of global seagrass meadows is ~ 0.4–2.6%, if this loss remained consistent it could result in the loss of 299 Tg C yr^{-1} of stored carbon (Pendleton *et al.* 2012). Much of the carbon released back into the atmosphere could equal to the amount of carbon released by CO_2 emissions in many small countries (Pendleton *et al.* 2012; Greiner *et al.* 2013).

During the 1930’s *Zostera marina* populations were significantly reduced due to the ‘wasting disease’, a pathogenic marine slime mould *Labyrinthula zosterae.* During this epidemic, an estimated 90% of *Z. marina* in the north Atlantic was lost (Bull *et al.* 2010). Wasting disease is still present in *Z. marina* beds but not at the scale of the 1930s epidemic (Bull *et al.* 2010). Increased stress due to higher summer temperatures is believed to have led to the outbreak of the ‘wasting disease’ during the 1930’s (Muehlstein *et al.* 1991; Bull *et al.* 2010). ‘Wasting disease’ can be spread directly from plant to plant either by being in direct contact with an infected plant or via an infected drift plant (Ralph & Short 2002). Symptoms of the ‘wasting disease’ are the initial presence of black-brown dots which then lead to larger blacker spots and streaks (Figure 1) then finally the plant dies (Ralph & Short 2002).

Figure 1 Infected plant with spots, large blackened region and streaking caused by the wasting disease (Ralph & Short 2002)

1.1.3 Conservation of seagrass in Wales

Seagrass beds (*Zostera* biotopes) have been recognised by the European Union as a 'subfeature' 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, lagoons and reefs, must be maintained in their present state, or where possible, restored to a more favourable state. Intertidal seagrass beds are present in 5 of the 7 predominantly Marine SAC's in Wales (Figure 32).

The European Community, as well as individual countries (including the UK) have pledged to develop plans and legislation to conserve biological diversity. In 1994, the UK Government published the UK Biodiversity Action Plan for species and habitats that were identified as being threatened. Both Intertidal and subtidal seagrass beds are listed under the Biodiversity Action Plan. Recently BAP has been superseded by the NERC Act (2008) and further by the Environment (Wales) Act, 2016. Seagrass beds are listed as a Section 7 habitat under the Environment (Wales) Act, due to the declines and level of threat to this habitat. Section 7 states that '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'.

Zostera beds are also on the OSPAR list of Threatened and/or Declining Species and Habitats (declining in Region II - North Sea and Region III - Celtic sea, and threatened in Region V – wider Atlantic).

1.2 Background to the intertidal SAC monitoring in Wales

The Habitats Directive establishes that the management of Special Areas of Conservation (SACs) should aim to achieve the **favourable conservation status** of habitat and species features. In the case of SACs, the features are the habitats and/or species listed in Annex I and Annex II of the Habitats Directive for which the individual site has been selected.

Natural Resources Wales (NRW), previously the Countryside Council for Wales (CCW), has a statutory duty to produce advice under Regulation 35 of the Habitats Regulations 1994, which states:

"*As soon as possible after a site becomes a European marine site, [NRW / EN] shall advise other relevant authorities as to –*

The conservation objectives for that site, and any operations which may cause deterioration of natural habitats or disturbance of species, for which the site has been designated."

The Regulation 35 advice package is the foundation for **feature condition monitoring**, which NRW is required to do to fulfil its function of reporting on the favourable conservation status of features.

CCW developed a programme of intertidal monitoring work across Wales during 2004 and 2005. These surveys were managed and implemented by the Institute of Estuarine and Coastal Studies (IECS, University of Hull). These projects focused on a wide range of sensitive habitats including *Zostera* beds, muddy gravels, caves, rockpools, algal-dominated rocky shores, *Sabellaria* reefs, underboulder communities, and various rare habitats and species.

Since 2006, Aquatic Survey and Monitoring Ltd. (ASML) have been contracted by CCW and subsequently NRW to continue development and implementation of the intertidal monitoring programme for each marine SAC, working as a team with NRW staff.

1.2.1 Pen Llŷn a'r Sarnau SAC – monitoring of *Zostera marina* at Porth Dinllaen

The results presented in this report are for the monitoring of the *Zostera marina* bed at Porth Dinllaen bay within the Pen Llŷn a'r Sarnau (PLAS) SAC (see Figures 2 and 3). The most recent monitoring was undertaken on 19th October 2016 and the results of this are presented below together with consideration of previous monitoring and studies of the *Zostera marina* at this location. The seagrass bed is a sub-feature of the SAC feature 'mudflats and sandflats not covered by seawater at low tide'.

The intertidal seagrass bed at Porth Dinllaen can be split into two distinct regions: a dense northern bed adjacent to the hamlet of Porth Dinllaen and a less dense bed to the south (Figure 3; Mercer 2011). The 2010 monitoring survey noted the particle size difference between the two beds, where the southern bed contained a lower proportion of fine sediment in comparison to the northern bed (Mercer 2011). The particle size correlates with the degree of wave exposure between the two beds, where the northern bed has more shelter in comparison with the southern bed which is more exposed to northerly and north-easterly winds (Mercer 2011).

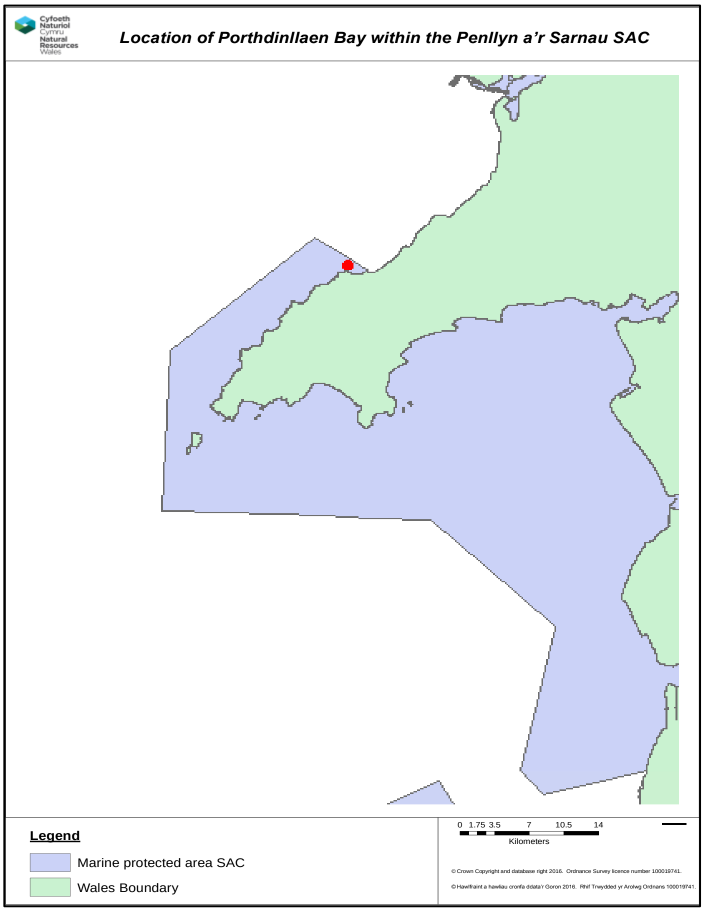


Figure 2 Location map of Porth Dinllaen bay in the Pen Llŷn a'r Sarnau SAC

Phase 1 surveys of intertidal habitats in the SAC were carried out between 1999 and 2001 (Brazier *et al.* 2007), providing detailed mapping of the intertidal biotopes with some information on characterising species. Methodological trials and surveys, designed for the purposes of developing and implementing SAC monitoring, have been carried out in more recent years.

1.2.2 Summary of intertidal *Zostera marina* studies at Porth Dinllaen 1997 – 2016

Since the initial Phase 1 mapping conducted in 1997, there has been periodic measurement of the extent of the intertidal seagrass bed in Porth Dinllaen in 2004, 2010 and 2016, undertaken as part of the SAC monitoring (Table 1). A variety of techniques have been used when conducting these surveys leading to variable measures between the surveys.

The intertidal monitoring primarily records the extent of the seagrass bed and some measures of quality, the extent mapping is undertaken by walking around the bed using a hand-held GPS to map the boundary. Differences in tidal heights and weather conditions at the time the monitoring is undertaken can affect the extent to which the tide goes out on any given date and this, in turn, influences the mapping of the intertidal seagrass as more or less of the bed is exposed.

Only a limited amount of data have been gathered on the density of the seagrass in the intertidal bed and its quality and temporal variability (Table 1). Both blade density and percent cover have been used to measure the density of the bed. The 2004 SAC monitoring survey included blade density in the methodology to gather more data on the spatial variability of the bed within the intertidal zone. Since 2004, blade density has not been repeated (Table 1), therefore inter-study comparisons of blade density cannot be made. For the 2010 and 2016 SAC monitoring surveys percent cover was used instead of blade density to measure the density of the bed (Table 1).

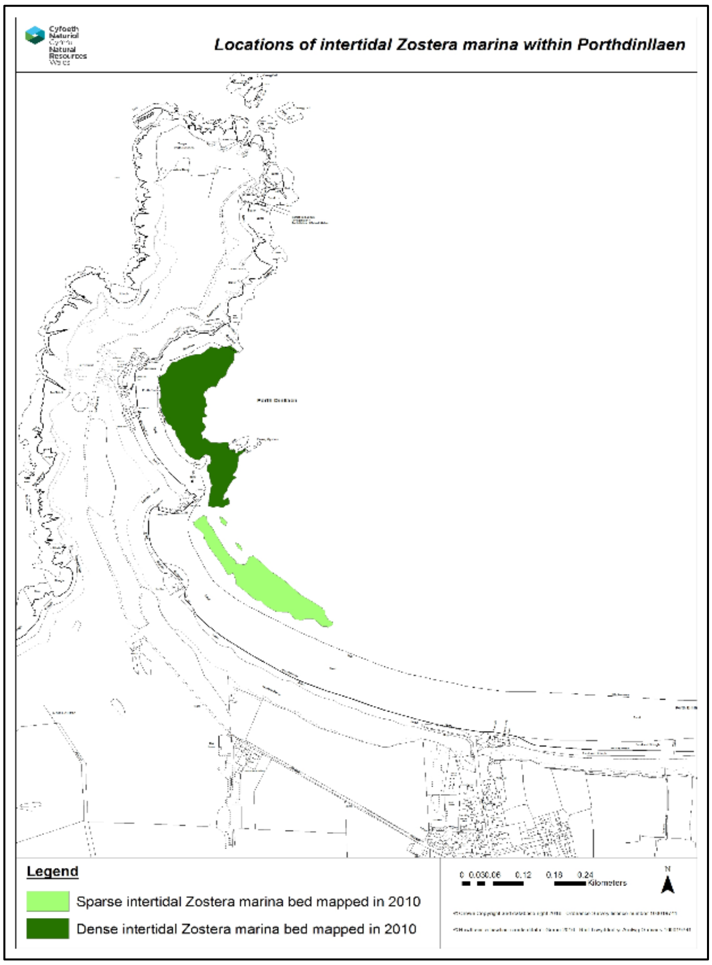


Figure 3 Map of Porth Dinllaen bay and locations of the two distinct *Z. marina* beds from the PLAS SAC monitoring survey 2010 (Mercer 2011)

Additional intertidal work has been conducted by Swansea University since 2013 as part of the Porth Dinllaen Seagrass Project managed through the Pen Llŷn a’r Sarnau SAC partnership. Subsequently Project Seagrass (a charity established within the Sustainable Places Research institute, Swansea University) has continued additional intertidal monitoring using the ‘seagrass watch’ method to collect the data (monitoring proforma -). Under this work, seasonal intertidal surveys within the intertidal zone have been conducted since 2013, where data on percent cover, blade length, density, epiphyte cover and presence and abundance of seagrass seeds have been collected. Under the work carried out by Swansea University, seagrass from Porth Dinllaen has also been sampled for carbon, nitrogen and phosphorus concentrations from the leaf tissues to gain knowledge of the health of seagrass meadows in the British Isles (Jones & Unsworth 2014; Jones 2014).

As well as chemical measurements, morphological measurements such as leaf width/ length and number of leaves per shoot were measured. The ratio of C:N acts as an indicator for light availability and the sampling of C:N:P assists in giving an indication of the status of the water quality within the location of the seagrass meadow (Jones & Unsworth 2014). Within a study sampling at several locations in the British Isles, Porth Dinllaen had one of the lowest C:N ratios (<15) which is an indication of light limitation. Combining the chemical and morphological measurements can help to form a picture of how changes in the quality of the surrounding environment can influence the *Zostera* (Jones and Unsworth 2014).

In addition to the SAC-related monitoring and work by Swansea University, water quality monitoring has been undertaken annually at Porth Dinllaen by NRW since 2013 as part of the Wales programme of bathing water monitoring. Samples from within the bay have been primarily analysed for bacteria (e.g. *E. coli*), with sparse data collected on nutrients.

Table 1 Porth Dinllaen SAC monitoring survey reports and data collected during the surveys

Monitoring Events	**1997 (Phase 1)**	**2004**	**2010**	**2016**
Biotope Mapping	✓			
Extent Mapping	✓	✓	✓	✓
Quality Measurements				
% Cover			✓	✓
Density (Blade Count)		✓		
Algal %			✓	✓
Associated Fauna/Flora		✓	✓	✓
Disease Index		✓		
Damage Assessment		✓	✓	✓
Mooring Lengths and Damage			✓	✓
Reference	Brazier *et al.* 2007	Boyes *et al*. (2008)	Mercer (2011)	Unpublished
Predicted tide height (m) on date of survey	-	0.4m	0.48	0.24

1.2.3 Monitoring Objectives

The Pen Llŷn a'r Sarnau SAC feature reported on here is:

Feature / attribute	**Site(s)**	**Purpose**
Mudflats not covered by seawater at low tide	Porth Dinllaen	To monitor the distribution, extent, abundance and damage of eelgrass *Zostera marina*

The primary objective of the 2016 SAC monitoring reported here at Porth Dinllaen was to map the current known intertidal extent and distribution of *Zostera marina*, collect data on abundance and quality across the bed and report on damage or observed impacts to the intertidal *Zostera marina* bed (such as vehicle tracks, moorings and dumping of waste e.g. scallop and crab shells).

2 Methodology

2.1 Mapping the extent of the intertidal seagrass bed – field methods

The methodology used in the 2016 monitoring event was adapted from Boyes & Mazik (2005). To map the extent of the intertidal seagrass bed, surveyors walked along the shore with GPS units in tracking mode and followed the edges of the seagrass bed using a prescribed methodology to map isolated and small areas of the bed. The same method was as used as described in Brazier (2013) and Boyes & Brazier (2008). Following the survey, the GPS units were downloaded and presented in the GIS software package, ArcGIS. The tracks demarcated the edge of the bed and was converted into polygons showing the area covered by *Zostera marina.*

2.2 Mapping the extent of the intertidal seagrass bed using aerial imagery

During periods where no field surveys were undertaken, aerial imagery was used to observe whether the extent of the seagrass in Porth Dinllaen could be determined. Aerial imagery for 2001, 2006, 2009 and 2013 were imported into ArcGIS along with the GPS data collected during the SAC monitoring surveys. To ensure that the polygons were consistent the landward (upper most) lower seaward boundary collected from the SAC monitoring survey was used.

In ArcGIS, a polygon was created around the boundary of the dark dense patches of seagrass, to define the *Z. marina* extent. The seaward boundaries for the 2004 and 2016 monitoring surveys were adjusted to match those used for the aerial imagery and 2010 monitoring survey areas. 2010 seaward boundary was used as it was the highest (seaward) limit of the bed during the SAC monitoring field surveys. By ensuring that the seaward boundary was fixed for all the polygons it removed any variability between the different tide heights. It also ensured a fixed baseline lower limit for field surveys and the aerial imagery.

The area of the polygon from the aerial photographs was determined by using the 'calculating the geometry' tool in ArcGIS. The polygons from the 2004-2016 fieldwork were layered over each other allowing for the visualisation of the extent over the years. Imagery used can be found in Appendix 10.

2.3 Seagrass abundance and quality of the intertidal seagrass bed

Prior to undertaking the fieldwork, a grid of sampling stations 50 m apart along a series of transects running in a west-east direction was created over the area of the intertidal *Zostera marina* bed based on previous survey data using ArcGIS (Figure 5). This sampling grid was then used in the field. Two pairs of surveyors using portable Garmin 64 GPS units with uploaded positions of the sampling stations undertook more detailed measurements at each sample point.

At each sampling station a 0.5 m x 0.5 m quadrat was placed on the seagrass bed and a photograph was taken (see Figure 4). *In situ* recording of percent cover of seagrass and of conspicuous species was undertaken within the quadrat. Species were recorded as percent cover for cover organisms (algae, barnacles, etc.) and as a semi-quantitative abundance for other organisms (Few, Some, Lots). The subjectivity of this method probably means that the results will be presented as Presence/Absence. The MNCR SACFOR scale was considered, but this method performs badly on a quadrat scale. Total counts are also not possible, due to the cryptic nature of the understorey of the seagrass and the limited amount of time available during survey.

The recording methodology is given in Appendix 1 and the recording proforma used in the field is given in Appendix 2.

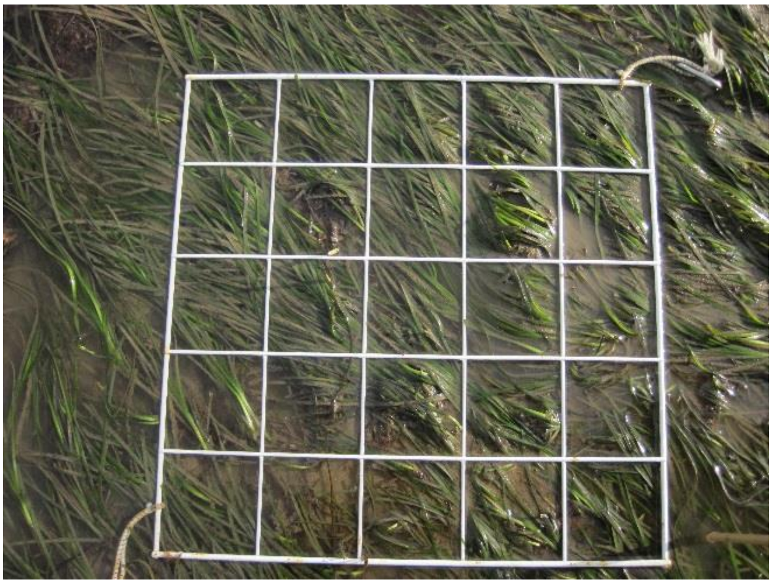


Figure 4 Quadrat positioned on the seagrass bed (20160919 NL Porth Dinllaen 0473)

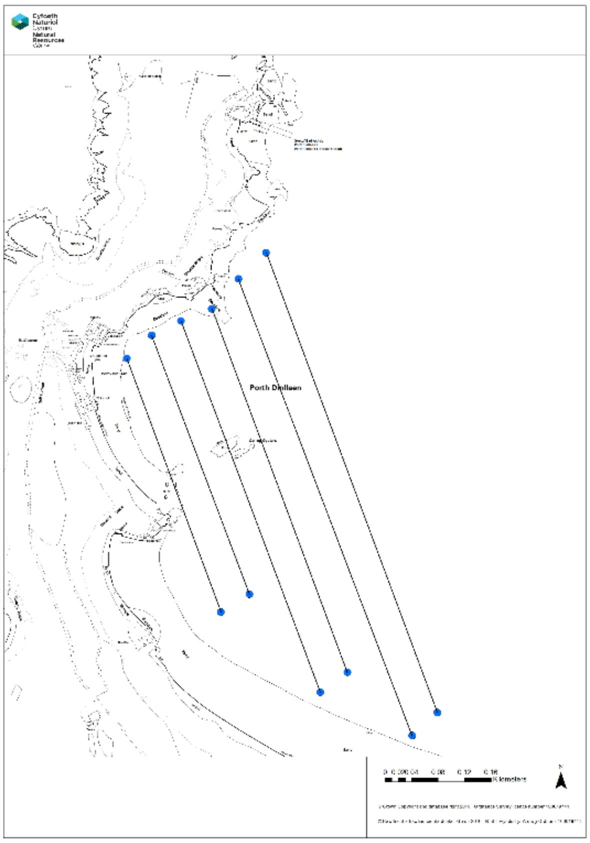


Figure 5 Grid created for quadrat sampling in and around the *Zostera marina* bed 2016

2.4 Damage and impacts to the *Zostera*

2.4.1 Vehicle tracks, deposit of waste and other non-mooring related impacts

The methodology for assessing damage and impacts to the *Zostera marina* bed used a 10 m x 10 m 'super-quadrat' which was measured using a tape and marking poles, with observations on damage type and severity made within each quadrat area. The 10 m x 10 m quadrats were repeated at 50 m intervals along the same north-south transect lines used for the smaller quadrat sampling stations described in section 2.3 above (Figure 5). In each 10 m x 10 m quadrat impact / damage and the damage type was noted and a damage index was used to determine a relative damage score. The recording proforma used in the field is in Appendix 3.

Figure 6 Discard of crab shells smothering parts of the seagrass (20160919 LK Porth Dinllaen 2283)

Figure 7 Tyre tracks observed over the seagrass, creating deep depressions (20160919 NL Porth Dinllaen 0475)

2.4.2 Mooring impacts / damage

Figure 8 Mooring that consists mainly of rope (20160919 BW Porth Dinllaen 0041)

Figure 9 Pooling effect in the seagrass caused by a mooring chain (20160919 BW Porth Dinllaen 0044)

The impact of all the intertidal moorings accessible on the low tide on the 19th October 2016 was assessed. At each mooring, a waypoint of the mooring location was taken using a GPS. The area around each mooring was photographed, the chain and rope length of the mooring was measured and an estimate of the area (m2) impacted by the mooring was made.

2.5 Healthy, safety and logistics

A Survey Plan and Risk Assessment were prepared and distributed to all the surveyors in advance of the survey. It included information on the survey location, work scope and plan, logistics, tide tables, potential hazards, assessment of risk from those hazards, actions/measures to minimise risk and contact details for emergency services, personnel and next of kin.

Field survey equipment included handheld GPS navigators (various makes and models, all set to British National Grid display), digital cameras (various makes and models, all set to high resolution and local time), 0.5 m x 0.5 m quadrats, weatherwriters and recording sheets and tape measures.

Microscopes, identification guides, laptop computers, laser printer and other field laboratory equipment were provided by ASML and NRW. GIS mapping software (ArcGIS), Microsoft Office software, Apple Aperture photo-cataloguing software and various other utilities were used for survey planning, data entry, downloading GPS data and digital photographs and cataloguing files.

2.6 Data analysis

This report presents the data obtained during the field survey in 2016 and considers it in the context of previous spatial data for the *Zostera marina* bed at Porth Dinllaen from the 1997 Phase 1 survey and 2004 and 2010 SAC monitoring surveys. The data analysis in the report covers spatial extent of *Z. marina*, % cover of *Z. marina* within quadrats, species present, impacts and mooring damage.

In addition to the field data, aerial imagery dating back to 2000 (Appendix 9) was used to investigate whether the extent of the *Zostera marina* bed at Porth Dinllaen could be measured from the aerial images for the years where no SAC monitoring took place.

The upper most seaward limit of the bed was based on the 2010 field survey data, when the bed was mapped on a low tide of 0.48 m. However, 2004 had the lowest tide of 0.4 m, but the seaward boundary for the 2010 SAC monitoring survey was higher, this may have been due to the atmospheric effects influencing the tide heights during the survey period. By using this datum for the seaward boundary, it ensures a more reliable comparison between the field surveys and aerial imagery.

The mean percent cover of *Z. marina* recorded from the field surveys was plotted on maps of Porth Dinllaen bay as graduated coloured squares in ArcGIS. Data on impacts from 2004, 2010 and 2016 field surveys were also plotted as coloured squares to visualise impacted regions within the seagrass.

Data analysis in this report is limited at present due to the size of the datasets, however it does include some comparable analysis of the results of the distribution and abundance of *Z. marina* from the different survey events.

The mean percent cover of *Z. marina* was calculated using Microsoft Excel for the 2016 dataset. Statistical analysis was carried out using regression analysis and ANOVA in

Microsoft Excel to determine relationship significance of extent from 2000 to 2016 which is the combination of aerial imagery and field work extent.

2.6 Quality Assurance

All the surveyors that participated in the field work were trained in the methodology to ensure consistency between results. A strict protocol was followed when creating the boundary of the *Z. marina* bed within the aerial imagery for consistent results (Appendix 10).

Species in Appendix 7 have been named according to WORMS and entered into the Marine Recorder database

2.7 Photography

Pictures included general location shots together with pictures of each quadrat and other subjects thought to be relevant to the survey. Jpeg photographs from individual cameras were re-named using the following convention:

'Date (year month day)' underscore 'Photographers Initials', underscore 'Survey location' underscore 'photograph number' e.g. 20160919_LK_Porth_Dinllaen_2283.jpg.

The photographs were organised using Apple Aperture software where captions and keywords were added. A catalogue of photographs was exported to Microsoft excel and this is included in Appendix 8.

3 Results

The results of the studies into the distribution and abundance of *Zostera marina* in Porth Dinllaen Bay are presented below. Data pertaining to the quadrats including sediment characteristics and presence of associated biota are presented in Appendices 6 and 7.

A full catalogue of photographs taken during the survey and archived by NRW is provided in Appendix 8.

3.1 Extent of intertidal *Zostera marina* in Porth Dinllaen bay from field surveys

A map showing the extent of *Z. marina* mapped in 2016 by surveyors during the field survey is shown in Figure 10. Figures 11 and 12 show the extent of *Z. marina* recorded from the 2004 and 2010 PLAS SAC monitoring surveys. These maps also illustrate the variation in the height of the seaward boundary of the seagrass bed, dependent on the height of the tide at the time of survey.

The largest extent of *Zostera marina* was recorded during the phase 1 survey in 1997, where a total of 7.08 ha was recorded (Figure 13). In 2016 the total intertidal extent of *Z. marina* was 2.95 ha (Figure 10), which was the lowest extent recorded during the PLAS SAC surveys.

Data from the Phase 1 survey (1997) have been removed from the analysis as it was an estimated extent of the intertidal *Z. marina* bed (that included 'potential' habitat) that is considered to be an overestimate.

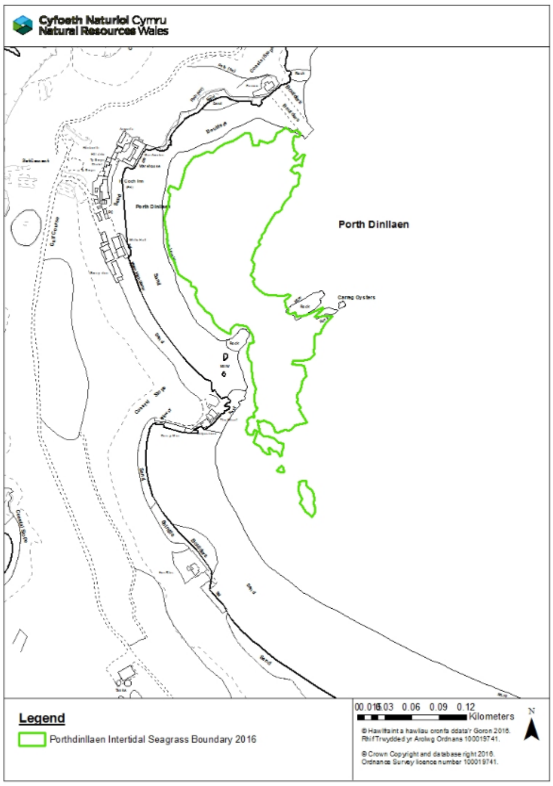


Figure 10 Extent of the *Z. marina* obtained by walking around the boundary with a handheld GPS, **2016**

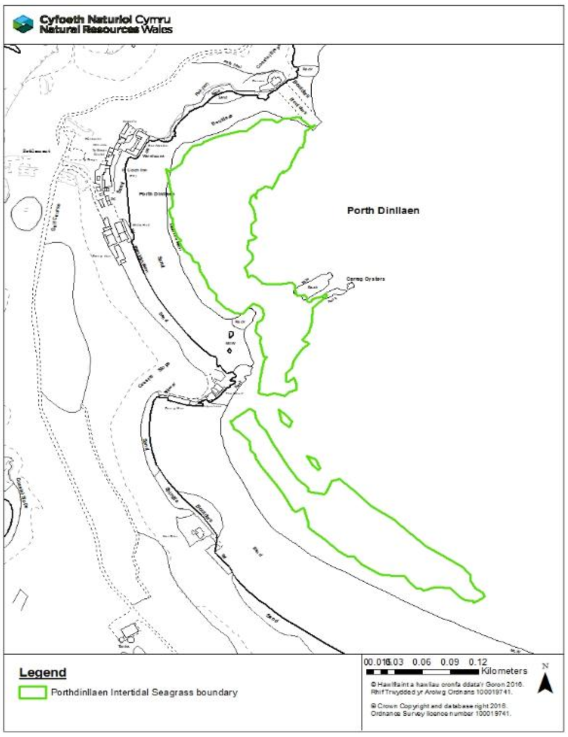


Figure 11 Extent of the *Z. marina* obtained by walking around the boundary with a handheld GPS, **2010** (Mercer 2011)

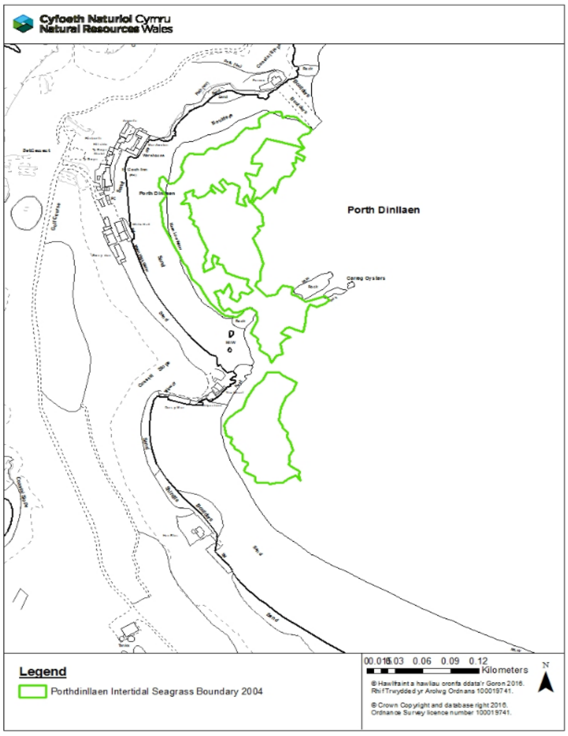


Figure 12 Extent of the *Z. marina* obtained by walking around the boundary with a handheld GPS, **2004** (Boyes *et al.* 2008)

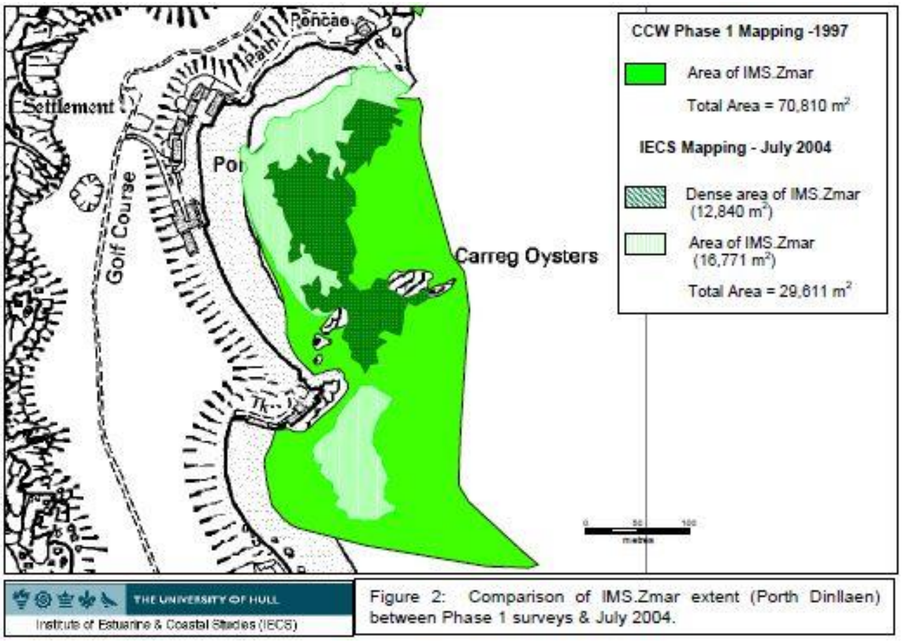


Figure 13 Comparison of the *Z. marina* extent between Phase 1 surveys and SAC monitoring survey 2004 (Boyes et al. 2008)

The results of the whole bed (i.e. the joint area of the north and south seagrass beds taken together) show that the 2016 survey had the lowest total area (2.95 ha) of *Z. marina* recorded in comparison with the 2004 and 2010 monitoring surveys (Figure 14). However, there are some possible issues regarding the mapping of the more southerly seagrass bed. In this area, the seagrass tends to exist as more isolated clusters, and differences in mapping during separate field events may result in variation where small clusters are either mapped individually or are mapped as a larger, single area. This variation is possible through differences in how the mapping protocol is implemented in the field and is most problematical where there are many small areas of seagrass in proximity to each other. The south bed is also more prone to wave action and is known to be variable in its density and patchiness of seagrass.

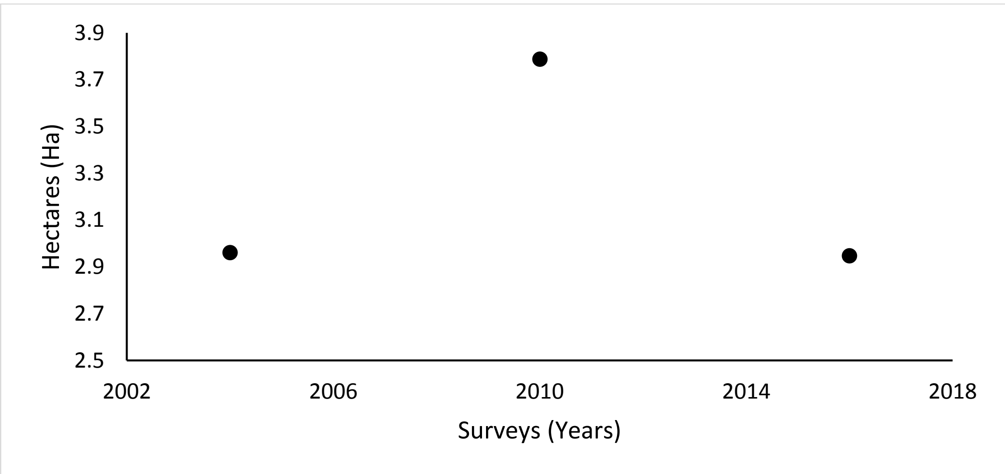


Figure 14 Total extent (ha) of intertidal *Zostera marina* from 2004-2016 (north and south beds combined). Data collected from field mapping of the seagrass bed during intertidal SAC monitoring events

To observe changes to the continuous area of the north seagrass bed, the polygon for the more southerly bed was removed from the calculations (Table 2). As described above, this area of seagrass (see Figure. 3) can have a highly variable extent and density of seagrass and removing it from the calculation gives a better indication as to the extent of the main (core) part of the continuous bed adjacent to Porth Dinllaen village (Table 2). For the north bed, between 2004 and 2010, the data indicates a small increase from 2.33 ha to 2.42 ha, and between 2010 and 2016 an increase of just over 0.5 ha from 2.42 ha (2010) to 2.89 ha (2016) (Figure 15). These figures do not take account for the variable seaward limit of the seagrass bed, due to differences in tide height during survey. For this reason, the data in Section 3.2 provide a better measure of the *Z marina* in the bay.

Table 2 Extent of the *Z. marina* bed from intertidal monitoring surveys at Porth Dinllaen in 2004, 2010, and 2016

Report	Year	Tide Height (m)	Area of north and south bed (ha)	Continuous area of the north bed (ha)
Brazier *et al.* 2007	1997	0.03	7.08	-
Boyes *et al.* 2008	2004	0.40	2.96	2.33
Mercer 2011	2010	0.48	3.79	2.42
This report	2016	0.24	2.95	2.89

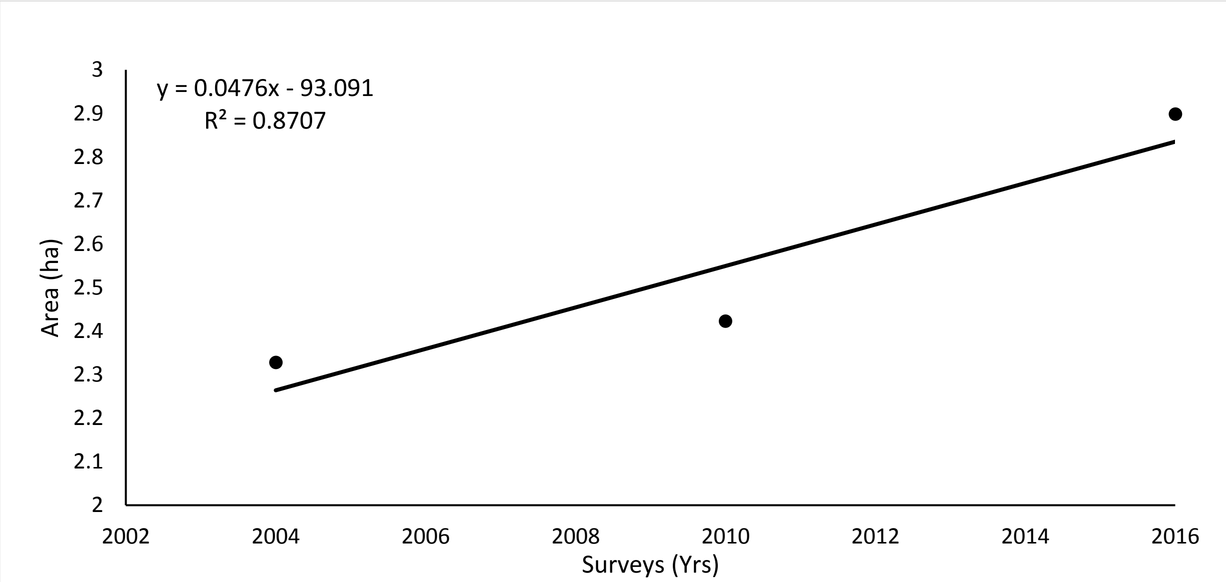


Figure 15 Extent of intertidal *Zostera marina* in Porth Dinllaen from 2004 to 2016 with the sparse south bed removed. Data collected as part of intertidal SAC monitoring

3.2 Extent of continuous *Zostera marina* derived from aerial imagery

To observe the extent of *Z. marina* in Porth Dinllaen prior to the phase 1 survey, aerial images from 1993 and 1996 were studied. Digitised extent data from these images are not available due to the poor resolution of the images, such that clear seagrass bed boundaries could not be determined. However, the fragmented and limited areas of likely seagrass can be seen on the images, for comparison with more recent aerial images (Appendix 10).

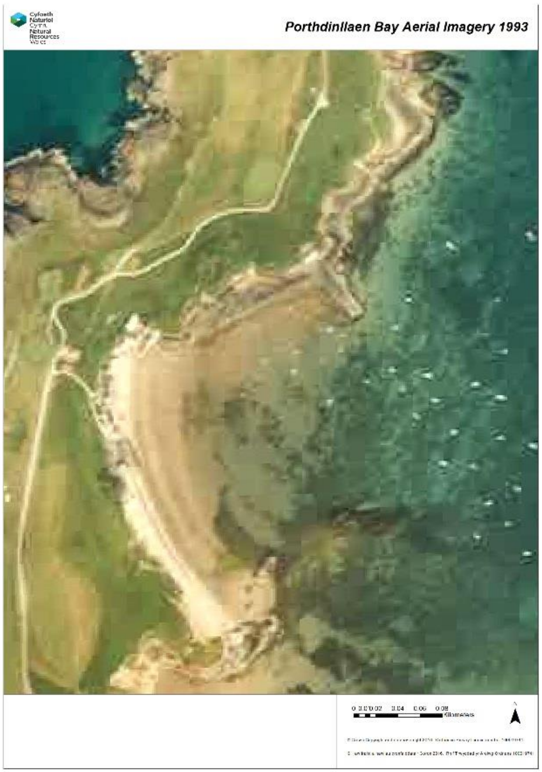


Figure 16 Extent of *Zostera marina* in Porth Dinllaen bay 1993

Figure 17 Extent of *Zostera marina* in Porth Dinllaen bay 1996

The polygons of intertidal seagrass extent were created in ArcGIS from aerial images for the years 2000, 2006, 2009 and 2013 and are shown in Appendix 10. Polygons were only created for the more continuous north *Z. marina* bed and the same lower shore mask was used, to keep the seaward boundary consistent.

The extent of the north *Z. marina* bed calculated from these polygons, together with the extent derived from field surveys over the period 2000 to 2016, are shown in Table 3, Figure 18 and Figure 19.

Table 3 Data used to create the polygons (Figure 19), including the area (ha) and the date the imagery/surveys were conducted

Aerial Data:	**Date**	**Extent of bed (ha)**	**% Change**	**5-year rolling mean (ha)**
Aerial 2000	21/07/2000	1.45	-	1.45
PLAS SAC Survey 2004	06/07/2004	2.24	54.5%	1.85
Aerial 2006	09/06/2006	2.20	-1.8%	1.96
Aerial 2009	01/06/2009	2.28	3.6%	2.04
PLAS SAC Survey2010	15/07/2010	2.40	5.3%	2.11
Aerial 2013	09/06/2013	2.36	-1.6%	2.30
PLAS SAC survey 2016	19/09/2016	2.34	-2.5%	2.32
Total Area Increase		**0.89**		
% Cover increase from 2000-2016			**61.4**	

The data indicate that the extent of the north *Z. marina* bed has increased in extent by 0.89 ha (61% increase) between 2000 and 2016. The lowest extent of *Z. marina* was recorded in 2000 and the greatest increase in extent occurs between 2000 (1.4 5 ha) and 2004 (2.24 ha). From 2004 to 2010 the data show a small overall increase from 2.24 ha to 2.40 ha. From 2010 to 2016 the data show a small decrease in *Z. marina* extent in the north bed from 2.40 ha to 2.30 ha. Regression analysis of the bed from 2000 to 2016 reveals a small positive correlation (r= 0.76, P=0.04, with a R^2 of 0.59). The 5-year rolling mean (a measure used in the Water Framework Directive angiosperm (seagrass) tool), shows a steady increase in extent mean from 2004 to 2016.

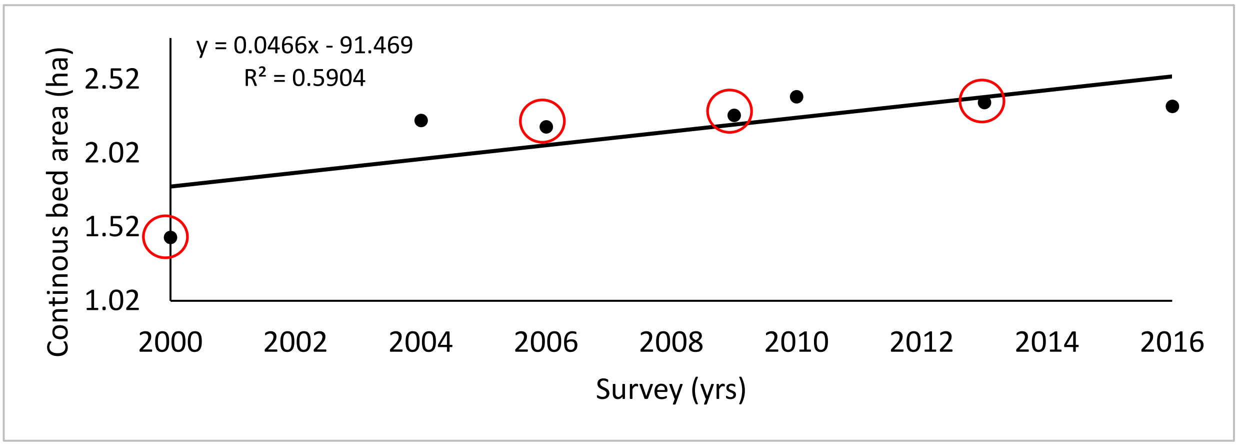


Figure 18 Porth Dinllaen intertidal *Z. marina* extents from 2000-2016 using aerial and SAC monitoring. Circled data points represent the area determined from aerial imagery

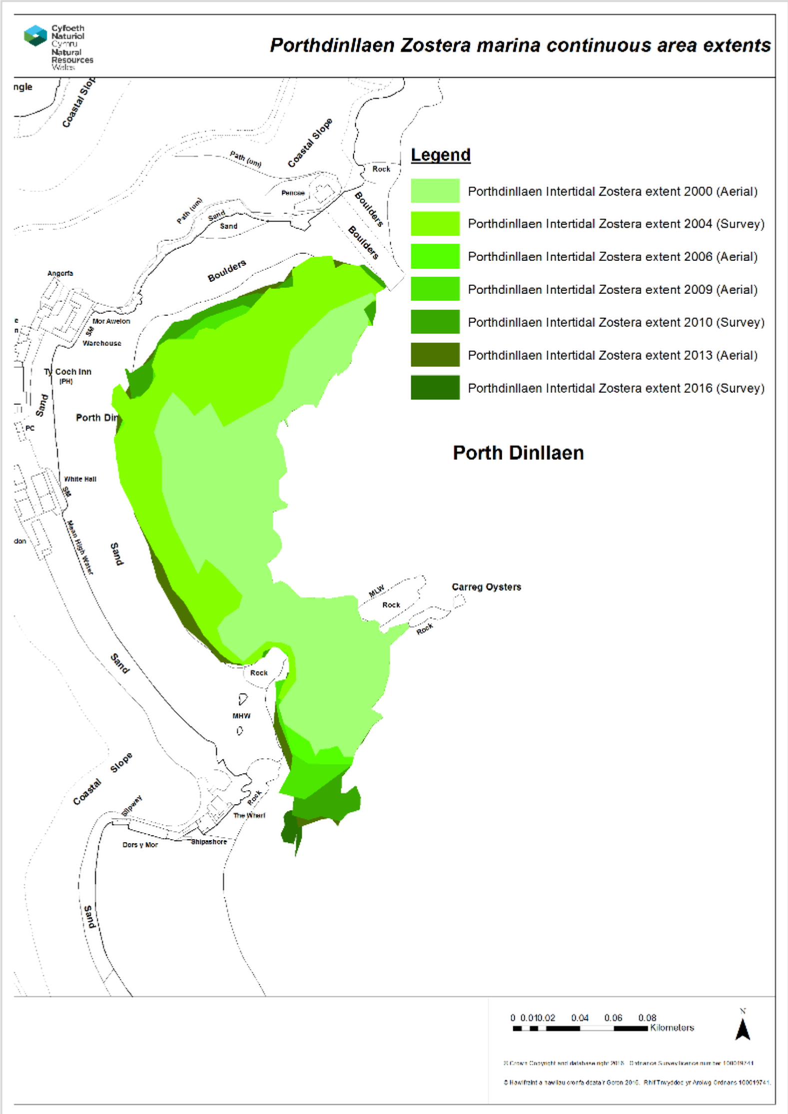


Figure 19 Extent (ha) of the continuous intertidal seagrass at Porth Dinllaen from 2000-2016. Aerial imagery and surveys taken between June-July, shown in Table 3

3.3 Measures of quality and condition of the seagrass bed

In 2016, a total of 16 quadrat sampling stations were completed across the intertidal seagrass bed (Appendix 6). A comparison of the percent cover recorded in 2016 and 2010 are shown in Figures 20 and 21.

The mean percentage cover of live *Z. marina* recorded in 2016 by all surveyors was 47.3%. The lowest percentage of *Z. marina* recorded was 0% (recorded in four quadrats) and the highest recorded was 99%, recorded in only 1 quadrat.

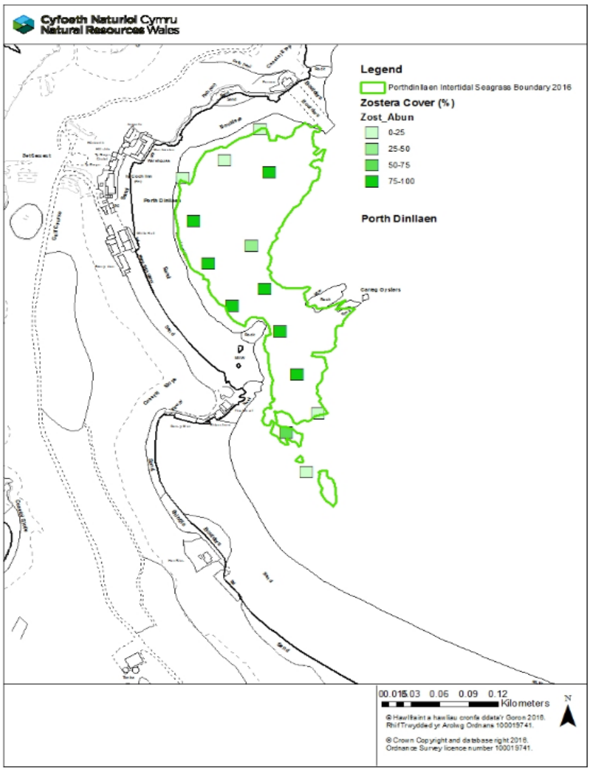


Figure 20 Percent cover of *Z. marina* observed within the quadrats, 2016 survey

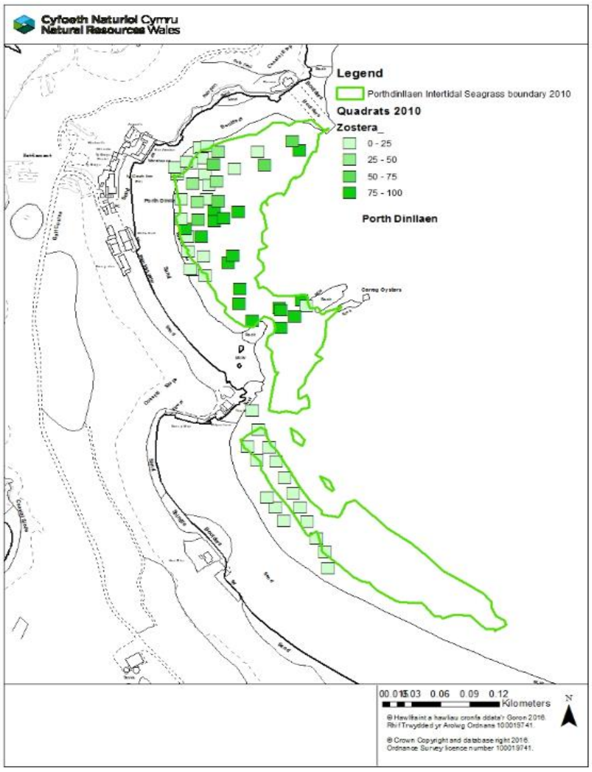


Figure 21 Percent cover of *Z. marina* observed within the quadrats, 2010 survey (Mercer 2011)

The highest percent cover of *Z. marina* in 2016 was located around Oyster rock and away from the regions containing high mooring concentrations. Lowest percent cover of *Z. marina* was in the south bed. This trend matches with the data collected during the 2010 survey, which was a more intensive survey of 53 quadrats. The data from both 2016 and 2010 indicate the greater sparsity of the seagrass within the south bed, which is in a more wave exposed region of the bay.

A total of 13 species were recorded during the survey. The most common species observed within the quadrats during the 2016 survey were peacock worm *Sabella pavonina*, sand mason worm *Lanice conchilega* and daisy anemone *Cereus pedunculatus*. A full comparison of the species observed in previous surveys has not been undertaken for this report.

3.4 Vehicle and other impacts / damage

The results from the survey of vehicle and other non-mooring impacts revealed that 12 of the 14 stations monitored in 2016 had been subject to some sort of impact, most of which was from human activities. Most of the impact was recorded within the more northern area of the north bed, where the highest proportion of intertidal moorings are located. Previous surveys (2004 and 2010) had similar results of higher concentrations of impact and damage occurring in this area of the bed (Figure 22). Figure 23 shows the damage caused to *Z. marina* from vehicles. A few stations had been impacted by erosion of the underlying sediment of the seagrass bed, leaving a very soft clay sediment with very little *Z. marina* present. The exact reason for this is not known and may be a combination of weather events, cyclical processes within the seagrass bed and human impact. During the 2016 survey an additional impact of discarded crab shells was noted which was confined to a few small discrete areas, therefore having a smothering effect on the plants. See Appendix 4 for the data on damage.

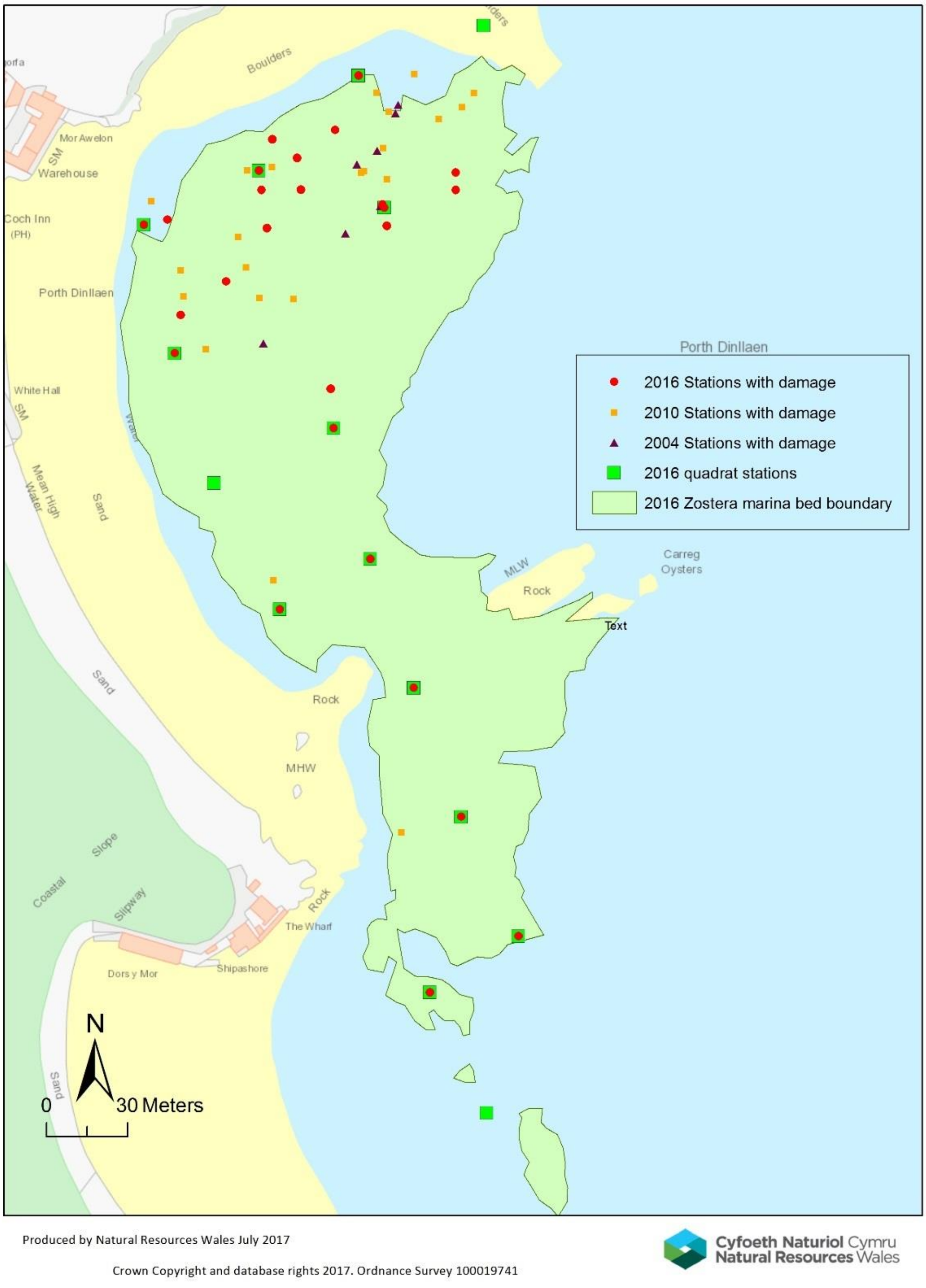


Figure 22 Impact and quadrat locations within Porth Dinllaen bay noted in 2004, 2010 and 2016

Figure 23 Tyre tracks observed over the seagrass, creating deep depressions (20160919 NL Porth Dinllaen 0475)

3.4.1 Mooring Damage

Mooring impact surveys were undertaken to obtain quantitative data on the mooring length (rope and chain) and damage to the surrounding *Z. marina*. Thirteen intertidal moorings were surveyed during the 2016 PLAS SAC monitoring survey (Figure 25). Regression analysis revealed that there was no relationship between the mooring length (rope and chain) and the extent of damage to *Z. marina* within the surrounding area (r= 0.16, P=0.6, with a R^2 of 0.0258).

The highest recorded damaged area was 20 m^2 (Figure 24). No distinct damage differences were observed between moorings with more rope riser than chain, but where there was chain, there was always some damage (Figure 26). Damage was observed surrounding some moorings (Figure 27 and Figure 28) where very little *Z. marina* cover remained. Data on moorings is in Appendix 5.

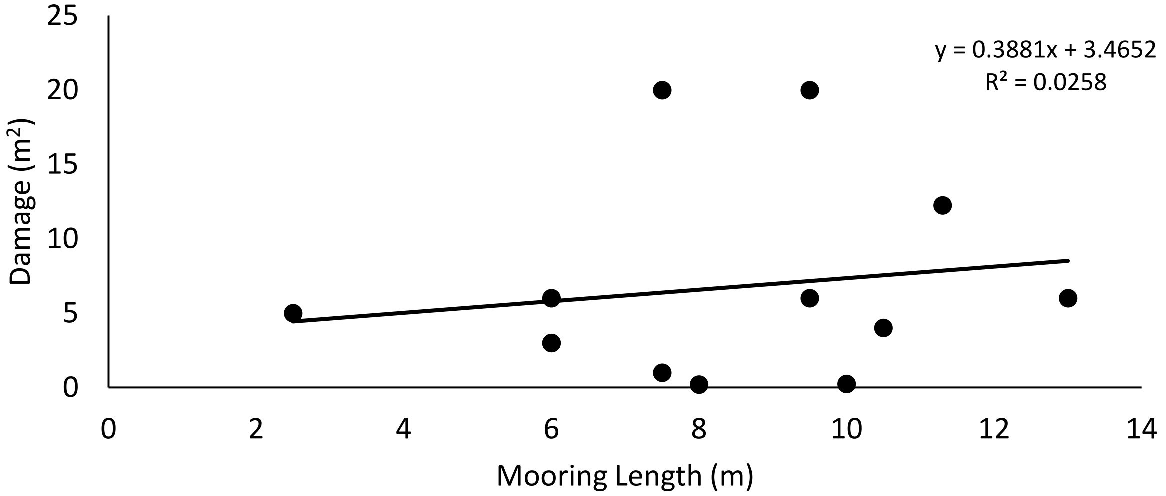


Figure 24 Damage (m^2) surrounding intertidal mooring block in Porth Dinllaen displaying no relationship between total length (m) of riser.

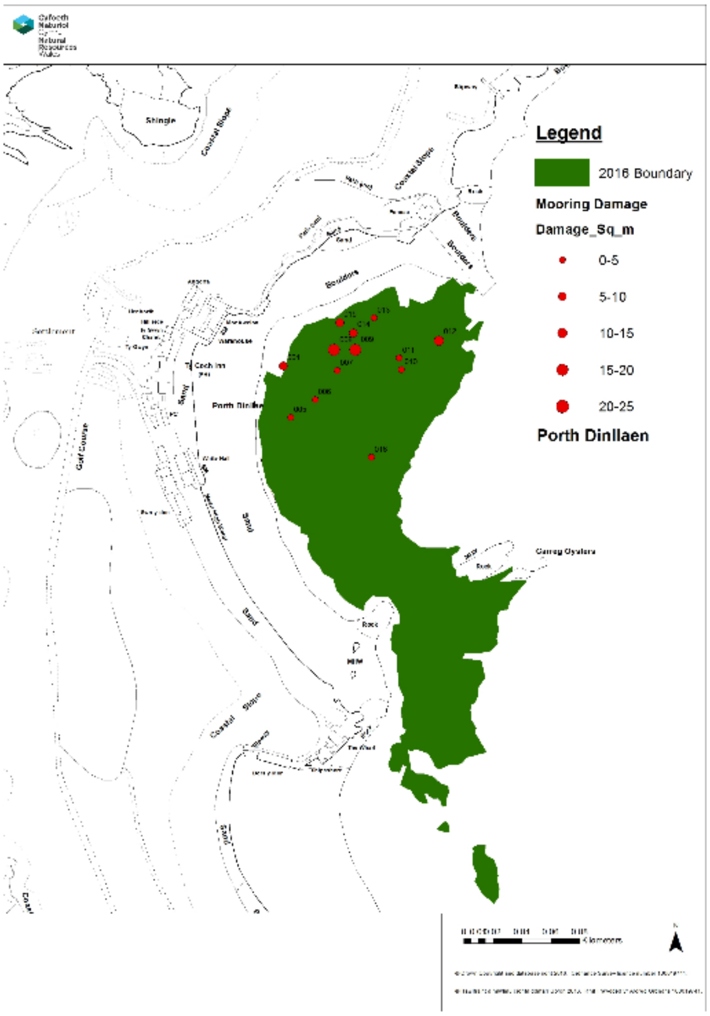


Figure 25 Damaged area surrounding the moorings (m^2), recorded during the 2016 SAC monitoring survey

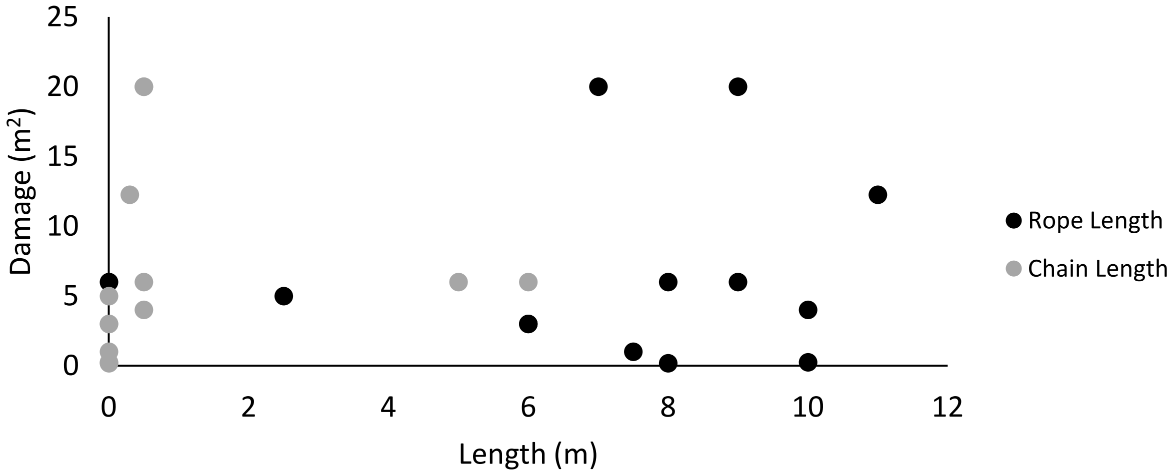


Figure 26 Damage (m^2) caused to the *Z. marina* surrounding the intertidal moorings in Porth Dinllaen and the relationship between mooring chain and rope lengths (m)

Figure 27 Damage caused by the chain of a mooring (20160919 BW Porth Dinllaen 0047)

Figure 28 Plucking damage created by the mooring chains (20160919 BW Porth Dinllaen 0048)

4 Discussion

4.1 Seagrass extent

4.1.1 Results from field survey and condition monitoring

The field survey methodology employed in Porth Dinllaen to study *Zostera marina* was based on that of Boyes and Mazik (2005) and is considered to provide a good framework for further monitoring. Some aspects of the methodology and results obtained are discussed below.

The results from the total extent of *Z. marina* recorded during PLAS SAC monitoring surveys within Porth Dinllaen from 2004 to 2016 revealed that there had been a small decrease in extent (Table 2). Changes in seagrass appear to be along the landward border. The 2016 PLAS SAC monitoring survey was conducted on a low spring tide (0.24 m) which was the lowest where extent mapping had been conducted therefore leading to an extended seaward extent.

Removal of the sparser south seagrass bed showed that there was an overall expansion of over 0.5 ha in the core continuous bed from 2004 to 2016 (Figure 17).

Inclusion of the sparse south bed data increases the variability in the mapped extent (Table 2). To have an accurate extent, larger patches within the sparse region could be mapped as in 2016 (Figure 10), where the small discrete patches were mapped individually. This requires sufficient time during low water and sufficient surveyors to complete the task. Where the seagrass is very sparse (clumps greater than 5 m apart) waypoints could be taken on the GPS to locate the patches during future surveys. Ensuring that the surveyors are briefed on the method required to map the extent decreases the inconsistency and allows for a more accurate extent of the seagrass bed. Removing the sparse region from the analysis allowed for a more accurate estimate for the continuous seagrass bed.

Walking around the boundary of the seagrass bed using portable GPS units set in tracking mode provides an easy method to create a map of the *Z. marina* extent. This method works well in Porth Dinllaen where the substratum is relatively firm. Post survey processing is minimal, but the positional accuracy of the GPS should be acknowledged (+/- 5m). The extent of the intertidal bed can be underestimated due to differences in tide height, undertaking the survey during the lowest spring tide enables optimum results.

Prevailing weather during the survey can lead to poor results. A large low pressure may prevent the tide from reaching its lowest point and a large swell may lead to inaccessible conditions to the seaward boundary. Variability between surveyors may occur but can be reduced by ensuring the protocol is followed along with a briefing before conducting the survey. Surveyors recording in pairs can also reduce the variability as they can moderate any significant differences.

4.1.2 Results from polygons derived from aerial imagery

Extent polygons created from aerial imagery in ArcGIS also revealed an increase of *Z. marina* in Porth Dinllaen from 2000 to 2016. The use of extent polygons from aerial imagery may lead to an underestimation of *Z. marina* as small clumps around the densest bed may not be visible from the imagery. Overestimation of the extent could also occur due to some dark regions being macroalgae (seaweed) which cannot be clearly distinguished from aerial imagery. Therefore, a protocol (Appendix 10) was followed to reduce the underestimation. Only the observable dense (dark) regions of the meadow were mapped to increase accuracy of the polygons.

Using aerial imagery is useful to observe the extent of the seagrass bed during years where no SAC monitoring has taken place, but it has several limitations and inaccuracies. Due to the quality of the imagery it is not possible to determine sparse regions of the seagrass, and it is difficult to distinguish between seagrass and macroalgae potentially leading to an overestimation of *Z. marina* bed extent in some regions of bay. The digitiser creating the polygons must be competent at identifying the seagrass from aerial images. The limits of precision are defined by the limitations of the method (creating polygons) and must be considered in presenting these results. The use of a drone to provide much greater resolution aerial imagery should be considered (Brazier 2013).

4.1.3 Field survey and aerial imagery data combined

Based on the combined field and aerial image-derived data the 61% increase in extent of seagrass in the continuous north bed from 2000 to 2016, is primarily to the landward edge of the bed and south of Oyster rock. As no field surveys were conducted during the periods where aerial imagery was taken, no comparison of the aerial and field extent comparison can be conducted to determine the degree of error and reliability for using aerial imagery. Protocols (Appendix 10) were followed to ensure that the aerial extent mapping was done consistently throughout the years and the results didn't vary dramatically between the aerial and field. Setting a fixed seaward boundary aided in removing the variability caused by different tide heights during the PLAS SAC field surveys. Considering the potential degrees of error in using the method, we are confident that there has been an increase in the extent of *Z. marina* within the north bed in Porth Dinllaen.

Aerial images from 1993 and 1996 (Figures 16 and 17) also indicate that the extent (7.08 ha) from the Phase 1 survey was an approximation. Observations from the 1993 and 1996 images showed that the north seagrass bed was patchy with a less dense patch in the middle which separated two distinct patches. Comparing these images to the recent aerial images also revealed that the less dense patch is still visible within the 2013 aerial imagery. Observations from the images help to back up observations of the increasing extent of the north bed in Porth Dinllaen.

All the monitoring surveys up to 2013 were undertaken between June-July, and 2016 was completed in Sept. The monitoring surveys were all conducted on low spring tides ranging from 0.48 m to 0.24 m. Undertaking surveys during the early spring period may lead to an underestimation of the seagrass bed extent. Surveys undertaken during the Autumn/ Winter period may also lead to and underestimation of the extent due to the seagrass dying back within the winter period or uprooted due to bad weather. It is not clear whether the seasonality of seagrass growth will be reflected in either the extent measure or whether just the density is affected. In *Zostera noltei*, there is evidence that the cover drops very low or to zero during the winter months (Pauls *et al*. 2017).

Aerial images were taken during June-July, allowing all the dates to be consistent. During these months, the water is less turbid, allowing the seagrass boundaries to be more visible for analysis. Tides are high within the aerial images but all are at similar states and conditions.

Figure 18 shows that aerial imagery had a lower average extent in comparison to the field survey, although this was not statistically significant. It is likely that any *Z. marina* bed with less than 20% cover would not show up in an aerial image taken from an aeroplane, so this is no surprise. To observe whether aerial imagery underestimates the extent, a field survey would need to be conducted at the same time as the aerial image is taken, this would then reveal the degrees of error in the extent mapping using aerial imagery.

4.2 Quality and condition of the seagrass bed

During 2016 monitoring, survey data on the percent cover and associated species was gathered. Only 16 stations were surveyed along the transects running NW to SE across the inner bay. Stations close to Oyster rock (south of the inner bay) had higher percentage cover than that of the stations within the northern area of the bay. The lower percent cover of *Z. marina* coincided with regions where anthropogenic and erosion have occurred.

A more intensive survey was conducted in 2010 where a total of 53 stations were sampled. Reviewing the maps (Figure 20 and Figure 21) confirms that the distribution of *Z. marina* in the SE is very sporadic, probably due to the increased exposure to wave action resulting in uprooting the plants during storms. A similar trend is observed within the 2010 data where percentage cover increases around Oyster rock where there are more sheltered conditions. Low cover is also observed within the northern area of the bed with high mooring concentration at the seaward edge, reflecting the issue of damage and scouring caused by moorings.

In addition to the quadrat data, notes on whether the *Z. marina* contained seeds were made during the 2010 survey. To obtain more data on the health of the bed, blade density was measured, this was only done as part of the monitoring methodology in 2004 (Boyes *et al.* 2008). Conducting thorough surveys, including blade density is more time consuming and would require more resources to repeat frequently. Seasonal data collected by Project Seagrass as part of Seagrasswatch (since 2013) could contribute to a better overall picture of the health of the seagrass in Porth Dinllaen. During the seasonal surveys, cores are taken to gather data on the seedbank of the *Z. marina* bed. The combination of PLAS SAC monitoring surveys and Seagrasswatch data is beneficial to understand the overall variability and health of the intertidal bed in Porth Dinllaen.

4.3 Impacts

The most frequent impact and damage observed on the seagrass bed during the 2016 SAC monitoring survey were moorings and vehicle tracks. Vehicle tracks were studied, with detailed experimental observations in Pauls *et al.* (2017).

The north end had the highest concentration of moorings and has the highest number of observations of impact (Figure 22). Around Oyster rock there are signs of erosion which is impacting the bed where plants are more susceptible to uprooting when sediment is lost. Future work would be required to observe whether this is a natural activity or whether human impacts have exacerbated the erosion.

Sargassum muticum was also recorded as present within the seagrass bed (Figure 29), but no quantitative data were collected on the abundance of *S. muticum* within the intertidal seagrass meadow. Observations in 2010 suggested that scour marks become stonier due to winnowing of sand and mud, resulting in the opportunity for large plants of *S. muticum* to establish, which in turn may impact on *Z. marina* through shading the *Z. marina*. Gathering more quantitative data on the presence of *S. muticum* would aid in determining whether the *S. muticum* is increasing within the bay.

Figure 29 *Sargassum muticum* within the seagrass (20160919 LK Porth Dinllaen 2267)

This type of survey technique provided an effective method to document and map impacts such as these on the seagrass bed. Surveyors could go back to the impacted area and observe recovery or decline of seagrass following the impact.

4.3.1 Moorings

Quantitative data on the damage surrounding moorings did not relate consistently with the length of the mooring lines alone, other factors are likely contributing to the impacted area.

Since the intertidal moorings are blocks that are not replaced on an annual basis, the extent of damage e.g. 20 m^2 cannot be determined by mooring chain and rope length alone. Ground evidence and photographs (Figure 27 and Figure 28) do confirm that there is an impact from the moorings but the quantitative data does not back up the theory that the damage is caused directly by moorings alone. Chains on moorings can lead to a ‘plucking’ effect when dragged along the substrate thus leading to the uprooting of *Z. marina* (Figure 28). Larger damaged areas may be caused by small impacted areas becoming bare and merging together to form a larger damaged area. As *Z. marina* is uprooted from the impacted areas, it causes the substrate to destabilize allowing *Z. marina* to be easily uprooted during impacts such as storms, wave action and boating, therefore causing the small impact areas to expand.

Previous data collected from the 2010 PLAS SAC monitoring survey are not directly comparable with the 2016 survey as different measurements were taken. Chain length only was measured in 2010 whereas total length, chain and rope length and details on the surrounding damage were measured in 2016.

The seasonal and annual nature of changes to moorings, boat size and hull type means that data with multi-year gaps cannot fully describe the impact. A sampling strategy that is on a time-scale comparable to changes in moorings (months) is required to fully understand and evaluate the nature of the impacts. Other variables such as windage, where single events (storms) may have a substantial effect, further confound attempts to understand the impacts. These data are however, useful to observe the recovery of the seagrass following the impact. An agreed protocol is essential to compare between surveys results. In future, it would be useful to have mooring line length details which could be provided by the National Trust when mooring checks are conducted.

4.4 Sampling

Proforma completion at each sampling station proved to be time consuming but briefing of surveyors prior to fieldwork ensures that they have optimal time at the site. Having two surveyors agreeing in the field reduces surveyor bias and single operator error. Taking photos of quadrats allows for the station to be reviewed later if queries are raised.

4.5 *Zostera marina* distribution and trend in Wales

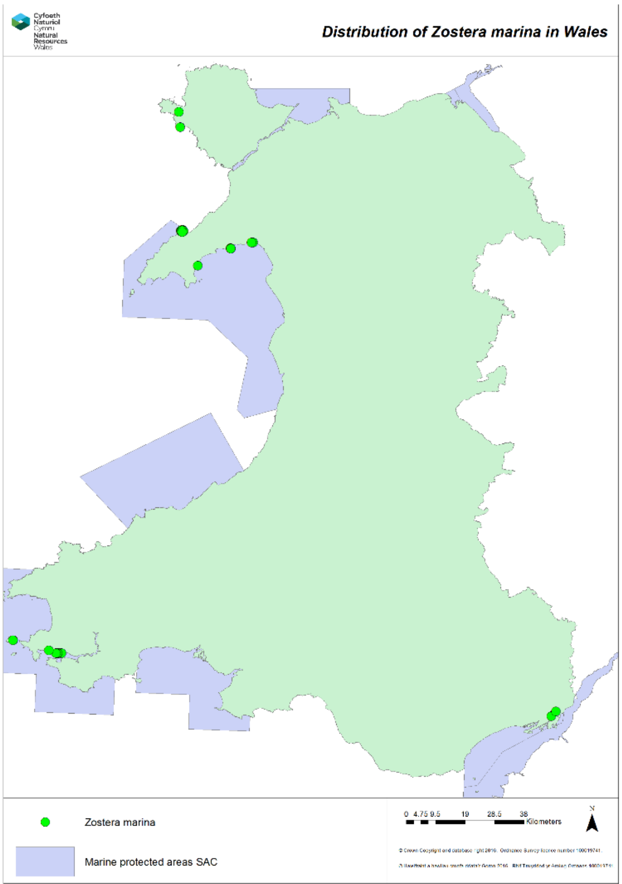


Figure 30 Distribution of *Z. marina* sites in Wales, also the Special Areas of Conservation in Wales

Since 2000 the number of *Z. marina* beds have increased in Wales. Mieszkowska *et al.* (2013) suggested that there had been a 27.8 ha (4.9%) increase of seagrass beds in

Wales (Boyes *et al.* 2009; Howson 2009; Mercer 2011). Most of the *Z. marina* beds are subtidal, only a few occupy the intertidal zone with the Severn having the largest intertidal bed. This bed is monitored regularly by NRW WFD teams.

Subtidal *Z. marina* in North Haven in Pembrokeshire (within the Skomer Marine Conservation Zone) has been monitored since 1979, and has been monitored roughly every 4 years since 1997 (Burton *et al.* 2014). Following the 2014 survey, the bed was the largest since the initial survey in 1979. In 1982 the extent of the seagrass bed recorded was 0.39 ha, whereas an extent of 0.82 ha was recorded in 2014. Changes in the extent of other *Z. marina* beds in Wales (Figure 30; Table 4) are unknown as they have only been mapped on *ad hoc* occasions and not monitored on a schedule.

Table. 4 Sites where *Z. marina* beds are present, including the periods where the extents were recorded or estimated following observations in the field

Sites	County	Zone	Species	Area (Ha)	Survey organisation	Recent Survey	Comment
Rhoscolyn	Anglesey	S	*Z. marina*	0.68	CCW Subtidal Team	2012	
Inland Sea	Anglesey	I	*Z. marina*	6.25	CCW Phase 1 Intertidal Survey	2004	
Severn Estuary	Monmouth-shire	I	*Z. marina and Z. noltei*	208.90	NRW WFD teams	2014	Recorded presence
Porth Dinllaen	Gwynedd	I	*Z. marina*	2.95	NRW PLAS 2016 SAC monitoring	2016	
Porth Dinllaen	Gwynedd	S	*Z. marina*	28.60	CCW Volunteer diver surveys	2008/09	
Abersoch	Gwynedd	S	*Z. marina*	3.0 ha	Brown, 2015	-	Approximation
Criccieth	Gwynedd	S	*Z. marina*	5.76	CCW Phase 1 Intertidal Survey	1997	Very sparse (estimate)
Pen y Chain	Gwynedd	S / I	*Z. marina*	0.81	CCW/ASML PLAS 2010 SAC monitoring	2008	Very sparse (approximation)
Gelliswick	Pembroke	S	*Z. marina*	22.01	Seascope (Mike Camplin)	2008	
Langoar Bay	Pembroke	S	*Z. marina*	1.03	Seascope (Mike Camplin)	2008	
Skomer	Pembroke	S	*Z. marina*	0.82	Skomer Team	2014	

Zone – I = Intertidal, S = Subtidal

5 Conclusions and Recommendations

Overall the data show that there is an overall extent increase of intertidal *Zostera marina* in the north bed in Porth Dinllaen. It is difficult to determine the trend for the south bed as it is patchy. More field surveys would be required to observe whether its increasing and becoming denser. As there are no quantitative data on the *Z. marina* bed pre-2000, it is difficult to determine whether the bed is increasing or recovering to its original extent pre-wasting disease in the 1930s. More frequent field mapping could lead to a more reliable measure of the extent of *Z. marina* in Porth Dinllaen and will help to determine whether the bed will reach a state of natural equilibrium. The *Z. marina* bed in Porth Dinllaen is susceptible to high energy wind driven waves from the north east. More frequent north easterly winds may lead to a decrease in extent but frequent mapping or surveys would aid understanding of the resilience of *Z. marina* following the natural events. Increased mapping may be possible by integrating the methodology into Seagrasswatch surveys that are conducted seasonally.

Using aerial imagery as a proxy for field survey was useful to obtain data on extent, but numerous variables decreased the reliability of the results. Comparison trials should be carried out looking at extent from aerial imagery and field survey when the aerial imagery is collected to determine mapping errors. There are a variety of environmental and anthropogenic impacts affecting the intertidal *Z. marina* bed in Porth Dinllaen such as sediment erosion, high wave energy, vehicles and moorings. Impact surveys revealed that there is damage to the *Z. marina* bed from moorings but no reliable quantitative data can be determined and explain the whole damage surrounding the moorings. To determine the total impact caused by moorings a recovery study will be carried out by the Porth Dinllaen seagrass project and National Trust. The study will observe whether the *Z. marina* recovers at different rates following different disturbance levels from mooring maintenance. To obtain more information on the water quality and nutrients of the water in Porth Dinllaen water samples collected by the WFD for bathing water analysis could possibly be analysed for nutrients such as nitrogen, nitrites and phosphorus.

Further Work:

- Recovery rate of *Z. marina* following an impact e.g. where a mooring has been removed, removed then replaced and one which has been physically moved – a study being discussed by Porth Dinllaen Seagrass Project and National Trust.
- Study on the impacts of vehicles on the intertidal seagrass in Porth Dinllaen - currently being written (Commissioned by Pen Llŷn a'r Sarnau SAC officer).
- Presence of *S. muticum* and whether more bare areas lead to increased settlement of *S. muticum.*
- Investigate the impact of erosion around Oyster rock, whether it is increasing or decreasing.
- Investigate the degrees of error using aerial imagery to map the extent of *Z. marina* by conducting a field survey during the same period as an aerial image is taken.
- Nutrient analysis of the water in Porth Dinllaen.
- Obtain quantitative data on the flowering and seeding of the bed.
- Determine the overall trend of *Z. marina* in Wales.
- Investigate methods for determining subtidal extent.
- Use of drones to photograph and determine the intertidal and subtidal extent.

6 References

Beck, M. W., Heck, K. L., Able, K. W., Childers, D. L., Eggleston, D. B., Gillanders, B. M., Halpern, B., Hays, C. G., Hoshino, K., Minello, T. J., Orth, R. J., Sheridan, P. F. & Weinstein, M. R. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *Bioscience* 51**,** 633-641.

Bertelli, C.M., & Unsworth, R.F.K. 2014. Protecting the hand that feeds us: Seagrass (*Zostera marina*) serves as commercial juvenile fish habitat. *Marine Pollution Bulletin*. 83 (2), 435-429.

Borum, J., Duarte, C.M., Krause-Jensen, D. & Greve, T.M. (Ed.). 2004. European seagrasses: an introduction to monitoring and management. Monitoring and Managing of European Seagrasses Project (M&MS): [s.l.]. ISBN 87-89143-21-3. 88 pp.

Boyes, S. & Brazier, D.P. 2008. Intertidal monitoring of the saltmarsh boundaries in the Burry Inlet, Carmarthen Bay and Estuaries SAC. CCW Marine Monitoring Report No 51.

Boyes, S. & Mazik, K. 2005. Monitoring of *Zostera noltii* in the Menai Strait and Conwy Bay SAC 2005. Report to CCW. Institute of Estuarine and Coastal Studies, University of Hull. December 2005.

Boyes, S., Hemingway, K. & Allen, J.H. 2008. Intertidal Monitoring of *Zostera marina* in Pen Llŷn a'r Sarnau SAC in 2004/2005. *CCW Marine Monitoring Report No. 28.* Countryside Council for Wales (CCW).

Boyes, S., Brazier, D.P., Burlinson, F., Mazik, K., Mitchell, E., & Proctor, N. 2009. Intertidal monitoring of *Zostera noltii* in the Menai Strait and Conwy Bay SAC in 2004/05. CCW Marine Monitoring Report No 31.

Brazier, D. P. 2013. Evaluating intertidal seagrass *Zostera noltei* beds – field survey vs remote sensing. CCW Marine Monitoring Report No: 103, pp 16 + v, Countryside Council for Wales, Bangor.

Brazier, P., Birch, K., Brunstrom, A., Bunker, A., Jones, M., Lough, N., Salmon, L. & G. Wyn. 2007. When the tide goes out. The biodiversity and conservation of the shores of Wales - results from a 10 year intertidal survey of Wales. Countryside Council for Wales. ISBN: 1 86961 152 1

Brown, D.B. 2015. Modelling the potential distribution of *Zostera marina* in Wales. MRes Thesis. Swansea University

Bull, J.C., Kenyon, J.E. & Cook, K.J. 2012. Wasting disease regulates long-term population dynamics. Oecologia. 169 (1), 135–142.

Bunker, F. StP. D. 2012. Intertidal SAC monitoring *Zostera noltei* in Angle Bay, Pembrokeshire Marine SAC 2008. CCW Marine Monitoring Report No: 81, 51pp + ix, Countryside Council for Wales, Bangor.

Burton, M., Lock, K., Clabburn, P., Griffiths, J., Newman, P., & Jones, J. 2015. Skomer Marine Conservation Zone Distribution and Abundance of *Zostera marina* in North Haven 2014.NRW Evidence Report No 68.

Constanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. & Van den Belt, M. 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.

Connor, D.W., Allen, J.H., Golding, N., Howell, K.L., Lieberknecht, L.M., Northen, K.O. & Reker, J.B. 2004. The Marine Habitat Classification for Britain and Ireland. Version 04.05. [On-line] Peterborough: Joint Nature Conservation Committee. [cited 10/01/2017]. Available from <http://www.jncc.gov.uk/marine/biotopes/default.htm>

Costa, P., Fidalgo, E., Gil, J., Passos, A.M., Pereira, P., Melo, P., Batista, F., & Cancela da Fonseca, L. 2006. The market features of imported non-indigenous polychaetes in Portugal and consequent ecological concerns. Scientia Marina 70, 287-292.

Coyer, J.A., Diekmann, O.E., Serrão, E.A., Procaccini, G., Milchakova, N.G.A., Pearson, S.W.T., & Olsen, J.L. 2004. Population genetics of dwarf eelgrass *Zostera noltii* throughout its biogeographic range. Marine Ecology Progress Series 281, 51 - 62.

Cunha, T., Hall, A., & Queiroga, H. 2005. Estimation of the *Diopatra neapolitana* annual harvest resulting from digging activity in Canal de Mira, Ria de Aveiro. Fisheries Research 76, 56-66.

Davison, D.M. & Hughes, D.J. 1998. *Zostera* biotopes (volume 1). An overview of dynamics and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science. (UK Marine SACs Project). 95pp.

Dyrynda, P. & Lewis, K. 1994. Sedimentary shores within Poole Harbour: Bait harvesting and other human impacts. Report to English Nature (South West Region) from the School of Biological Sciences, Swansea University.

Fonseca, L., Costa, P., & Fidalgo, E. (2008). Poliquetas: sua obtenção, impactos e medidas de gestão. *14º Congresso da Associação Portuguesa para o Desenvolvimento Regional - Ambiente e Conservação da Natureza*, Tomar, Portugal, pp 851.

Greiner, J.T., McGlathery, K.J., Gunnell, J., & McKee, B.A. 2013. Seagrass Restoration Enhances “Blue Carbons” Sequestration in Coastal Waters. *PLOS ONE*. 8 (8), doi: 10.1371/journal.pone.0072469.

Hemminga, M.A., & Duarte, C.M. 2000. *Seagrass Ecology*. Cambridge: Cambridge University Press. 0-521.

Howson, C.M. & Picton, B.E. (eds.). 1997. The species directory of the marine fauna and flora of the British Isles and surrounding seas. Ulster Museum and the Marine Conservation Society. Belfast. 508 pp.

Howson, C. 2009. Intertidal SAC monitoring, Carmarthen Bay and Estuaries SAC (September 2009). CCW Marine Monitoring Report No: 79, Countryside Council for Wales, Bangor.

Hull, S.L, Tobin, M.L., Musk, W.A. & Brazier, D.P. 2008. Intertidal Monitoring of rocky reefs in Milford Haven, Pembrokeshire Marine SAC. CCW Marine Monitoring Report No 42.

Jones, B.L. & Unsworth, R.K.F., R. Soc. open sci. 2016 3 150596; DOI: 10.1098/rsos.150596.

Jones, B. 2014. Development of a potential indicator of ecological status in the British Isles, using the seagrass, *Zostera marina*. MRes Thesis, Swansea University.

Mazik, K. & Boyes, S. 2009. Intertidal monitoring of eelgrass *Zostera noltii* in the Burry Inlet, Carmarthen Bay and Estuaries SAC. CCW Marine Monitoring Report No 53.

Mercer, T.S. 2011. Across-Wales intertidal SAC monitoring, Pen Llŷn a’r Sarnau SAC July 2010. CCW Marine. Monitoring Report No: 88, pp 70 + vii, Aquatic Survey and Monitoring Ltd. Bollihope, Co. Durham.

Mieszkowska, N., Firth, L. & Bentley, M. 2013. Impacts of climate change on intertidal habitats, *MCCIP Science Review 2013*, 180-192, doi:10.14465/2013.arc19.180-192.

Orth, R.J., Tim, J.B., Carruthers, W.C., Dennison, C.M., & Duarte, J.W. 2006. A global crisis for seagrass ecosystems. Bioscience, 56: 12.

Pauls, L., Camplin, M. & Bunker, A. 2017. Anthropogenic impacts on *Zostera noltei* beds. Case study in Angle Bay, Pembrokeshire Marine SAC. NRW Evidence Report xx, Natural Resources Wales

Muehlstein, L.K., Porter, D. & Short, F.T. 1991. *Labyrinthula zosterae* sp. nov., The Causative agent of wasting disease of Eelgrass, *Zostera marina*. *Mycologia*. 83 (2), 180-191.

Pendleton, L., Donato, D.C., Murray, B.C., Crooks, S., Jenkins, W.A. *et al*. 2012. Estimating global “blue carbon” emissions from conversion and degradation of vegetated coastal ecosystems. PLOS ONE 7: e43542. doi:10.1371/journal.pone.0043542. PubMed: 22962585.

Ralph, P.J. & Short, F.T. 2002. Impact of the wasting disease pathogen. *Mar Ecol Prog Ser*. 226 (1), 265–271.

Unsworth, R.K.F., Collier, C.J., Waycott, M., McKenzie, L.J., & Cullen-Unsworth, L.C. 2015. A framework for the resilience of seagrass ecosystems. *Mar. Pollut. Bull.* **100**, 34–46.

WoRMS Editorial Board. 2017. World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. Accessed 2017-07-14. doi:10.14284/170

Appendix 1 Recording Protocols

Sampling points at each site are to be chosen based on a grid system with sampling Stations 50 m apart – this is based on the full extent of the bed.

GPS coordinate and photograph to be taken at each sampling point. Data to be collected using a 0.25 m^2 quadrat gridded at 10 m intervals within each quadrat the following information should be recorded (see recording proforma):

Z. marina cover is to be expressed as percentage cover based on the area of sediment covered by plants. Where less than 5% cover is recorded, the number of plants comprising this percentage should be recorded as one, few or many.

Cover of *Enteromorpha* sp., and the associated faunal species (visible on the surface, these parameters are to be expressed as percentage cover with presence/absence of faunal species being recorded.

A brief description of the substratum (including sediment type, signs of erosion, presence of standing water, ripples, shell debris).

Recording of quadrat data should cease (i.e. the extent of the grid sampling area) when four consecutive quadrats with no *Z. marina* have been recorded. This will effectively give a 100m buffer zone around the *Zostera* bed. In cases where the *Z. marina* bed has clearly ended (e.g. where unsuitable habitat can be seen for over 50m), it is not considered necessary to continue sampling along the transect.

Zostera may not be present within the quadrats but may be present in the surrounding area. It is suggested that the presence of sparse (up to 30 % cover) *Zostera* is recorded with a brief description of general / average density and the extent (if feasible). This will depend on the size of the mudflat and the area available for colonisation by *Zostera.* Any particularly dense patches (>50% cover) should be recorded as points (or mapped boundaries if the area is large enough) and the general characteristics recorded. Any distinctive / good quality patches of *Zostera* of significant size which occur between quadrats should be noted (GPS point, photograph, general description).

The characteristics (sediment type, algal cover, mussel crumble, and associated fauna) of quadrats which do not contain *Zostera* should be recorded to give an indication of the extent of the habitat which could potentially become colonised by *Zostera.*

To remove any bias, the quadrat should consistently be placed in front of the right foot of the navigator.

Evidence of wasting disease, damage and the presence of epiphytes should be recorded as shown below. Damage should be assessed every 50m (10 x 10m area).

To assess the damage caused by moorings, the location of mooring should be marked using a GPS and a photo then taken. The chain and rope length should then be measured and the area damaged estimated (m^2).

Appendix 2 *Zostera marina* recording pro-forma

Sheet number:

Site Name: General OS grid ref:

Date: Surveyor(s):

Weather conditions:

Transect No							
Quadrat No							
Northing							
Easting							
Photo Nos							
Substratum type							
% Z. noltei							
< 5% scale							
% Chlorophycota							
% mussel crumble							
% species A							
% species B							
% species C							
% species D							
% species E							
% species G							
% species H							
% species I							
% species J							
% species K							
% species L							
% species M							
% species N							
Notes							

Appendix 3 Pro-forma for *Zostera* damage

Observations based on a 10 x 10 m area, marked out using poles.

Damage type:

Trampling, quad bikes, Moorings / boats, bait digging, cockle dredging / collection.

Zostera health

- Total percentage cover of *Zostera*
- Uprooted plants as a percentage of the total plant cover
- Dead plants as a percentage of the total cover
- Sedimentation / smothering as a percentage of the vegetated area.

SCORE: **0** = 0% **1** = 1-10% **2** = 11-30% **3** = 31-50% **4** = >51%

Physical Effects

Depressions (foot prints, tracks, holes), degree of churning of the sediment

SCORE:

% of area affected	**0** = 0%	**1** = 1-10%	**2** = 11-30%	**3** = 31-50%	**4** = >51%
Average depth	**0** = <1 cm	**1** = 1-5 cm	**2** = 6-10 cm	**3** = >11 cm	
Average area / size	0 = none	**1** = footprint	**2** = tyre track / hole	**3** = area >5x5 m	
% of area churned	**0** = 0%	**1** = 1-10%	**2** = 11-30%	**3** = 31-50%	**4** = >51%
% standing water*	**0** = 0%	**1** = 1-10%	**2** = 11-30%	**3** = 31-50%	**4** = >51%

*% of area covered by standing water refers to standing water in depressions and holes caused by the activities listed above. It does not include natural areas of standing water.

Frequency

SCORE:

0 – no fresh depressions / holes. Sedimentation in depressions has occurred to the extent that the depressions are barely visible and the cause of the depression is not immediately obvious (e.g. visible tread from tyres). Evidence of re-growth of *Zostera*.

1 – Occasional use. Up to 20% fresh depressions. Other depressions show signs of long term sedimentation (possibly weeks or months) so that sharp edges / distinct features are masked. Evidence of re-growth of *Zostera*.

2 – Regular use. 21-50% fresh depressions. Some sedimentation / smoothing of features. No re-growth

3 – Very frequent use. >51% fresh depressions with little evidence of recent sedimentation (e.g. over the past 5 days). No re-growth

The above is designed to be as objective as possible but will require a degree of common sense / subjectivity in order to assess factors such as the age of features / frequency of use and whether or not standing water is the result of an activity causing damage or appears to be naturally present. This score system should be tested in the field and a score to show favourable conservation status, damage / unacceptable damage determined.

Appendix 4 Intertidal damage survey data, 19th Sept 2016, Porth Dinllaen

Surveyors: LK= Lucy Kay, KR- Kirsten Ramsey, NL= Natasha lough, LG= Laura Grant, BW= Ben Wray.

Quadrat Station Name	Impact Station Name	Easting	Northing	Record-ers	Zostera cover (scale 1-4)*	Damage type	Uprooted plants	Dead plants	Smoth-ering	Depres sions (area)	Depth of depress -sion	Depres-sion area/size	Stand-ing water
ZQA01	ZImp15	227622	341559	NL, LG	0	Vehicle Tracks	1	1	1	0	2	2	4
ZQA04	ZImp22	227672	341416	NL, LG	4	Mooring and Vehicle Tracks	1	0	1	3	3	3	3
ZQB05	ZImp23	227722	341387	NL, LG	4	Mooring	1	0	0	2	3	3	4
ZQB03	ZImp20	227692	341483	NL, LG	2	Mooring	0	0	0	4	3	3	4
ZQC01	ZImp01	227701	341614	NL, LG	1	Mooring	0	0	0	3	3	3	4
ZQA02	ZImp18	227633	341511	LK, KR	4	Vehicle tracks		0	0	1	1	2	4
ZQB07	ZImp25	227760	341295	LK, KR	-	Mooring with anchor							
ZQA07	ZImp26	227728	341274	LK, KR	3	Possible erosion	0	0	0	0	0	0	0
ZQB06	ZImp24	227739	341339	LK, KR	4	Possible erosion	0	0	0	0	0	0	0
ZQB04	ZImp21	227706	341435	LK, KR	2	Erosion of surface: soft clay 20cm deep	0	0	0	0	0	0	0
ZQB01	ZImp05	227664	341579	LK, KR	3	Tracks and mooring	0	0	0	2	1	2	4
ZQC02	ZImp11	227711	341565	LK, KR	4	Tracks and mooring	0	0	0	1	1	2	2
	ZImp09	227736	341569	LK, KR	-	Shellfish Debris	0	0	1	0	0	0	

* scale: **0** = 0% **1** = 1-10% **2** = 11-30% **3** = 31-50% **4** = >51% (see Appendix 3)

Appendix 5 Intertidal mooring survey data, 19th Sept 2016, Porth Dinllaen

Surveyor – Ben Wray, Camera – Olympus TG4, GPS – Garmin GPSMAP

Mooring Station Name	way point	easting	northing	photo number	chain length (m)	Rope Length (m)	Damage (m^2)
ZM01	15	227669	341590	48,49	5	8	6
ZM02	13	227693	341594	44,45	0.5	10	4
ZM03	14	227678	341583	46,47	0.5	9	6
ZM04	8	227665	341572	33,34	0.5	7	20
ZM05	9	227680	341572	35,36	0.5	9	20
ZM06	12	227737	341578	41-43	0.3	11	12.25
ZM07	11	227710	341566	39,40	0	7.5	1
ZM08	10	227712	341558	37,38	0	8	0.19
ZM09	7	227667	341557	32,52	0	2.5	5
ZM10	4	227630	341560	28,29	6	0	6
ZM11	6	227652	341537	31	0	6	3
ZM12	5	227635	341525	30	0	6	3
ZM13	16	227691	341498	50,51	0	10	0.25

Appendix 6 Intertidal *Zostera marina* survey details from quadrats, Sept 2016, Porth Dinllaen

Surveyors: LK= Lucy Kay, KR- Kirsten Ramsey, NL= Natasha lough, LG= Laura Grant, BW= Ben Wray

	ZQA01	ZQA02	ZQA03	ZQA04	ZQA06	ZQA07	ZQA08	ZQA09
Transect	1	1	1	1	1	1	1	1
Waypoint	3	10	4	5	13	14	6	15
Easting	227622	227633	227648	227672	227710	227728	227749	227763
Northing	341559	341511	341463	341416	341320	341274	341229	341176
Date	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16
Surveyors	NL, LG	LK, KR	NL, LG	NL, LG	LK, KR	LK, KR	NL, LG	LK, KR
Camera	Canon D10	Fujifilm XP	Canon D10	Canon D10	Fujifilm XP	Fujifilm XP	Canon D10	Fujifilm XP
Photo number	472	2256, 2257	473	474	2263	2265	482	2269
Substratum Description	mfs	mfs; with rocks	mfs	mfs	gs	gfs	fs	rippled sand
Sorting (well=1 - Poor=5)				1			1	
Stability (Stable=1 - Poor= 5)			2	1			1	
Softness (Firm=1 - soft=5)	2		1	2			2	
Sand ripples							P	P
Anoxic layer (cm)		0.5		1	1	1	1	

	ZQB01	ZQB02	ZQB03	ZQB04	ZQB05	ZQB06	ZQB07	ZQB08	ZQB09	ZQC01	ZQC02
Transect	2	2	2	2	2	2	2	2	2	3	3
Waypoint	22	21	8	20	7	19	18	17	16	9	23
Easting	227664	227678	227692	227706	227722	227739	227760	227784	227805	227701	227711
Northing	341579	341532	341483	341435	341387	341339	341295	341249	341203	341614	341565
Date	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16	19/09/16
Surveyors	LK, KR	LK, KR	NL, LG	LK, KR	NL, LG	LK, KR	LK, KR	LK, KR	LK, KR	NL, LG	LK, KR
Camera	Fujifilm XP	Fujifilm XP	Canon D10	Fujifilm XP	Canon D10	Fujifilm XP	Fujifilm XP	Fujifilm XP	Fujifilm XP	Canon D10	Fujifilm XP
Photo number	2279	2278	486	2277	483	2274	2273	2271, 2272	2270	488	2280
Substratum Description	sns	FS	sfmsh	mfS	fsh: in a pool	FS	pool	pool	rippled sand	msfst	medS
Sorting (well=1 - Poor=5)										1	
Stability (Stable=1 - Poor=5)										1	
Softness (Firm=1 - soft=5)										3	
Sand ripples									P		
Anoxic layer (cm)	0.05	0.05		0.05							1

Appendix 7 Intertidal *Zostera marina* species data from quadrats, Porth Dinllaen

For % cover (0.25 = <1%)

	ZQA01	ZQA02	ZQA03	ZQA04	ZQA06	ZQA07	ZQA08	ZQA09
Algae cover %	<5					6	<5	
Zostera marina %	<5	98	90	95	20	75	<5	0
Zostera marina <5% scale	few						few	
Chlorophycota (total) %	<1							
Anemonia viridis								
Cereus pedunculatus				S				
Arenicola marina							F	
Lanice conchilega	S	F	F	F	F		S	
Sabella sp		F						
Pagurus bernhardus				F				
Macropodia sp						F		
Littorina littorea				F				
Nassarius reticulatus						F		
Pomatoschistus								
Rhodophyta indet						2%		
Phaeophyceae filament	<5						<5	
Chorda filum								
Fucus serratus						2%		
Chorophyta filament	<5							

	ZQB01	ZQB02	ZQB03	ZQB04	ZQB05	ZQB06	ZQB07	ZQB08	ZQB09	ZQC01	ZQC02
Algae cover %		1	<5	4		3					
Zostera marina %	1	96	35	90	90	98	-	-	0	<5	99
Zostera marina <5% scale	many									few	
Chlorophycota (total) %	5									10	
Anemonia viridis						F					
Cereus pedunculatus				S		F					F
Arenicola marina											
Lanice conchilega			S			F					F
Sabella sp	F	F	F	F		S					
Pagurus bernhardus										F	
Macropodia sp											
Littorina littorea										S	
Nassarius reticulatus											F
Pomatoschistus					F						
Rhodophyta indet			F	1%							
Phaeophyceae filament											
Chorda filum		1		4		3					
Fucus serratus											
Chorophyta filament		5								10	

Appendix 8 Catalogue of photographs

Filename	Date	Time	Camera	Photo-grapher	Stn	Notes
20160803_TSM_Porthdinllaen_0337.JPG	03/08/2016	16:58:56	Lumix	TSM	Q1	Zostera quadrat, top of the bed within moorings
20160803_TSM_Porthdinllaen_0338.JPG	03/08/2016	17:04:12	Lumix	TSM	Q2	Zostera quadrat, top of the bed within moorings
20160803_TSM_Porthdinllaen_0339.JPG	03/08/2016	17:09:26	Lumix	TSM	Q3	Zostera quadrat, top of the bed within moorings
20160803_TSM_Porthdinllaen_0340.JPG	03/08/2016	17:16:08	Lumix	TSM	Q4	Zostera quadrat, top of the bed within moorings
20160803_TSM_Porthdinllaen_0341.JPG	03/08/2016	17:24:24	Lumix	TSM	Q5	Zostera quadrat, top of the bed within moorings
20160803_TSM_Porthdinllaen_0342.JPG	03/08/2016	17:33:46	Lumix	TSM	Q6	Zostera quadrat, top of the bed within moorings
20160803 DPB Porthdinllaen 063 CalcorQ.JPG	04/08/2016	11:59:22	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 064 CalcorQ.JPG	04/08/2016	12:00:42	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 066 CalcorQ.JPG	04/08/2016	12:03:10	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 067 CalcorQ.JPG	04/08/2016	12:06:18	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 070 CalcorQ.JPG	04/08/2016	12:06:34	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 071 CalcorQ.JPG	04/08/2016	12:06:52	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 072 CalcorQ.JPG	04/08/2016	12:07:42	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 074 CalcorQ.JPG	04/08/2016	12:09:44	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 075 CalcorQ.JPG	04/08/2016	12:10:16	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 076 CalcorQ.JPG	04/08/2016	12:10:52	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 077 CalcorQ.JPG	04/08/2016	12:11:36	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 078 CalcorQ.JPG	04/08/2016	12:12:06	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 079 CalcorQ.JPG	04/08/2016	12:12:40	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 080 CalcorQ.JPG	04/08/2016	12:13:20	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 DPB Porthdinllaen 081 CalcorQ.JPG	04/08/2016	12:21:22	Olympus TG3	DPB		Possible Callithamnion corymbosum
20160803 BW Porthdinllaen 0388.JPG	03/08/2016	16:47:04	Canon D10	BW	Q1	Damage assessment 10x10m squares - getting idea of 10m distance for quadrat size
20160803 BW Porthdinllaen 0389.JPG	03/08/2016	16:47:40	Canon D10	BW	Q1	Damage assessment 10x10m squares - overview of Q1 (tide didn't go out)
20160803 BW Porthdinllaen 0390.JPG	03/08/2016	16:51:28	Canon D10	BW	Q1	Damage assessment 10x10m squares - Zostera in Q1
20160803 BW Porthdinllaen 0391.JPG	03/08/2016	16:53:18	Canon D10	BW		Damage assessment 10x10m squares - mooring close to Q1
20160803 BW Porthdinllaen 0392.JPG	03/08/2016	16:55:08	Canon D10	BW	Q2	Damage assessment 10x10m squares - vehicle tracks Q2

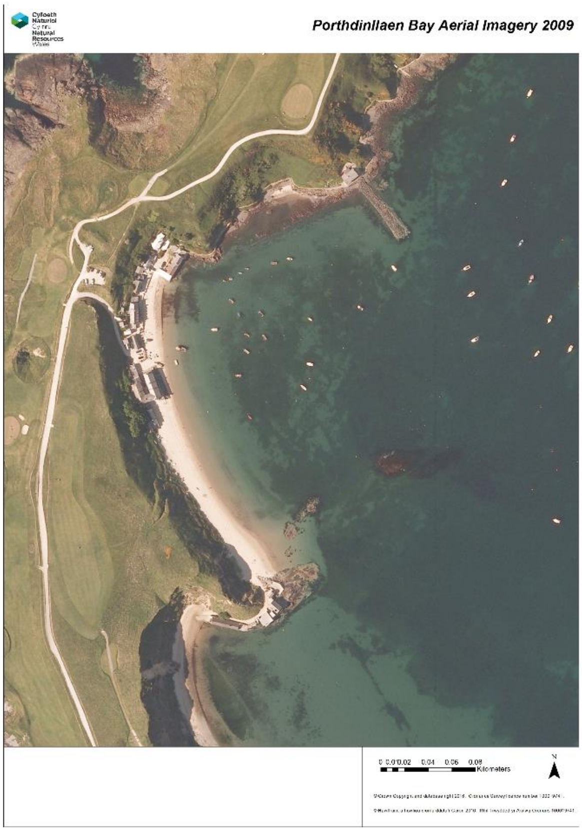
20160803 BW Porthdinllaen 0393.JPG	03/08/2016	16:55:18	Canon D10	BW	Q2	Damage assessment 10x10m squares - seabed view Q2
20160803 BW Porthdinllaen 0394.JPG	03/08/2016	16:56:10	Canon D10	BW	Q2	Damage assessment 10x10m squares- Zostera at edge of vehicle track Q2
20160803 BW Porthdinllaen 0395.JPG	03/08/2016	16:57:02	Canon D10	BW	Q2	Damage assessment 10x10m squares- dense patch of Zostera in Q2
20160803 BW Porthdinllaen 0396.JPG	04/08/2016	11:47:30	Canon D10	BW	Q2	Damage assessment 10x10m squares - Lucy & Jake by vehicle tracks Q2
20160803 BW Porthdinllaen 0397.JPG	03/08/2016	16:57:58	Canon D10	BW	Q2	Damage assessment 10x10m squares- vehicle track Q2
20160803 BW Porthdinllaen 0398.JPG	03/08/2016	16:58:26	Canon D10	BW	Q2	Damage assessment 10x10m squares - Lucy & Jake by vehicle tracks Q2
20160803 BW Porthdinllaen 0399.JPG	03/08/2016	17:05:40	Canon D10	BW	Q3	Damage assessment 10x10m squares - view of seabed Q3 (tide didn't go out)
20160803 BW Porthdinllaen 0400.JPG	03/08/2016	17:05:46	Canon D10	BW	Q3	Damage assessment 10x10m squares - Lucy & Jake at Q3
20160803 BW Porthdinllaen 0401.JPG	03/08/2016	17:10:38	Canon D10	BW	M1	Mooring impact monitoring - Lucy & Jake by M1
20160803 BW Porthdinllaen 0402.JPG	03/08/2016	17:11:56	Canon D10	BW	M1	Mooring impact monitoring - rope riser on mooring block M1
20160803 BW Porthdinllaen 0403.JPG	04/08/2016	11:48:02	Canon D10	BW	M2	Mooring impact monitoring - Lucy & Jake by M2
20160803 BW Porthdinllaen 0404.JPG	03/08/2016	17:13:52	Canon D10	BW	M2	Mooring impact monitoring - rope riser on mooring block M2
20160803 BW Porthdinllaen 0405.JPG	03/08/2016	17:14:00	Canon D10	BW	M2	Mooring impact monitoring - rope riser on mooring block M2
20160803 BW Porthdinllaen 0406.JPG	03/08/2016	17:15:38	Canon D10	BW	M3	Mooring impact monitoring - area around M3 (tide didn't go out)
20160803 BW Porthdinllaen 0407.JPG	03/08/2016	17:22:44	Canon D10	BW	M3	Mooring impact monitoring - seabed area adjacent to M3
20160803 LK Porthdinllaen 0384.JPG	03/08/2016	15:48:50	Canon D10	LK		Digger replacing rock armour stone at Hen Blas
20160803 LK Porthdinllaen 0385.JPG	03/08/2016	15:48:58	Canon D10	LK		Digger replacing rock armour stone at Hen Blas
20160803 LK Porthdinllaen 0386.JPG	03/08/2016	16:08:56	Canon D10	LK		Digger replacing rock armour stone at Hen Blas
20160803 LK Porthdinllaen 0387.JPG	03/08/2016	16:09:18	Canon D10	LK		Ruts in exposed shore clay, digger replacing rock armour stone at Hen Blas
20160803 LK Porthdinllaen 0408.JPG	04/08/2016	11:43:38	Canon D10	LK		Alium growing by coast path near lifeboat station
20160803 LK Porthdinllaen 0409.JPG	03/08/2016	18:13:00	Canon D10	LK		Intertidal monitoring group waiting for lifeboat to launch
20160803 LK Porthdinllaen 0410.JPG	03/08/2016	18:18:24	Canon D10	LK		Lifeboat launching
20160803 LK Porthdinllaen 0411.JPG	03/08/2016	18:18:32	Canon D10	LK		Lifeboat, Porthdinllaen
20160919 BW Porthdinllaen 0028.JPG	19/09/2016	15:46:22	Olympus TG3	BW	ZM10	Mooring 4
20160919 BW Porthdinllaen 0029.JPG	19/09/2016	15:46:56	Olympus TG3	BW	ZM10	Mooring 4

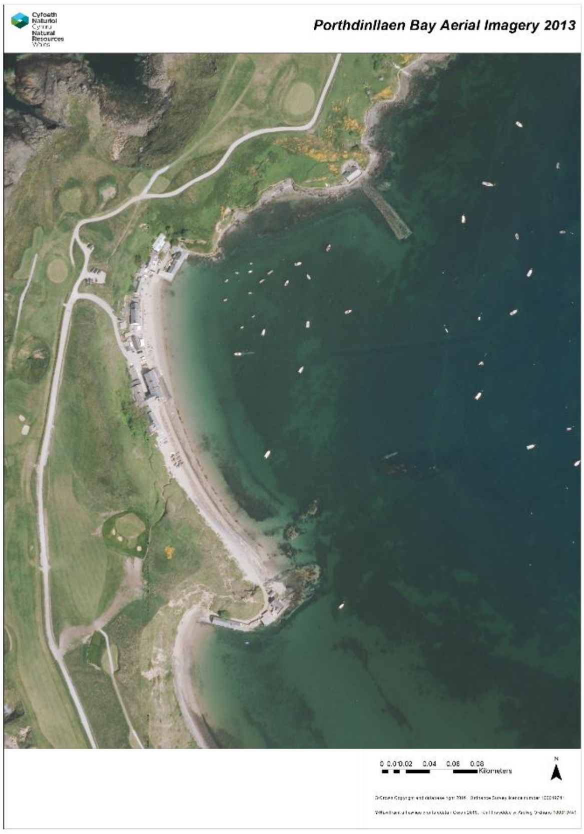
20160919 BW Porthdinllaen 0030.JPG	19/09/2016	16:19:42	Olympus TG3	BW	ZM12	Mooring 5
20160919 BW Porthdinllaen 0031.JPG	19/09/2016	16:23:12	Olympus TG3	BW	ZM11	Mooring 6
20160919 BW Porthdinllaen 0032.JPG	19/09/2016	16:25:16	Olympus TG3	BW	ZM09	Mooring 7
20160919 BW Porthdinllaen 0033.JPG	19/09/2016	16:27:58	Olympus TG3	BW	ZM04	Mooring 8
20160919 BW Porthdinllaen 0034.JPG	19/09/2016	16:28:10	Olympus TG3	BW	ZM04	Mooring 8
20160919 BW Porthdinllaen 0035.JPG	19/09/2016	16:35:12	Olympus TG3	BW	ZM05	Mooring 9
20160919 BW Porthdinllaen 0036.JPG	19/09/2016	16:35:30	Olympus TG3	BW	ZM05	Mooring 9
20160919 BW Porthdinllaen 0037.JPG	19/09/2016	16:38:02	Olympus TG3	BW	ZM08	Mooring 10
20160919 BW Porthdinllaen 0038.JPG	19/09/2016	16:38:12	Olympus TG3	BW	ZM08	Mooring 10
20160919 BW Porthdinllaen 0039.JPG	19/09/2016	16:41:46	Olympus TG3	BW	ZM07	Mooring 11
20160919 BW Porthdinllaen 0040.JPG	19/09/2016	16:41:52	Olympus TG3	BW	ZM07	Mooring 11
20160919 BW Porthdinllaen 0041.JPG	19/09/2016	16:48:26	Olympus TG3	BW	ZM06	Mooring 12
20160919 BW Porthdinllaen 0042.JPG	19/09/2016	16:48:38	Olympus TG3	BW	ZM06	Mooring 12
20160919 BW Porthdinllaen 0043.JPG	19/09/2016	16:48:50	Olympus TG3	BW	ZM06	Mooring 12
20160919 BW Porthdinllaen 0044.JPG	19/09/2016	16:52:54	Olympus TG3	BW	ZM02	Mooring 13
20160919 BW Porthdinllaen 0045.JPG	19/09/2016	16:53:08	Olympus TG3	BW	ZM02	Mooring 13
20160919 BW Porthdinllaen 0046.JPG	19/09/2016	16:55:52	Olympus TG3	BW	ZM03	Mooring 14
20160919 BW Porthdinllaen 0047.JPG	19/09/2016	16:56:34	Olympus TG3	BW	ZM03	Mooring 14
20160919 BW Porthdinllaen 0048.JPG	19/09/2016	16:59:16	Olympus TG3	BW	ZM01	Mooring 15
20160919 BW Porthdinllaen 0049.JPG	19/09/2016	16:59:28	Olympus TG3	BW	ZM01	Mooring 15
20160919 BW Porthdinllaen 0050.JPG	19/09/2016	17:49:10	Olympus TG3	BW	ZM13	Mooring 16
20160919 BW Porthdinllaen 0051.JPG	19/09/2016	17:51:40	Olympus TG3	BW	ZM13	Mooring 16
20160919 BW Porthdinllaen 0052.JPG	19/09/2016	18:01:50	Olympus TG3	BW	ZM09	Mooring 7
20160919 LK Porthdinllaen 2256.JPG	20/09/2016	15:29:06	FujiFilm XP	LK	ZQA02	WP 10
20160919 LK Porthdinllaen 2257.JPG	20/09/2016	15:29:12	FujiFilm XP	LK	ZQA02	WP 10
20160919 LK Porthdinllaen 2258.JPG	20/09/2016	15:29:16	FujiFilm XP	LK		Kirsten
20160919 LK Porthdinllaen 2259.JPG	20/09/2016	15:29:20	FujiFilm XP	LK		Kirsten
20160919 LK Porthdinllaen 2260.JPG	20/09/2016	15:29:18	FujiFilm XP	LK		Vehicle tracks
20160919 LK Porthdinllaen 2261.JPG	20/09/2016	15:30:40	FujiFilm XP	LK	ZImp25	Mooring anchors
20160919 LK Porthdinllaen 2262.JPG	20/09/2016	15:30:42	FujiFilm XP	LK	ZImp25	Mooring anchors

20160919 LK Porthdinllaen 2263.JPG	20/09/2016	15:30:44	FujiFilm XP	LK	ZQA06	WP 13
20160919 LK Porthdinllaen 2264.JPG	20/09/2016	15:30:48	FujiFilm XP	LK		Possible erosion
20160919 LK Porthdinllaen 2265.JPG	20/09/2016	15:30:48	FujiFilm XP	LK	ZQA07	WP 14
20160919 LK Porthdinllaen 2266.JPG	20/09/2016	15:30:52	FujiFilm XP	LK		*Sargassum muticum*
20160919 LK Porthdinllaen 2267.JPG	20/09/2016	15:30:54	FujiFilm XP	LK		*Sargassum muticum*
20160919 LK Porthdinllaen 2268.JPG	20/09/2016	15:30:54	FujiFilm XP	LK	ZImp26	Possible erosion WP 14
20160919 LK Porthdinllaen 2269.JPG	20/09/2016	15:30:58	FujiFilm XP	LK	ZQA09	WP 15
20160919 LK Porthdinllaen 2270.JPG	20/09/2016	15:31:00	FujiFilm XP	LK	ZQB09	WP 16
20160919 LK Porthdinllaen 2271.JPG	20/09/2016	15:31:06	FujiFilm XP	LK	ZQB08	WP 17
20160919 LK Porthdinllaen 2272.JPG	20/09/2016	15:31:08	FujiFilm XP	LK	ZQB08	WP 17
20160919 LK Porthdinllaen 2273.JPG	20/09/2016	15:31:08	FujiFilm XP	LK	ZQB07	WP 18
20160919 LK Porthdinllaen 2274.JPG	20/09/2016	15:31:12	FujiFilm XP	LK	ZQB06	WP 19
20160919 LK Porthdinllaen 2275.JPG	20/09/2016	15:31:12	FujiFilm XP	LK		Wide photo from WP 19
20160919 LK Porthdinllaen 2276.JPG	20/09/2016	15:31:12	FujiFilm XP	LK		Possible erosion
20160919 LK Porthdinllaen 2277.JPG	20/09/2016	15:31:14	FujiFilm XP	LK	ZQB04	WP 20
20160919 LK Porthdinllaen 2278.JPG	20/09/2016	15:31:18	FujiFilm XP	LK	ZQB02	WP 21
20160919 LK Porthdinllaen 2279.JPG	20/09/2016	15:31:18	FujiFilm XP	LK	ZQB01	WP 22
20160919 LK Porthdinllaen 2280.JPG	20/09/2016	15:31:22	FujiFilm XP	LK	ZQC02	WP 23
20160919 LK Porthdinllaen 2281.JPG	20/09/2016	15:31:24	FujiFilm XP	LK	ZImp11	Tyre tracks
20160919 LK Porthdinllaen 2282.JPG	20/09/2016	15:31:26	FujiFilm XP	LK	ZImp11	Tyre tracks
20160919 LK Porthdinllaen 2283.JPG	20/09/2016	15:31:32	FujiFilm XP	LK	ZImp09	Shellfish debris
20160919 LK Porthdinllaen 2284.JPG	20/09/2016	15:31:36	FujiFilm XP	LK	ZImp09	Shellfish debris
20160919 LK Porthdinllaen 2285.JPG	20/09/2016	15:31:36	FujiFilm XP	LK		General view looking SW from inner harbour breakwater
20160919 LK Porthdinllaen 2286.JPG	20/09/2016	15:33:58	FujiFilm XP	LK		General view looking SW from inner harbour breakwater
20160919 NL Porthdinllaen 0472.JPG	19/09/2016	16:51:46	Canon D10	NL	ZQA01	WP 3
20160919 NL Porthdinllaen 0473.JPG	19/09/2016	17:15:46	Canon D10	NL	ZQA03	WP 4
20160919 NL Porthdinllaen 0474.JPG	19/09/2016	17:28:10	Canon D10	NL	ZQA04	WP 5
20160919 NL Porthdinllaen 0475.JPG	19/09/2016	17:38:46	Canon D10	NL	ZImp15	WP 5 (Porthdinllaen Zostera damage)
20160919 NL Porthdinllaen 0476.JPG	19/09/2016	17:39:00	Canon D10	NL		WP 5 (Porthdinllaen Zostera damage)
20160919 NL Porthdinllaen 0477.JPG	19/09/2016	17:43:18	Canon D10	NL		Sagartiogeton

20160919 NL Porthdinllaen 0478.JPG	19/09/2016	17:43:26	Canon D10	NL		Sagartiogeton
20160919 NL Porthdinllaen 0482.JPG	19/09/2016	17:55:58	Canon D10	NL	ZQA08	WP 6
20160919 NL Porthdinllaen 0483.JPG	19/09/2016	18:16:28	Canon D10	NL	ZQB05	WP 7 - mooring
20160919 NL Porthdinllaen 0484.JPG	19/09/2016	18:22:40	Canon D10	NL		Damage - depression in seagrass
20160919 NL Porthdinllaen 0485.JPG	19/09/2016	18:22:42	Canon D10	NL		Damage - depression in seagrass
20160919 NL Porthdinllaen 0486.JPG	19/09/2016	18:29:06	Canon D10	NL	ZQB03	WP 8
20160919 NL Porthdinllaen 0487.JPG	19/09/2016	18:37:54	Canon D10	NL	ZImp20	Damage - depression in seagrass
20160919 NL Porthdinllaen 0488.JPG	19/09/2016	18:47:00	Canon D10	NL	ZQC01	WP 9
20160919 NL Porthdinllaen 0489.JPG	19/09/2016	18:58:22	Canon D10	NL	ZImp01	General photo- mooring Damage

Appendix 9 Aerial photographs


Porthdinllaen Bay Aerial Imagery 2009
0 0.01 0.02 0.04 0.06 0.08
Kilometers
N


Porthdinllaen Bay Aerial Imagery 2013
0 0.01 0.02 0.04 0.06 0.08
Kilometers
N

Appendix 10 Protocol to determine extent from aerial imagery using ArcGIS

- GPS tracks created by surveyors from the field survey were imported into ArcGIS- 2004, 2010, 2016 ensuring that they were projected in British National Grid.
- 2010 had the highest seaward boundary therefore it was used as a template to form the base of the aerial imagery polygons.
- Aerial imagery layers where then imported - 2000, 2006, 2009, 2013.
- For each year, the template seaward boundary was imported as a shape file (.shp)
- The scale was set to 1:800
- Using the ‘Editor’ tool and ‘add vertices’ were used to create the polygon.
- To create the polygon the dense dark outline of the seagrass bed was followed.
- Large blowouts weren’t mapped around as *Z. marina* would be sparsely present.
- Following the creation of the polygon the area was then determined using the ‘Calculate Geometry’ tool.
- All layers were then saved into a file geodatabase (.gdb) in Arc catalogue.

Polygons created for the aerial images (2000, 2006, 2010and 2013) can be seen below.


Porthdinllaen Bay Aerial Imagery 2000
Legend
Porthdinllaen Intertidal Seagrass boundary 2000 (Aerial)
0 0.01 0.02 0.04 0.06 0.08
Kilometers
N


Porthdinllaen Bay Aerial Imagery 2006
Legend
Porthdinllaen Intertidal Seagrass Boundary 2006 (Aerial)
0 0.01 0.02 0.04 0.06 0.08
Kilometers
N


Porthdinllaen Bay Aerial Imagery 2009
Legend
Porthdinllaen Intertidal Seagrass Boundary 2009 (Aerial)
0 0.01 0.02 0.04 0.06 0.08
Kilometers
N


Porthdinllaen Bay Aerial Imagery 2013
Legend
Porthdinllaen Intertidal Seagrass Boundary 2013 (Aerial)
0 0.01 0.02 0.04 0.06 0.08
Kilometers
N

Appendix 11 Data Archive Appendix

Data outputs associated with this project are archived as project 41, Media No 1526 on server–based storage at Natural Resources Wales.

Recommended citation for this volume:

Davies, J., Wray, B. & Brazier, D.P. 2017. Intertidal SAC monitoring of *Zostera marina* at Porth Dinllaen, Pen Llŷn a'r Sarnau SAC, 2016. Pp 51 + xii. Natural Resources Wales Evidence Report No. 064, Bangor.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] A series of GIS layers on which the maps in the report are based with a series of word documents detailing the data processing and structure of the GIS layers.

[E] A spreadsheet of survey metadata and data from field survey.

[F] A full set of images produced in jpg format.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue http://libcat.naturalresources.wales (English), http://catllyfr.cyfoethnaturiol.cymru (Welsh), by searching 'Dataset Titles'.

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Published by:
Natural Resources Wales
Maes y Ffynnon
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Bangor
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