ACA Pen Llŷn a'r Sarnau SAC

Prosiect Morwellt Porthdinllaen Seagrass Project

Adolygiad o'r wybodaeth gyfredol

A review of current knowledge

2015

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Crynodeb Gweithredol

Mae'r adroddiad hwn yn adolygu a chrynhoi'r ymchwil a'r gwaith archwilio a gynhaliwyd ar y dolydd morwellt ym Mhorthdinllaen ac mae'n archwilio gwerth gwasanaeth ecosystem y cynefinoedd hyn gan roi amlinelliad pellach o'r ffactorau posib sy'n dylanwadu ar eu hyfywedd hirdymor. Mae morwellt (*Zostera marina*) ym Mhorthdinllaen yn cynnwys amcangyfrif o 28 hectar neu fwy ac mae'n eang drwy gydol yr ardaloedd rhynglanwol ac islanwol. Mae angen ymarfer mapio trylwyr er mwyn darparu mwy o amcangyfrifon a phatrymau dosbarthu gofodol cywir. Ceir 26 adroddiad ymchwil neu arolwg presennol sy'n trafod neu ymchwilio'r dolydd morwellt helaeth ym Mhorthdinllaen; mae chwech o'r rhain yn bapurau ymchwil a adolygwyd gan gymheiriaid academaidd.

Mae'r 26 adroddiad hyn yn cyflwyno tystiolaeth gref o werth y morwellt ym Mhorthdinllaen ar gyfer cefnogi bioamrywiaeth ac ar gyfer darparu cynefin pwysig i bysgod ifanc ar gyfer rhywogaethau o bwysigrwydd masnachol uchel (e.e. Lleden, Penfras yr Iwerydd a'r Morlais). Mae rhywogaethau eraill o ddiddordeb sylweddol (oherwydd eu pwysigrwydd masnachol, gwyddonol a chadwraeth) hefyd wedi'u cofnodi yn y safle megis Môr-gyllell, Ystifflog, cimwch a phedair rhywogaeth o Bibell Fôr yn ogystal â'r gragen fylchog sy'n byw yn hir *Arctica islandica.* Yn ogystal, mae'r gwaddodion o dan y morwellt yn llawn rhywogaethau o infertebratau bychan sy'n cyfrannu ymhellach at fioamrywiaeth y safle ac sy'n ffynhonnell fwyd i amrywiaeth o bysgod, adar ac infertebratau mudol mawr. Mae Porthdinllaen hefyd yn werthfawr fel harbwr gweithiol a lleoliad twristaidd sy'n cefnogi'r economi lleol ac yn darparu ased diwylliannol pwysig.

Ceir tystiolaeth gynyddol bod y morwellt ym Mhorthdinllaen yn agored i amrediad o bethau sy'n achosi straen. Mae hyn yn cynnwys pwysau a ddaw wrth ddefnyddio cychod (angorfeydd sefydlog ac angorau) a cherbydau'n cael eu gyrru dros y safle pan fo'r llanw'n isel. Mae tystiolaeth o effaith angorfeydd cychod sefydlog ar forwellt ym Mhorthdinllaen yn gryf iawn. Ceir hefyd bryderon bod gwymon ymledol yn effeithio ar y safle a bod ansawdd y dŵr o bosib yn dirywio. Mae pethau eraill sy'n achosi straen (ar raddfa fwy) yn cynnwys newid hinsawdd a'r cynnydd cysylltiedig yn lefel y môr yn ogystal â cholli prif ysglyfaethwyr ym Môr Iwerddon.

Mae angen data ychwanegol er mwyn diffinio mecanweithiau'r achosion hyn o straen yn gliriach ac argymhellir bod rhaglen fonitro dymhorol a blynyddol yn cael ei sefydlu er mwyn cynhyrchu sail wybodaeth well sy'n ymdrin â newid hirdymor mewn morwellt yn y safle. Argymhellir ymarfer mapio morwellt manwl hefyd ar draws yr ardaloedd rhynglanwol ac islanwol er mwyn darparu asesiad cywir o faint y morwellt.

Canfod ffordd o ddiogelu adnoddau ecolegol y safle wrth hwyluso'i ddefnydd parhaus gan fudd-ddeiliaid mewn modd cynaliadwy yw prif bryder awdurdodau statudol a grŵp llywio morwellt ACA Pen Llŷn a'r Sarnau. O ganlyniad, comisiynwyd astudiaethau ar y defnydd o systemau angorfeydd gwahanol/addasedig sy'n isafu/lleihau'r difrod i'r morwellt ac sy'n galluogi'r dolydd i adfer yn yr hirdymor. Mae cynigion i wella gwerth y bae i dwristiaid hefyd wedi'u paratoi.

Oherwydd gwerth cydnabyddedig y gwasanaethau ecosystem a ddarperir gan ddolydd morwellt, ein dealltwriaeth gyfyngedig o drothwyon ecolegol, a'r llu o bwysau ar ddolydd morwellt yn y safle hwn, mae'r adolygiad hwn yn casglu bod angen gweithredu brys er mwyn atal a gwrthdroi'r difrod i'r morwellt. Mae corff cynyddol o dystiolaeth yn dangos amrywiaeth o ddatrysiadau ymarferol priodol er mwyn cefnogi'r gwaith o ddatrys gwrthdaro ymhlith budd-ddeiliaid.

Executive Summary

This report reviews and summarises the research and survey work that has been conducted on the seagrass meadows at Porthdinllaen and examines the ecosystem service value of these habitats further outlining the factors potentially influencing their long-term viability. Seagrass (*Zostera marina*) at Porthdinllaen covers an estimated 28 hectares or more and is extensive throughout the intertidal and subtidal areas. A thorough mapping exercise is required to provide more accurate cover estimates and spatial distribution patterns. There are 26 existing research or survey reports that discuss or investigate the extensive seagrass meadow at Porthdinllaen; six of these are academic peer reviewed research papers.

These 26 reports present strong evidence of the value of the seagrass at Porthdinllaen for supporting biodiversity and for providing important juvenile fish habitat for species of high commercial importance (e.g. Plaice, Atlantic Cod and Pollock). Other species of significant interest (due to their commercial, scientific, conservation importance) have also been recorded at the site such as Cuttlefish, Squid, lobster and 4 species of Pipefish as well as the long-lived clam *Arctica islandica.* In addition, the sediments below the seagrass are rich in small invertebrate species that further contribute to the sites biodiversity and that are the food source of a variety of fish, birds and large motile invertebrates. Porthdinllaen is also valued as a working harbour and tourist location supporting the local economy and providing an important cultural asset.

There is growing evidence that the seagrass at Porthdinllaen is being subjected to a range of stressors. This includes pressure from boating (fixed moorings and anchors) and the driving of vehicles over the site at low tide. Evidence of the impact of fixed boat moorings on seagrass at Porthdinllaen is particularly strong. There are also concerns that the site is being impacted by invasive seaweed and that water quality might be declining. Other (larger scale) stressors include climate change and associated sea level rise as well as the loss of top predators in the Irish Sea.

Additional data is required to more clearly define the mechanisms of these stressors and establishment of a seasonal and annual monitoring programme is recommended to generate an improved knowledge base covering long-term change in seagrass at the site. A detailed seagrass mapping exercise is also recommended across the intertidal and subtidal areas to provide an accurate assessment of seagrass extent.

Finding a means to protect the sites ecological resources, whilst facilitating its continued use by stakeholders in a sustainable manner is of prime concern to the statutory authorities and the Pen Llŷn a'r Sarnau SAC seagrass steering group. As a result studies have been commissioned into the use of alternative/adapted mooring systems that minimise/reduce the damage to seagrass and enable meadow recovery in the long-term. Proposals to enhance the value of bay to tourists have also been prepared.

Due to the recognised value of ecosystem services provided by seagrass meadows, our limited understanding of ecological thresholds, and the array of pressures on seagrass meadows at this site this review concludes that urgent action is required to halt and reverse seagrass damage. A growing body of evidence demonstrates a variety of appropriate practical solutions to support stakeholder conflict resolution.

Contents

Introduction

Porthdinllaen and the seagrass project

Porthdinllaen (52° 56.600'N, 4° 34.014'W) is a small sheltered bay situated on the north coast of the Llŷn Peninsula, north-west Wales. It is within the Llŷn Peninsula Area of Outstanding Natural Beauty as well as being a part of the Pen Llŷn a'r Sarnau Special Area of Conservation (SAC). In addition to its status for nature conservation the bay is also important for tourism, recreational boating and fishing.

Within the bay exists a sandy beach that is popular with tourists and local visitors and a small public house that due to its location immediately next to the beach attracts additional visitors to the bay, particularly during the summer months. The bay is also of value to visitors from the adjacent golf course and its location within the Welsh Coastal Path means that the site is popular with walkers. As one of the few sheltered North Easterly facing environments on the North coast of the Llŷn Peninsula it is an important mooring site for recreational and commercial vessels, some of which are part of the local fishing fleet. Importantly the bay has a sea defence structure that provides greater protection from wind and waves within the inner bay.

Although the majority of vessels now using the Harbour are of a recreational nature, historically the Harbour was dominated by boats of a commercial and industrial nature. At present a series of permanent moorings are present within the intertidal and subtidal environments where boats moor, typically this is more prevalent in the summer than in the winter.

Due to the sheltered nature of the site it is also a favourable environment for a range of biodiverse, sensitive and important marine habitats and species. Particular focus is placed on the extensive coverage of marine plants (seagrass) throughout the bay, commonly referred to as eelgrass (which is the focus of the present report). A range of other important habitats and species are present, including rocky shores and algal dominated habitats. The seagrass in the bay is defined as part of the intertidal mudflat and sandflat feature of the Pen Llŷn a'r Sarnau SAC, and it is also a feature of the Porthdinllaen i Borth Pistyll Site of Special Scientific Interest (SSSI). Seagrass is a valued marine habitat and its importance is also recognised in Wales through its listing as a habitat of principal importance under S42 of the Natural Environment and Rural Communities Act 2006.

The former Countryside Council for Wales (now part of Natural Resources Wales) considered the seagrass to be in an 'unfavourable condition'. As a result of this definition a process of investigation and community engagement was commenced by the Pen Llŷn a'r Sarnau SAC relevant authorities group in order to facilitate a long-term sustainable approach to the management of the bay. This has been referred to as the Porthdinllaen Seagrass Project. To date the Porthdinllaen Seagrass Project has commissioned a series of research projects to collect data about the site, commenced some local community school education initiatives and facilitated a range of workshops and meetings with local stakeholders in order to develop an appropriate long-term strategy to management of the site. Given that a range of extensive scientific studies have now been conducted within the seagrass at Porthdinllaen it was felt by the Pen Llŷn a'r Sarnau SAC relevant authorities group that the results of these studies and their implications for the management of the site should be reviewed in order to consolidate the findings of the studies to date and identify knowledge gaps to inform the focus of future work.

Aims of this report

The aims of this report are four-fold as follows:

1. Collate all known information sources relating to the seagrass meadows at Porthdinllaen
2. Conduct a thorough review of all known information sources relating to the seagrass meadows at Porthdinllaen
3. Interpret the information relating to the seagrass meadows at Porthdinllaen in order to determine what is clearly known about the ecology, distribution, status and health of the seagrass at the site
4. Make recommendations about knowledge gaps and define priorities for further biological studies.

What are seagrass meadows?

Seagrasses are the only plants adapted to live in the sea. They are rhizomatous in that they have stems that spread horizontally below the sediment surface, and can form extensive clonal plants. Seagrass meadows develop when the plants become widespread over large areas. In contrast to other vegetation that lives in the sea (e.g. seaweeds or other algae), seagrasses flower, develop fruit and produce seeds just like terrestrial plants. They also have roots and a vascular system that transports gases and nutrients around the plant.

Different species of seagrass live in shallow sea areas in both the tropics and temperate waters at higher latitudes around the globe. The seagrass commonly referred to as 'eelgrass' (*Zostera marina* L.) is one of only two 'true' seagrass species found in the UK, the other being dwarf eelgrass *Zostera noltii*. Eelgrass is the dominant seagrass species at Porthdinllaen, although anecdotal evidence suggests there could be minor coverage of *Z. noltii*. Eelgrass is relatively common in the coastal seas of the northern hemisphere (20–70°N), where it occurs across a variety of environments (from sheltered sandy bays to anoxic muddy estuaries and turbid high current pebbles) and shows a high diversity of life-history, morphology and growth dynamics. Due to its delicate nature, eelgrass is limited to a distribution in sheltered environments where it can hold together sand and fine sediment. It is susceptible to a variety of direct and indirect impacts, in particular physical disturbance [1].

In the UK eelgrass is most commonly constrained to a maximum water depth of about 7m (below chart datum) due to its high light requirements as a photosynthetic organism. Estimates from across its geographical range suggest that it requires between 12 and 37% of surface irradiance to survive in the long-term [2]. Seagrasses, like any angiosperm, require a sufficient supply of nutrients, however elevated nutrient levels can quickly result in reduced water quality and smothering by macro and microalgae [3].

Porthdinllaen seagrass in a Welsh, UK and global context

It is well documented that seagrass meadows have been degraded, destroyed and often lost indefinitely [4]. Conservative estimates suggest that globally at least 51,000km^2 of seagrass has been lost, with many remaining seagrass meadows in a highly degraded state [1, 4, 5]. Although in the UK long-term monitoring undertaken at a sufficient scale to make quantitative extrapolations is limited to only a hand full of studies [6-8], considerable historical records of the presence and absence of seagrass are available. From this it has been estimated that the UK has lost between 25% and 49% of its seagrass in the last 25 years [9]. In Wales, a detailed analysis of available data and historical

records from county biodiversity records describes the distribution of seagrass meadows in 1997 and how this had altered over time [10]. The report clearly illustrates that Wales has lost a significant proportion of its seagrass over the last 50-100 years [10] with particular loss thought to have occurred around Anglesey, in Milford Haven and along the South Wales coast. The report by Quentin Kay is the best available source of historic data on the distribution of seagrass [10], but it is likely that this is a conservative estimate due to a lack of data. The loss of the once vast coastal oysters and their fisheries in the 1800's may well have resulted in a large loss of seagrass as was documented to have occurred in other areas of the North Atlantic [11].

Seagrass meadows are categorised as a habitat in decline in OSPAR Region II (Greater North Sea – The North-East Atlantic) and under threat in all areas where they occur [12]. In the UK, seagrass meadows are identified as a Feature of Conservation Importance (FOCI) for English Marine Conservation Zones (MCZs) and they are a Scottish MPA search feature under the Marine Scottish Act. Seagrasses are a UK priority Biodiversity Action Plan Habitat and in Wales are listed as a habitat of principal importance under S42 of the Natural Environment and Rural Communities Act 2006. Importantly for Porthdinllaen, seagrass meadows are a component of the intertidal mudflat and sandflat feature of the Pen Llŷn a'r Sarnau Special Area of Conservation designated under the European Habitats Directive [13]. Under this directive seagrass meadows are also considered as a sub-feature of subtidal sandbank features.

Where is the seagrass at Porthdinllaen and how has it changed over time?

Where is the seagrass?

In spite of the known presence of seagrass at Porthdinllaen, to date there has been no single detailed mapping exercise undertaken which has looked at the seagrass meadow in its entirety. A series of studies since 1997 have used a variety of techniques to enable broad estimates of the seagrass coverage in both the intertidal zone and the sub-tidal areas. The overall extent of the seagrass meadow has been estimated from these studies but is not specifically monitored.

Other mapping studies at Porthdinllaen have looked at the presence of seagrass around boat moorings but the findings from these studies do not provide an overall picture that is representative of the entire meadow.

The most comprehensive mapping undertaken to date comprises the following:

Intertidal zone:

- 1997 (CCW Phase 1 intertidal mapping) [15]
- 2004 and 2010 (as part of the Pen Llŷn a'r Sarnau SAC feature condition monitoring) [13, 14].

Subtidal zone:

- 2008 & 2009 (Countryside Council for Wales (CCW) volunteer diver surveys) [20, 21]

These studies are summarised in Egerton, 2011 [16].

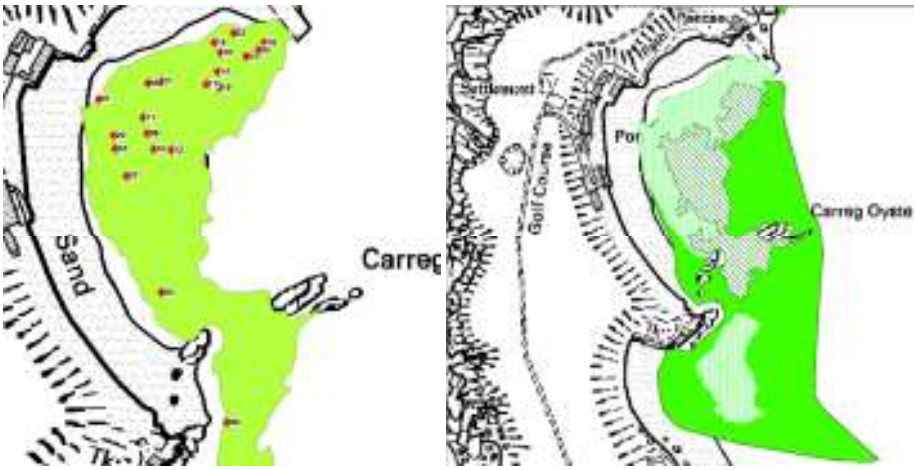


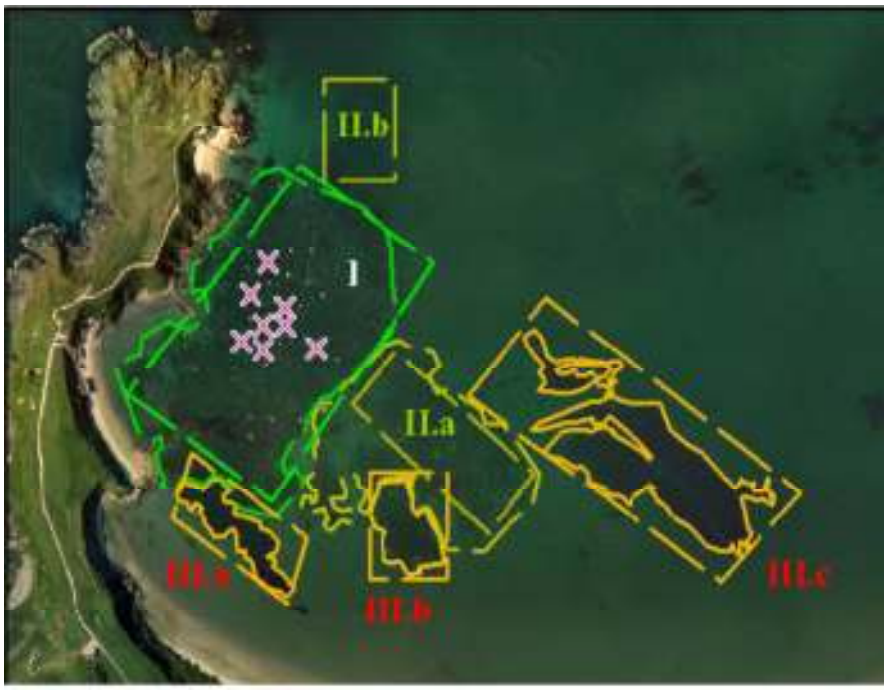
Figure 1. Intertidal seagrass mapping in 2004 (left – From Boyes et al 2008 [13]) and 2010 (right – From Mercer et al 2010 [14]). Green areas show seagrass.

The intertidal seagrass meadow was mapped in 1997, 2004 and 2010. However due to the differences in methodology and the timings of the surveys relative to the tidal cycle, estimates for the area of intertidal seagrass are highly variable between years. For example the surveys in 2004 and 2010 Figure1 a and b appear to have differences in area on the eastern (deeper) side where tidal height would greatly influence the area of observed seagrass.

This makes it difficult to distinguish differences caused by methods versus those induced by anthropogenic or other impacts. Importantly the above studies (Figure 1) [13, 14] document extensive intertidal seagrass coverage of between 2.9 ha and 7.1 ha and report on observed impacts to the intertidal seagrass (see further discussion in section titled 'Physical Impacts on the seagrass').

In addition to the quantitative data within the reports mentioned there are also numerous species records available for the presence of intertidal *Z. marina* at Porthdinllaen in the 1970s. The detailed review by Kay (1998) [10] analysed all records available from local record centres and any associated publications. These observations indicate that intertidal seagrass has been observed to be present at Porthdinllaen for at least 40 years.

Subtidal areas of the seagrass meadow were partially mapped by volunteer SCUBA divers in 2008 and 2009 [20 & 21]. These surveys used seabed transects that were spatially defined using GPS surface marker buoys. They collected data on the presence or absence and density of seagrass in defined areas. Data was then compared relative to the potential distribution of seagrass estimated from a 2006 aerial photograph of Porthdinllaen (which was taken when the water was very clear and clearly shows distinct dark areas within the bay) (see Figure 2). The authors did not extrapolate their data to create an area estimate of seagrass (hectares) but this was done at a later date by Egerton [16]. Egerton 2011 used the data from the intertidal surveys, the 2008 and 2009 surveys and the aerial imagery to estimate the extent of the seagrass meadow at Porthdinllaen to be approximately 29 hectares (Figure 3). This work separated the seagrass into five areas which corresponded to five categories of seagrass and provided area estimates for each category (see Table 1).



Box ID	Ground-truth central datums?	Cardinal extents attempted?	Predicted Habitat	Seabed type and cover Confirmed
I	✓	✓ (N & S)	seagrass	Sandy and mixed ground (pebbles and cobbles) with seagrass.
IIa	✓	✓ (N & S)	some seagrass with cobbles and or algae	Sand & pebbles with seagrass.
IIb	✓	×	some seagrass with cobbles and or algae	No Seagrass (too deep)
IIIa	×	×	*drift algae*	*Unconfirmed*
IIIb	✓	×	drift algae	Sand & pebbles with seagrass
IIIc	✓	✓ (W,E & S)	drift algae	Sand covered with mixed brown seaweeds and occasional low density **seagrass** patches.

Figure 2. Seagrass mapping at Porthdinllaen in 2008 conducted using a combination of aerial photographic imagery and in water ground truthing. The image shows areas of potential seagrass. 6 sampling 'boxes' were created prior to survey to focus the survey effort. Imagery is from © Countryside Council for Wales, 2008. Figures and information are taken from Morris & Goudge 2008 [20]. Although the survey ground truthed the image, no area estimate (hectares) was placed on the amount of seagrass present.

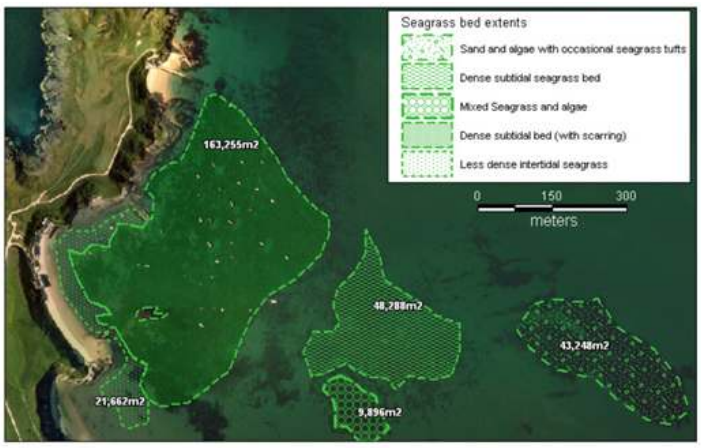


Figure 3. Estimated subtidal seagrass extent and approximate density at Porthdinllaen. Figure is taken from the study by Egerton (2011) [16] and based on field survey data collected during CCW-run volunteer diver surveys in 2008 and 2009.

Based on observations (from repeated SCUBA, intertidal surveys and freediving within the seagrass at Porthdinllaen between 2012 and 2014), the seagrass distribution and area estimate presented by Egerton (2011) are reasonable. It is important to recognise that that these estimates only provide a 'snap-shot' of the seagrass distribution and extent and, due to the difficultly of surveying underwater, the maps of the extent and distribution of the seagrass are indicative approximations. There are errors associated with any particular mapping technique used and any marine habitat mapping exercise needs to acknowledge the significance of the error that is present [18]. It is also important to note that the distribution of a seagrass meadow is not static and will change in extent naturally from year to year [19]. Obtaining further information about the variability of the Porthdinllaen seagrass meadow will help to separate the natural variability from variability caused by anthropogenic activity.

Table 1. Estimates of seagrass area (m^2) for different assemblage types in Porthdinllaen. Figures taken from Egerton 2011, Fig 1.

Habitat descriptor	**Area (m^2)**
Sand and algae with occasional seagrass tufts	43248
Dense subtidal seagrass	48288
Mixed seagrass and algae	9896
Dense subtidal seagrass (with scarring)	163255
Less dense intertidal seagrass	21662
Total (m^2)	286349
Total (ha)	28.6

Due to a lack of comparable methods and inadequate data availability there is limited capacity to understand temporal change within seagrass distribution and extent at Porthdinllaen. The only known historical sources of information arise from aerial imagery (going back to 1946) available in the report by Egerton (2011) [16]. Although the imagery provides no quantification of seagrass coverage, the area of seagrass assessed in 2008 and 2009 [20, 21] appears to be significantly greater than in previous years. This supports anecdotal evidence from long-term residents of Porthdinllaen that the seagrass is now more spatially extensive than in living memory (authors' personal communication). Historical imagery and local ecological knowledge should however be used cautiously with respect to understanding sub-tidal versus intertidal seagrass as the subtidal area is inaccessible to easy viewing.

How dense is the seagrass?

Several small scale targeted surveys have taken density measurements of the seagrass at Porthdinllaen [13, 20-27]; however these measurements have not been sufficiently extensive to provide a thorough assessment of the overall seagrass density or its temporal or spatial variability.

The survey data that is available lacks spatial coverage, uses a variety of different density measurement methods (shoot density, blade density, and % cover) and have been conducted over several different areas and scales (see Table 2). For this reason it is not possible to make inter-study comparisons of data to make any further inferences about the status of the seagrass beyond what is considered at an individual study level (see section titled 'What is the condition of seagrass at Porthdinllaen').

The most robust available data from the subtidal environment comes from two studies examining fixed mooring impacts on subtidal seagrass [20, 22]. The density of the seagrass was assessed using an accurate metric (shoot counts) in known locations using accurate dGPS and is therefore highly repeatable. Although the data is robust the spatial coverage is still limited due to the focus of these studies on the impacts of fixed moorings.

In the intertidal, the most spatially extensive surveys of density come from the intertidal CCW SAC monitoring survey in 2010 [14] and the 2009 MSc thesis of Linda Thomas [25]. The CCW survey is of greater validity and highly repeatable as % cover reference cards to estimate seagrass density were used and photographic records were taken. The study randomly placed 64 quadrats throughout the intertidal seagrass meadow, with each quadrat's location recorded using dGPS. This SAC monitoring survey will be repeated once every 6 –yearly. There are no surveys that have been undertaken at Porthdinllaen that provide any form of temporal (seasonal or annual) description of seagrass variability.

The seagrass density data that is available for Porthdinllaen does suggest there is variability in the density of seagrass throughout the meadow, within and between the subtidal and intertidal environments and at an inter-annual basis, but the data is insufficient at the moment to provide any firm conclusions. The intertidal mapping work [13, 14, 25] and the analysis of spatial data by Egerton [16] also clearly shows how seagrass within areas of the intertidal inner harbour are less dense than other areas, and that density is lowest close to fixed boat moorings [20, 25] (see later discussion in section titled 'What is the condition of seagrass at Porthdinllaen'). The seagrass density data collected by volunteer surveys in 2008, 2009 and 2012 is insufficient to describe the whole meadow

but the surveys are potentially repeatable due to the recording of relatively high accuracy dGPS points (1m accuracy) which would provide a baseline to which future data could be compared.

Table 2. Summary values for seagrass density and canopy height data available for the seagrass at Porthdinllaen (n = number of samples).

				Shoot Density (shoots.m^{-2})		Canopy Height (cm)		% cover		Blade Density (blades.m^{-2})	
Survey Year	**Report**	**Location**	**n**	**Max**	**Ave**	**Max**	**Ave**	**Max**	**Ave**	**Max**	**Ave**
2014	ZEN data collection	Intertidal (west Carreg Oysters)	20	855	471	38	20	85	56		
2012	Stamp et al 2012	Subtidal (all data incl control sites)	507	464	115	92	28				
2012	Stamp et al 2013	Subtidal (North Outer Harbour)	234	426	128	75	16				
2012	Stamp et al 2014	Subtidal (South Outer Harbour)	252	464	83	92	19				
2010	Mercer et al 2010	Intertidal (Inner harbour)	64					100	35		
2009	Morris et al 2009	Various locations excl moorings	145	503	115						
2009	Thomas 2009	Intertidal (Inner harbour)	45			56	24	95	47		
2008	Morris et al 2008	Subtidal >10m from moorings	109	452	184						
2004	Boyes et al. 2008	Intertidal (Inner harbour)	12							1945	974

How has the seagrass changed?

Existing data about the seagrass provides snap-shot information about seagrass coverage, density and health at Porthdinllaen, it does not provide sufficient quantitative data capable of examining temporal change of these parameters. However, wider studies globally, and specifically those on *Z. marina* in Northern Europe, have shown that the coverage, density and health of seagrass meadows naturally change between seasons and years [6, 8, 28, 29]. A typical *Z. marina* meadow from the north Atlantic goes through a seasonal cycle with maximum biomass (and maximum shoot density) occurring in late summer/early autumn and lowest density in late winter. Like many terrestrial plants, seagrasses senesce in the autumn and winter with storms causing dying shoots and leaves to break off and become redistributed [30]. In a healthy system these patterns of temporal change depend upon local weather patterns and longer term climatic change, however, changes can be exacerbated in a system which is under stress. Anecdotal evidence from long-term residents of Porthdinllaen describes pronounced seasonal variability in the intertidal seagrass density and extent.

Role and Importance of Porthdinllaen seagrass.

Seagrass meadows are a highly valued marine ecosystem that support the coastal environment by, amongst other things, filtering water, providing habitat that supports biodiversity and creating extensive nurseries for many commercially important fish species [31]. The benefits that seagrass meadows provide to the human population are termed “ecosystem services” – see Table 3 for further information. The majority of these ecosystem services can be generically applied to seagrass meadows globally, however the extent of services may in some cases vary locally and depend upon the health of the meadow and the specific seagrass plant species present. An unhealthy seagrass meadow, for example, may have less dense shoots and as such provide less available habitat for associated fish species. Specific ecosystem services investigated at Porthdinllaen to date include provision of fish nursery grounds and biodiversity support and there has been some work on the provision of cultural resources (e.g. value for fishing, tourism) from the seagrass meadow. These are discussed in more detail below.

Table 3. Ecosystem services provided by *Zostera marina* in Porthdinllaen. Ecosystem Services are critical for human wellbeing [32]and can be defined as "the benefits that humans derive, directly or indirectly, from ecological functions" [33]. Ecosystem services are made up of provisioning, regulating, cultural and supporting services, and can confer direct or indirect benefit to society. Seagrass ecosystems are critical contributors to wellbeing and the economy in coastal societies worldwide.

Provisioning Services *Products obtained from ecosystems*	**Regulating Services** *Benefits obtained from regulation of ecosystem processes*	**Cultural Services** *Nonmaterial benefits obtained from ecosystems*
Fisheries nursery and feeding grounds - physical shelter for faunal species and nursery grounds for commercially important faunal species (fish, crabs and molluscs) - recreational shrimp fishery - Detailed seasonal fish surveys (Unsworth unpublished data) reveal the importance of the site for 10 species of commercially important juvenile fish (Cod, Saithe, Bib, Pollock, Whiting, Mullet, Bass,Plaice, Brill, Herring) - Evidence from other areas of the Atlantic reveal that juvenile fish living within *Z. marina* grow faster and have better long-term survival rates than those living in other nearshore habitats [34] **Food for waterfowl** **Biological indicator (environmental change)** **Tourism** **Advertising/promotional material**	**Coastal protection** - buffer against erosion and sediment stabilisation **Carbon sequestration** - during photosynthesis takes up carbon dioxide (CO^2) converting it to food for the plant and releases oxygen (O_2) into the water which supports other marine life	**Aesthetic, spiritual and recreational values** - favoured location for divers, sheltered seagrass contains diverse fauna to observe and remains a potential dive site in most conditions - sea kayaking tours sometimes utilise the bay and observe the seagrass for the same reasons **Recreational fishery (fish and invertebrates)** **Research** **Education**

Supporting services

Services necessary for the production of all other ecosystem services

Production of large quantities of organic material that support complex food webs
Filtering nutrients and sediments accumulating and recycling organic and inorganic materials
Sediment stabilisation
Oxygenation of water and sediments
Biodiversity

- support high biodiversity: fish, invertebrates and algae [35]. Infaunal characterising species include the burrowing urchin (*Echinocardium cordatum*), razor shells (*Ensis* sp.) and other bivalves, lugworm (*Arenicola marina*), and sand mason worm (*Lanice conchilega*). Epifaunal communities include the snakelocks anemone (*Anemonia viridis*), hermit crab (*Pagarus bernhardus*), shore crab (*Carcinus maenas*), grey topshell (*Gibbula cineraria*), and netted dogwhelk (*Hinia reticulata*). Epiphytic algae on Zostera leaves confer further biodiversity and include some species that are confined to the Zostera habitat [23]. Zostera beds are therefore an important target for conservation initiatives, including protection under the UK Biodiversity Action Plan [23].

Species richness

- *Z. marina* enhances biodiversity and species richness through ecosystem engineering and provision of a complex physical structure as well as enhanced primary productivity

Fish nursery grounds

The following research is available relating to the fish assembalges of Porthdinllaen:

*Bertelli, C. M., and R. K. F. Unsworth. 2014. Protecting the hand that feeds us: Seagrass (Zostera marina) serves as commercial juvenile fish habitat. Marine Pollution Bulletin **83**:425–429. [39]*

McCloskey, R. M. 2013. Investigating fish assemblage response patterns to temporal and habitat variation within a seagrass meadow MRes Thesis, Swansea University, UK. [26]

Peters, J. R., R. M. McCloskey, S. L. Hinder, and R. K. F. Unsworth. 2014. Motile fauna of sub-tidal Zostera marina meadows in England and Wales. Marine Biodiversity:1-8. [40]

*Unsworth, R. K. F., J. R. Peters, R. M. Mccloskey, and S. L. Hinder. 2014. Optimising stereo baited underwater video for sampling fish and invertebrates in temperate coastal habitats. Estuarine Coastal And Shelf Science **150**:281–287. [41]*

Unswroth RKF: Seine net and fyke net survey data from Porthdinllaen. Unpublished data 2014 [43]

Weigall, T. 2014. Temporal variation in the fish community of a cold-temperate seagrass (Zostera marina) meadow in the U.K. MRes Thesis, Swansea University, UK. [42]

Seagrass meadows are an important nursery habitat for young fish as they provide a high level of shelter from predators and an abundant food supply such as small crustaceans [36]. These benefits provided by seagrass are thought to result in young fish growing faster and having a higher chance of survival when they spend a period of time living in seagrass relative to alternative habitat [37]. Although its role as a fish nursery is the major reason commonly cited when discussing the value of seagrass for conservation, evidence from some locations suggests that the value of seagrass as a fish nursery habitat can change according to environmental gradients and anthropogenic impacts [36, 38]. Having locally specific information on the value of the nursery function is essential for appropriate planning and management.

Studies examining fish usage of seagrass in Porthdinllaen have been conducted seasonally since 2012 by researchers from Swansea University. A subsection of this data has been published in peer reviewed literature [39-41] and these documents provide convincing evidence of how seagrass meadows at Porthdinllaen support an abundance of juvenile fish of commercial importance.

Commercial fish species recorded as using the Porthdinllaen seagrass meadows as nursery habitat are listed in Table 4. To date 40 species of fish have been recorded at Porthdinllaen, 33 of which have been recorded in the seagrass with 22 recorded in the sand adjacent to the seagrass (38 of these species are reported within the thesis of Tom Weigall [42], whilst a further 2 are in unpublished data [43]). Within the studies undertaken to date at Porthdinllaen, fish abundance and diversity is consistently higher in the seagrass relative to the sand (non-vegetated habitat) areas, with much higher juvenile fish densities. Analysis within the MRes thesis of Tom Weigall based on data collected between April 2012 and July 2014 (6 sampling trips across different seasons and 145 samples) found fish density to be on average 1.9 times higher in seagrass than in sand (seagrass 26.7 ± 2.4 fish per sample, sand 14.2 ± 3.0 fish per sample) [42]. Such higher density in seagrass relative to adjacent non-vegetated habitat is consistent with data from throughout the whole distribution of *Zostera marina* [44]. The dominant species found in the seagrass at Porthdinllaen are Plaice, 15 spined Stickleback, Sand Gobies and Pollock.

Table 4. Commercial fish species recorded to use Porthdinllaen seagrass meadow as nursery habitat.

Common Name	Latin Name	Sampling Gear	Studies
Atlantic Cod	*Gadus morhua*	Baited video, Seine net	McCloskey, Bertelli, Peters
Pollock	*Pollachius pollachius*	Baited video, Seine net	McCloskey, Bertelli, Peters
Saithe	*Pollachius virens*	Baited video, Seine net	Bertelli, Peters
Bib/Pouting	*Trisopterus luscus*	Baited video, Seine net	Bertelli, Peters
Whiting	*Merlangius merlangus*	Baited video, Seine net	Bertelli, Peters
Plaice	*Pleuronectes platessa*	Seine net	McCloskey, Bertelli
Brill	*Scophthalmus rhombus*	Seine net	Bertelli, Weigall
Herring	*Clupea hurengus*	Seine net	McCloskey, Bertelli
Mullet	*Chelon labrosus*	Seine net	McCloskey, Bertelli, Peters
Bass	*Dicentrarchus labrax*	Seine net	Weigall
Dogfish	*Scyliorhinus canicula*	Baited video, Seine net	Peters, Weigall

Research at Porthdinllaen on fish assemblages assessed the species present and their size and frequency using a range of netting and video techniques. Sampling has been conducted day and night and compared the seagrass meadows to the adjacent sand flat habitat. This data has either been peer reviewed and published in the academic literature [40, 41] or has been reviewed by external master's thesis examiners for Swansea University (senior marine scientists).

All available data on seagrass fish assemblages at Porthdinllaen supports the same conclusion that the seagrass meadows provide important fish nursery grounds.

Seagrasses are of increasing interest to the general public due to a growing awareness of their role in supporting seahorse populations. In Porthdinllaen, while there are no scientific recordings of the presence of seahorse, four species of pipefish (relatives of seahorses) are present (worm, snake, greater and deep mouthed pipefish) [42]. There is some local anecdotal evidence that seahorses used to be present in the bay, but this is not substantiated by any specific studies. Such anecdotal references to seahorses being observed in the seagrass at Porthdinllaen accord with other similar observations from seagrass meadows in North Wales during the 1970's/80's (e.g. Inland Sea between Anglesey and Holy Island). However, none of these sightings have been verified and require further investigation.

Biodiversity within the seagrass meadow at Porthdinllaen

In addition to the 40 species of fish that have been recorded to be present in the seagrass at Porthdinllaen, a range of other studies have documented the abundant invertebrates and algae that reside in the meadows.

The following research is available relating to marine biodiversity at Porthdinllaen:

Edwards, M., Bunker, F., Maggs, C.A. & Johnson, M.P. (2003). Biodiversity within eelgrass (Zostera marina) beds on the welsh coast: analysis of epiflora and recommendations for conservation. Species Challenge Fund report to CCW. [23]

Cullen-Unsworth, L. C., L. Nordlund, J. Paddock, S. Baker, L. J. McKenzie, and R. K. F. Unsworth. 2014. Seagrass meadows globally as a coupled social-ecological system: implications for human wellbeing. Marine Pollution Bulletin 83:387-397. 52]

Griffin J & Unsworth RKF (2014) Zostera Experimental network (www.zenscience.org). Unpublished data

Johnson, M. P., M. Edwards, F. Bunker, and C. A. Maggs. 2005. Algal epiphytes of Zostera marina: Variation in assemblage structure from individual leaves to regional scale. Aquatic Botany 82:12-26. [48]

National Biodiversity Network Gateway (2015) All data relating to Porthdinllaen https://data.nbn.org.uk/ (data is from surveys by Seasearch, Natural Resources Wales and the Conchilogical Society)

Stamp, T. (2012). Porthdinllaen seagrass project (Pen Llŷn a'r Sarnau SAC) - Sediment Core Sampling October 2012, summary report. A report to Gwynedd Council. [46]

The ability of seagrass to help bind and hold sediments together is seen as one of its key ecosystem services. This three dimensional structure that it creates provides potential habitat for a range of flora and fauna. In addition to the habitat seagrass creates above the sediment, seagrass also creates a dense matting of roots and rhizomes below the sediment surface. The roots and rhizomes of seagrass provide an important function as they exude oxygen into a sedimentary environment that is prone to oxygen depletion. This oxygen has the potential to make the environment more affable for invertebrates that live within sediments than might otherwise be the case [45]. This is particularly the case in muddy environments prone to anoxia. At Porthdinllaen seagrass grows in a range of different substrate, from mud to larger shells and gravels. This sediment together with the seagrass supports a range of biodiversity.

Large motile invertebrates

During the extensive fish assessment work by Swansea University (since 2012), static fyke nets have collected a range of large motile invertebrates including cuttlefish (*Sepia officinalis*), squid (Sepiola sp.), lobster (*Homarus gammarus*), brown crab (*Cancer pagurus*), green crab (*Carcinus maenas*) and spider crab (*Maja squinado*).

Macro-invertebrates

Within the National Biodiversity Network data there are records of 200 macro invertebrates present at Porthdinllaen, although it is not immediately clear from the data what habitat these are linked to. The main groups of macro invertebrates recorded at Porthdinllaen can be seen in table 5. Of interest are the large numbers of mollusc species that have been identified from the site by the Conchiological Society.

Surveys of sediment invertebrate infauna were conducted during 2012 [46a & 46b] and were a first assessment of the sediment infauna communities and the potential changes in infaunal biota as a result of the impact of boat moorings on seagrass at Porthdinllaen. Core samples were collected from three contrasting habitats (mooring scars, sediment without seagrass, and seagrass meadow), and the infaunal species within these were identified and compared. Sediment samples were also collected to compare the sediment characteristics between the three habitats. Given the trial nature of the study by Stamp (2012) only a limited number of cores were taken and only an interpretation of the data was undertaken. From this survey 111 invertebrate and algae species within sediments were documented [46b]. Of particular note was a lone observation of the long-lived clam *Arctica islandica* which is a Biodiversity Action Plan species and is included on the NERC Act 2006: Section 42 list of species of principal importance for conservation of biological diversity in Wales [46b]. The more common infaunal species observed were *Rissoa parva*, a small herbivorous gastropod, and *Galathowenia oculata*, a deposit feeding polychaete worm. As only 8 samples were taken and

analysed the survey cannot be considered representative of the whole bay and seagrass meadow, however, the findings of the study provide a useful initial baseline of the infaunal species [46b].

Table 5. Number of species within each invertebrate Taxon recorded within the NBN Gateway.

Taxon	No of Species recorded
annelid	17
bryozoan	6
cnidarian	8
crustacean	21
echinoderm	2
mollusc	133
sponge	7
tunicate	6

During 2014, researchers at Swansea University collaborated in the global Zostera Experimental Network (ZEN) (zenscience.org). The ZEN project used a consistent peer reviewed and tested methodology at 20 sites throughout the Northern Hemisphere distribution of *Zostera marina* to examine the relationship between biodiversity and ecosystem services within seagrass beds. Extensive assessments of biodiversity (microbial, genetic, macroalgae and invertebrate) were undertaken of the seagrass at Porthdinllaen and at Pen-y-chain, on the southern side of the Llŷn Peninsula. Although the data is as yet unpublished, 10 species of attached invertebrate fauna were documented as living on the seagrass. These species were broadly similar between sites although there were less grazing invertebrates present at Porthdinllaen. The low diversity and abundance of grazers may reflect a less resilient [47] and potentially altered food web, however, such a premise requires further research. Samples on genetic and microbial diversity taken within the ZEN project are yet to be processed.

Algae

The National Biodiversity Network contains records of 42 species of algae present at Porthdinllaen. These records are from observations made during the CCW phase 1 intertidal surveys in 1997 and the surveys of Chris Lumb in 1983. Additional species level records are available from unpublished data relating to the Zostera Experimental Network (ZEN) surveys in 2014. The ZEN surveys recorded 28 species of algae. Excluding any duplication this equates to the presence of 65 species of algae at Porthdinllaen.

Micro-algae that grows in abundance on the seagrass leaves is referred to as epiphytic algae. A comparative assessment of algal epiphytic assemblages in seagrass was conducted within four Welsh subtidal seagrass meadows during 2002, including Porthdinllaen [48]. The research, published in peer reviewed literature, revealed that the structure of the epiphytic assemblages was always related to individual leaf length. The epiphytic assemblages at Porthdinllaen were found to contain much lower numbers of species than other sites [23, 48]. This finding may reflect the smaller leaf lengths measured at Porthdinllaen, however the exact explanation for lower species diversity is not clear.

Other reasons seagrass is important at Porthdinllaen

The following research is available relating to other reasons seagrass at Porthdinllaen is important:

Cullen-Unsworth, L. C., L. Nordlund, J. Paddock, S. Baker, L. J. McKenzie, and R. K. F. Unsworth. 2014. Seagrass meadows globally as a coupled social-ecological system: implications for human wellbeing. Marine Pollution Bulletin 83:387-397. [52]

Cullen-Unsworth, L. C., and R. K. F. Unsworth. 2013. Seagrass Meadows, Ecosystem Services, and Sustainability. Environment 55:14-27. [31]

Seagrasses perform a range of services that are extremely important for the coastal environment and also for human wellbeing [31]. Seagrasses are very effective at trapping sediments from the water column and as the trapped sediments build up their complex root structure, it helps stabilise the seabed. Seagrasses are highly effective at absorbing nutrients; as the plants die and degrade nutrients become available to various plants and animals. The trapping of sediments and the absorption of nutrients additionally helps make the water clearer. Seagrasses also produce large amounts of oxygen that is released into the air (via the water column) and are increasingly recognised for how they lock carbon dioxide (as organic matter – from plants and from particulate carbon in the water column) into the sediments rather than re-emitting it into to the atmosphere (therefore playing a role in global carbon sequestration).

At Porthdinllaen there is very little data available that quantifies the value of these services at a local level. However, there is evidence from around Europe and globally that outlines the generic value of seagrass meadows in providing these services [49-51]. This value is consistently higher in seagrass than in many other marine habitats. It is to be expected that seagrass sediments at Porthdinllaen are of value as a carbon store but further research is needed to quantify this.

Seagrass meadows represent a clear example of a linked social-ecological system [52] whereby the ecological services of seagrass meadows provide a multitude of benefits to people that confer a sense of wellbeing. By stabilising sediments, creating habitat for associated fauna, making the water clearer and helping maintain the beach, Cullen-Unsworth et al. 2014 propose that seagrasses at Porthdinllaen enhance local wellbeing [52]. An example of this is the recreational fishing that takes place at low tide for prawns that are present in the seagrass, which provides a cultural service giving material and non-material benefit though the provision of a recreational activity.

What is the economic value of seagrass?

Many of the ecosystem services that seagrasses provide have a potentially high economic value, not least through the provision of critical habitat for many commercially and recreationally important fish and invertebrate species. Seagrass meadows are an important resource base for rural communities contributing significantly to human wellbeing through shoreline protection and the provision of fishing and bait collection grounds, as well as providing a socio-culturally important resource with high recreation and aesthetic values. In spite of the availability of broad information on the economic value of seagrass, few empirical studies quantify these values in monetary terms [53]. The two values currently available are those estimated for nutrient cycling and carbons sequestration - its economic value as a fishery and fish habitat is not yet fully understood but available evidence (from a biological perspective) does suggest that this is very high [37, 54].

Seagrasses and algae beds combined have a minimum estimated value of US$ 19,004 ha^{-1} yr^{-1} (in 1997) for their nutrient cycling capacity alone [33]. Essentially seagrass filters the water and this

value equates to the costs to replacing seagrass with filtration systems. Unfortunately the value is outdated but does provide a guide to the importance of this function. The carbon sequestration value of seagrass has also been recently quantified and is estimated as in excess of US$43,000 per hectare per year [55]. Placing this in context we know that there is up to 28 ha of seagrass at Porthdinllaen and this could have a total value for carbon storage of US$1.2 million.

Given the lack of local empirical data on the economic value of seagrass meadows in Wales there is clearly a need for such research to be conducted.

What is the condition of the seagrass at Porthdinllaen and what are the factors affecting it?

Conditions driving seagrass loss

Seagrass meadows are comprised of plants adapted to live in the marine environment. Just like their terrestrial cousins these plants need sufficient light to photosynthesise and require conditions that allow growth without being outcompeted by other more dominant species. Seagrasses are unable to withstand much physical disturbance and are vulnerable to direct physical impacts. They are also readily damaged by indirect impacts that can affect the environmental conditions they rely on to survive. Water quality and altered food web (e.g. loss of key species and/or overexploitation) are particular drivers of such changes. Given the sensitivity of seagrasses to adverse environmental change, understanding their condition relative to thresholds of damage is critically important.

It is known from studies undertaken in various parts of the world that seagrasses reach environmental thresholds (e.g. not enough light, too many nutrients, too much physical stress) beyond which they rapidly disappear [56, 57]. It would appear clear therefore that advanced warning of changes in these environmental parameters are required in order to be able to prevent further loss of habitat [56]. Restoration of seagrass meadows after loss has occurred but is extremely difficult and costly therefore finding ways to prevent loss is a more viable option.

In countries where national or regional seagrass monitoring programmes exist, scientists have commonly progressed beyond the basic measurements of just seagrass presence/absence, coverage and density to monitor the actual environmental status (light availability, nutrients) of the meadow essential to the survival of the seagrass [58-60]. This provides early warnings of stress in the system before collapse is likely to occur, enabling management authorities to take appropriate action.

What do we know about the environmental condition of seagrass at Porthdinllaen?

The following research is available relating to the environmental condition of seagrass at:

Jones, B. 2014. Development of a potential indicator of ecological status in the British Isles, using the seagrass, Zostera marina. MRes Thesis, Swansea University, UK. [27]

Jones, B. L., and R. K. F. Unsworth. 2015. The degradation of marine ecosystem service provision: seagrass in the British Isles. ***In Review*** *Royal Society Open Science. [61]*

The environmental status of seagrass at Porthdinllaen was assessed as part of a survey of seagrass meadows around the British Isles in 2013, the first study of its kind in the UK to be undertaken [27, 61]. The study examined the nutrient status of the meadow and measured a series of variables considered to be good indicators of the environmental status of the habitat (selected from the scientific literature) [62]. The seagrass at Porthdinllaen was compared to thirteen other locations, these included a range of sites subjected to a gradient of increasing impacts (e.g. industry, catchment, tourism). By examining multiple indicators of environmental status the study enabled the development of an index of 'seagrass health'. The study conducted in 2013 focussed on the subtidal seagrass at Porthdinllaen and found it to be in a poor state of health relative to other locations. Other sites assessed to be of poor status included Skomer, Southend-On-Sea, Solent and Milford Haven. The seagrass at Porthdinllaen was found to have high concentrations of Nitrogen and Phosphorus, exhibited low shoot length and the C:N (carbon:nitrogen) ratio (indicator of light availability) was low [27]. Although valuable in providing an overview of the status of seagrass in the

UK, the study was spatially and temporally limited. It does however outline some strong evidence that the health of the seagrass at Porthdinllaen is poor [27].

Degradation of the seagrass food web

The following research is available relating to the degradation of the food web at Porthdinllaen:

Weigall, T. 2014. Temporal variation in the fish community of a cold-temperate seagrass (Zostera marina) meadow in the U.K. MRes Thesis, Swansea University, UK. [42]

Smith, A. 2014. The invertebrate assemblage and trophic control of two *Zostera marina* meadows in north west Wales. *MRes Thesis, Swansea University, UK. [63]*

Seagrass meadows contain a complex food web, the interactions of which serve to support the productivity of the meadows themselves. For example, small invertebrate crustaceans are known to graze on the algal epiphytes that grow on the seagrass. The grazing helps the seagrass by enabling higher light penetration to the photosynthetic apparatus of the seagrass plants. When the seagrass meadow food web becomes disrupted, such interactions can become damaged and make the seagrass more vulnerable to degradation. At Porthdinllaen, fish surveys recorded the 15 spined stickleback as the most abundant and consistently present species in the seagrass [42]. This stickleback species is an effective predator of small grazing crustaceans and is possibly present in high abundance due to the lack of large predators. Studies on grazing invertebrates at Porthdinllaen within the ZEN project found Amphipods to be potentially important grazers that were in low abundance, possibly facilitated by the result of a trophic cascade from overfishing of commercially important top predators [63]. Such a premise requires further testing.

Trophic cascades where a food web is disrupted by, for example, the removal of top predators can make seagrass more vulnerable to impacts as documented in seagrass meadows in Sweden [64]. The food web interaction between sticklebacks and invertebrate grazers at Porthdinllaen remains the hypothesis of researchers at Swansea University; however the evidence from Sweden highlights the potential vulnerability of the seagrass at Porthdinllaen to the impacts of food web disruption.

Physical impacts on the seagrass at Porthdinllaen

The following research is available relating to the presence of physical impacts on seagrass at Porthdinllaen:

Boyes, S., K. Hemingway, and J. H. Allen. 2008. Intertidal monitoring of Zostera marina in Pen Llyn a'r Sarnau SAC in 2004/2005. Countryside Council for Wales, Bangor (UK). [13]

Egerton, J. 2011. Management of the seagrass bed at Porthdinllaen. Initial investigation into the use of alternative mooring systems. Report for Gwynedd Council. [16]

Hemingway, K., A. J.H., and S. Boyes. 2004. Intertidal Monitoring of Zostera marina in Pen Llyn a'r Sarnau SAC in 2004. Report: YBB084-F-2004-PLAS-Z.mar. Report to the Countryside Council for Wales. [65]

Morris, E. S., and H. Goudge. 2008. Piloting the Use of Volunteer Divers in Subtidal Marine Monitoring in Wales: Preliminary Seagrass Surveys in Porthdinllaen and Milford Haven. CCW Marine Monitoring Interim Report. [20]

Morris, E. S., N. Hirst, and J. Easter. 2009. Summary of 2009 Seagrass Surveys in Porthdinllaen. CCW Marine Monitoring Interim Report. [21]

Stamp, T. 2012. Porthdinllaen seagrass project (Pen Llŷn a'r Sarnau SAC) - Sediment Core Sampling October 2012, summary report. A report to Gwynedd Council. [46 a & b]

Stamp, T. E. M. 2013. Porthdinllaen seagrass bed, Pen Llŷn a'r Sarnau SAC: a survey of moorings in the outer harbour and their impact on the seagrass 2012. A report to Gwynedd Council. [22]

Thomas, L. 2009. The effects of anthropogenic disturbance on intertidal Zostera marina beds at Porthdinllaen, North Wales, UK. MSc thesis. Imperial College, London. [25]

Unsworth, R. K. F., and C. M. Bertelli. 2012. Porthdinllaen mooring survey - April 2012. A report by SEACAMS for the National Trust. [71]

General impact observations

As sensitive marine habitats, seagrass meadows are highly susceptible to physical impacts and disturbance [1]. One major source of such disturbance at Porthdinllaen is that caused by the impacts of boats and their associated moorings (see Figures 4 and 5 and discussion below). This is because the chains and anchors associated with various types of moorings drag over the seagrass and repeatedly tear the plants, eventually ripping up their roots and rhizomes and reducing the capacity for recovery to occur.

There is extensive evidence in literature documenting the loss of seagrass, globally and in the UK, from direct physical disturbance [1, 12] and many of these impacts can be seen at Porthdinllaen (see table 6).

Table 6. Physical stressors observed on seagrass at Porthdinllaen and their cause

Stressor	**Potential impact of the Damage**
Boat moorings (chains)	Scouring of the seagrass resulting in removal of shoots
Boat keels	Creation of short ditches through meadow and damage to seagrass shoots
Boat scouring	Scouring of the seagrass as the boat lands on seagrass at low tide resulting in damage to removal of shoots
Anchors	Dropping of anchor in seagrass damaging the shoots as the anchor is recovered
Tractors	Compression of sediments, creation of tracks through meadow and damage to seagrass shoots
Dumping of fishery waste	Lobster and brown crab shell waste suffocating seagrass
Digging seagrass by commercial shellfish gathers	Loss and disturbance of seagrass
Coastal development	Loss and disturbance of seagrass

In 2003 and 2004, two studies documented the occurrence of boat based damage to seagrass at Porthdinllaen [22, 65]. These impacts were from fixed chain moorings, keel damage, tyre tracks and anchors and were described together with the inclusion of a series of associated photographs. Although illustrative these impacts were not assessed quantitatively.

In addition an intertidal study of the seagrass at Porthdinllaen in 2008, the study by Boyes et al [13], provided further evidence of the occurrence of a series of physical impacts on the seagrass. This study provided some level of quantification to the assessment of physical damage at the site and recorded 7 sites where physical damage was present; these were all within the northern (inner harbour) end of the meadow.

Other small scale sources of physical disturbance are evident at Porthdinllaen (author personal observation) such as the depositing of lobster and brown crab shells on the seagrass resulting in suffocation, and anecdotal evidence of digging within the seagrass at extreme low tides by groups of shellfish gatherers.

Figure 4. Images showing the physical and indirect impacts on the intertidal seagrass at Porthdinllaen (author photos). From left to right a) presence of high density of boats moored in shallow seagrass, b) tyre tracks through seagrass, c) yacht keel stuck into seagrass, d) halo surrounding seagrass mooring, e) degraded seagrass in upper intertidal area, f) thick epiphytic algal growth on seagrass.

Although there is qualitative evidence of the presence of all eight potential physical stressors outlined in Table 4 at Porthdinllaen there is limited quantitative evidence of the specific impact of the majority of these, with the exception of boat moorings impacts (see next section) and an isolated case of coastal development at the entrance to the bay.

In spite of the lack of quantitative evidence of all impacts specifically at Porthdinllaen, enough is known about the biology and life history of seagrass, and in particular the eelgrass *Zostera marina* [1, 51, 66], to conclude that all the stressors described in Table 4 have the potential to negatively impact the health and productivity of the seagrass.

Impacts of fixed boat moorings on seagrass

There is extensive evidence from international peer reviewed academic literature of the damage caused by boat moorings on seagrass [1, 67-70] and this has been corroborated at a local scale at Porthdinllaen [16, 20-22, 71]. Static moorings cause scarring of seagrass because weighted chains repeatedly tear and uproot seagrass shoots and rhizomes within the circular footprint of the mooring [70, 72].

It can be concluded with a very high degree of certainty that boat moorings impact seagrass causing a reduction in the extent and density of seagrass and creating patches within seagrass meadows.

This fragmentation of seagrass beds reduces their overall resilience to other impacts (natural and man-made). Figure 3 provides a visual perspective on how moorings placed in seagrass at four sites in the UK and France have clearly resulted in the complete loss of habitat in a halo area surrounding the mooring.

In 2008 volunteer divers led by experienced and qualified scientists surveyed the seagrass density and condition surrounding 5 fixed moorings [20] (it is not clear what sort of moorings were sampled in 2008). In 2012, 31 fixed moorings were surveyed [22] by a similar method to that used in 2008 in order to gather information from a larger number of moorings. In the 2012 study, two of the moorings were a concrete block design and 29 were identified as a two anchor mooring design [22]. Both the 2008 and 2012 studies sampled mainly at 4 compass directions around each mooring (north, east, south and west), and sampled 3 quadrats at 5m intervals along a transect. The two studies mostly found reduced seagrass density closer to the moorings and that seagrass shoot density increased with increasing distance away from the mooring up to a distance of approximately 25m from the mooring. Seagrass shoot canopy height showed a less clear picture with some indication of reduced canopy height closer to the moorings in some compass directions, but on the whole a less clear indication of change with distance from the mooring. The density changes were inconsistent around the different compass rose directions sampled with little impact recorded in some directions. Where impacts were clear these were mostly in line with the direction of the prevailing wind suggesting the impact wasn't uniform around the mooring but focussed around the areas that the mooring mostly drags. The variations in the location of the impacted area with respect to individual moorings may reflect the slight displacement of the mooring when it is put back in from one year to the next. The 2012 survey could have benefitted from increased sampling frequency closer to the actual mooring and recording seagrass density and canopy height at the base of the actual mooring.

The presence of the moorings does appear to be reducing seagrass density within an area around each mooring. It is known that that the location of the moorings does vary slightly from year to year (even with the use of GPS there will be some degree of error and hence displacement of the specific location of each mooring), and this has the effect of slightly displacing the area of impact from one year to the next. As a result the area impacted by each mooring may actually be quite extensive when multiple years are considered.

Studies by researchers at Swansea University [71] have also made rapid qualitative descriptions of the seagrass surrounding fixed moorings at Porthdinllaen and recorded similar persistent low or no seagrass present at close proximity to the mooing. These findings were similar to those of Stamp 2013 [22].

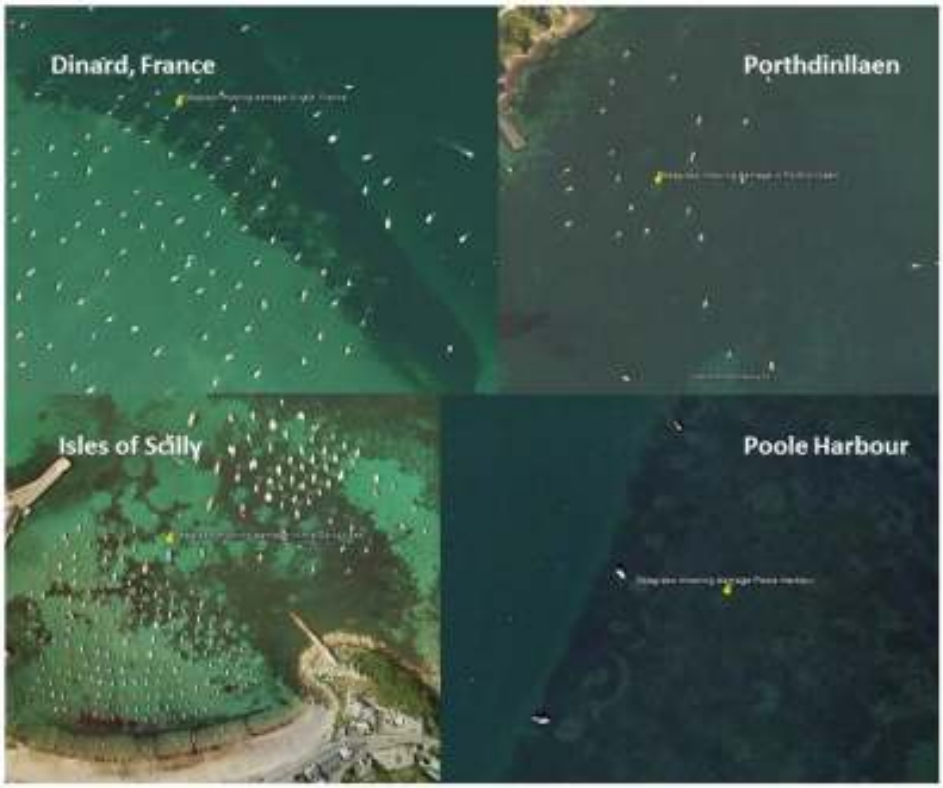


Figure 5. Aerial imagery showing damage to seagrass (*Zostera marina*) caused by boat moorings in the UK and France. The dark areas within the images show seagrass and the circular light areas are where halos have appeared, denuded of any seagrass due to the presence of fixed moorings.

An MSc level research thesis of Kings College London also documented strong evidence at Porthdinllaen of the loss of seagrass cover and density with increasing proximity to the areas of the moorings in the intertidal [25]. This corroborates studies by and on behalf of the Countryside Council Wales who recorded areas of seagrass close to intertidal moorings that were highly impacted.

Other factors potentially affecting the seagrass at Porthdinllaen

In addition to the issues of localised physical disturbance (e.g. Table 4, Figures 4 and 5), there are a range of other factors at Porthdinllaen that have the potential to impact upon the seagrass meadow. These are both local and regional issues (disease, water quality and invasive species) as well being of a global nature (climate change and sea-level rise).

The following research is available relating to other factors influencing seagrass at Porthdinllaen:

Morris, E. S., and H. Goudge. 2008. Piloting the Use of Volunteer Divers in Subtidal Marine Monitoring in Wales: Preliminary Seagrass Surveys in Porthdinllaen and Milford Haven. CCW Marine Monitoring Interim Report. [20]

Morris, E. S., N. Hirst, and J. Easter. 2009. Summary of 2009 Seagrass Surveys in Porthdinllaen. CCW Marine Monitoring Interim Report. [21]

Stamp, T. E. M. 2013. Porthdinllaen seagrass bed, Pen Llŷn a'r Sarnau SAC: a survey of moorings in the outer harbour and their impact on the seagrass 2012. A report to Gwynedd Council. [22]

Unsworth, R. K. F., J. C. Bull, and C. M. Bertelli. 2014a. Options for long-term seagrass monitoring at Porthdinllaen, Wales. Report produced by Swansea University on behalf of Gwynedd Council. [78]

Invasive species

Habitats exhibiting ecological disturbance and stress are often associated with the presence of increased numbers of invasive species. As seagrasses are sensitive to environmental degradation and physical disturbance the potential for the introduction of invasive alien species is high [73]. It remains unclear whether invasive species result in seagrass decline, or whether they simply exploit niches created by degradation in the seagrass meadow from other causes. Understanding these mechanisms could help design more effective management strategies that help control invasive species [74]. The non-native brown seaweed Wire weed *Sargassum muticum,* for example, very quickly invades *Z. marina* beds in areas where the beds are in decline. Although there are no indications of any direct competition between *S. muticum* and *Z. marina*; *S. muticum* impedes regeneration of Zostera beds [75, 76].

Disturbance of seagrass meadows has been shown to contribute to colonisation by invasive species and they are often subject to the presence of multiple introduced species, but the cumulative effect of these has been virtually unstudied [73].

S. muticum has been recorded as a potential threat to the seagrass in Porthdinllaen [21, 22], with the alteration of sediments surrounding moorings providing suitable habitat for colonisation [73]. Surveys in 2012 [22] highlighted that *S. muticum* was widely distributed throughout the harbour and present in 39.6% of transects compared to 20% of quadrats in 2008 [21], indicating an almost 100% increase in recorded abundance. The significance of this is that *S. muticum*, once established within a habitat, can suddenly rapidly spread to become a dominant component of a habitat often outcompeting native species. As anthropogenic pressures upon *Z. marina* increase, *S. muticum* represents a significant threat to the health of *Z. marina* beds across Wales and Europe. The increasing abundance of *S. muticum* in Porthdinllaen could therefore have a seriously detrimental impact on *Z. marina* in the future. When considered in combination with the patchy nature and variable density of *Z. marina* within Porthdinllaen, it appears there is opportunity for *S. muticum* to spread and expand within the seagrass bed and potentially outcompete the seagrass [22]. In high abundance *S.muticum* also presents a problem for boaters as it can grow to lengths which stretch out across the surface of shallow waters providing an impediment to boat keels, rudders and propellers [77].

Elevated nutrient levels at Porthdinllaen from sewage disposal and fertilizer use could result in further proliferation of *S. muticum* [27, 78]. To date the presence of *S.muticum* in Porthdinllaen appears largely constrained to attachment in areas of coarse sediments and around moorings where loss of seagrass has occurred. Coarse sediments have become more abundant in the area, however to date no detailed survey has examined *S.muticum*'s presence throughout the entirety of the meadow [78]. Stamp and Morris (2012) recommend a trial eradication programme for *S. muticum* at Porthdinllaen [22], however, as its density is currently low relative to that of the seagrass, Unsworth et al (2014) advise the continuation of monitoring instead and for this monitoring to be more widely spread across the seagrass meadow as a whole [78].

Disease

A wasting disease, caused by the protist *Labyrinthula zosterae* (a parasitic slime mould that causes black spot disease on seagrass), is suspected as the cause of the North Atlantic population declines of *Z. marina* in the 1930s, as well as more recent localized die-offs [79]. During the 2009 seagrass

surveys at Porthdinllaen wasting was observed across the site, however, it is unclear whether it was naturally occurring or from infection by *Labrynthula sp*.[21]. Confirmation of a *Labyrinthula* infection would require laboratory analysis.

Wasting was also recorded by Stamp and Morris in 2012 [22] who focused data collection around moorings. Wasting disease was found to have a low level of occurrence across all surveyed seagrass and not considered to be a significant problem at the site. The wasting observed could be related to annual die-back of *Z. marina* and again was not confirmed to be caused by *Labyrinthrula spp*. The low level of occurrence of wasting observed in 2012 suggests that it was not prevalent at that time; however, the authors recommended that it should be monitored as an indicator of seagrass health.

Climate change

The primary effects of climate change on seagrass meadows will relate to temperature changes and storm events resulting in altered growth and physiological functioning, and changed environmental conditions [80]. Ultimately climate change may lead to alterations in the distribution of seagrasses species, and potentially habitat loss or degradation [80], but improving the resilience of the system by increasing the health of the seagrass and the integrity of the food web may provide a means of reducing potential future loss or degradation.

The direct effects of increased temperature on the resistance of seagrass depends on the individual species' thermal tolerances, including their optimum temperatures for photosynthesis, respiration, and growth, and how these processes compete for carbon resources [80]. Subtidal seagrass at Porthdinllaen, particularly those near their depth limit, exist at a threshold where photosynthetic carbon gain is very closely balanced with respiration requirements [81]. As temperatures rise, respiration increases increasing the need for light, and reducing colonisation depth [81]. Seawater warming may also increase toxicity stress [82] and alter seagrass phenology [83]. However, warming ocean temperatures will occur in conjunction with rising sea levels and water quality impacts both of which could reduce light penetration and photosynthetic carbon gain in deep-water habitats, thus further reducing colonising depth [84] and reducing the capacity of plants to deal with stress. Factors that promote the resilience (e.g. improved water quality, more balanced food web) of these meadows will therefore be critical in determining their long-term viability. Although the thermal tolerance for *Zostera marina* is quite high, increasing temperature increases the need for high light, therefore conditions of poor water quality that can reduce light availability may increase the susceptibility of *Zostera marina* to the impacts of climate change.

Increasing atmospheric carbon dioxide will alter seawater chemistry. In areas where seagrasses are carbon limited, this may increase primary productivity for a time, however, it is not clear if this increased productivity would be sustained. The changes that will occur in seagrass communities are difficult to predict and further research is required [80] including long-term monitoring of existing beds.

What are the consequences of seagrass degradation and loss at Porthdinllaen?

The following research is available relating to other factors influencing seagrass at Porthdinllaen:

McCloskey, R. M. 2013. Investigating fish assemblage response patterns to temporal and habitat variation within a seagrass meadow MRes Thesis, Swansea University, UK. [26]

Stamp, T. 2012. Porthdinllaen seagrass project (Pen Llŷn a'r Sarnau SAC) - Sediment Core Sampling October 2012, summary report. A report to Gwynedd Council. [46a & b]

Thomas, L. 2009. The effects of anthropogenic disturbance on intertidal Zostera marina beds at Porthdinllaen, North Wales, UK. MSc thesis. Imperial College, London. [25]

In closer proximity to the subtidal boat moorings and intertidal moorings with chain risers, the seagrass becomes less dense and more fragmented and this will ultimately impact upon the animal and plant life that inhabits the seagrass, as has been demonstrated by numerous studies both in the UK and abroad [85-87]. The impacts of habitat fragmentation on animals and plants have been studied exhaustively in relation to seagrass and other marine and terrestrial ecosystems and has been found to negatively influence biodiversity and habitat provision [88-92]. At Porthdinllaen a number of studies have investigated the impacts of seagrass habitat degradation on associated fauna and found similar results (see Figure 6 below). A loss or reduction of biodiversity ultimately leads to a reduction in the ecosystem services the habitat can provide and its resilience to extreme conditions (e.g. storms).

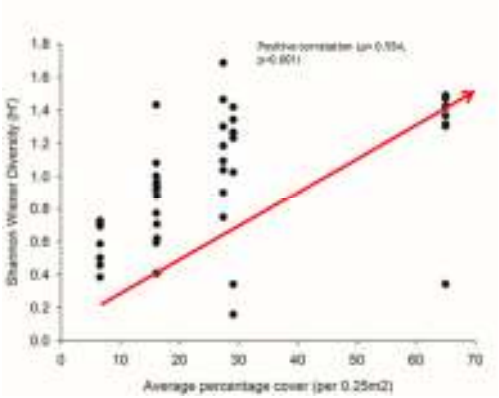


Figure 6. Change in fish diversity with increasing seagrass density at Porthdinllaen (Figure from McCloskey 2014).

A two year (2012-2013) study conducted by Swansea University provides evidence that the diversity and abundance of seagrass fish communities in Porthdinllaen declines significantly as the seagrass decreases in density [26] (see Figure 6). Another study found that epiphytic (diatom) assemblages present on the leaves of the *Z. marina* plants was also altered by the presence of the moorings [25].

In 2012 a study examined the benthic infaunal communities associated with seagrass compared to communities associated with bare sediments and those associated with sediments within boat mooring scars [46a&b]. The study, although limited with respect to sample size, provides further evidence of the loss of biodiversity (see Figure 7) within sediments surrounding boat moorings when compared to seagrass and naturally bare sediment.

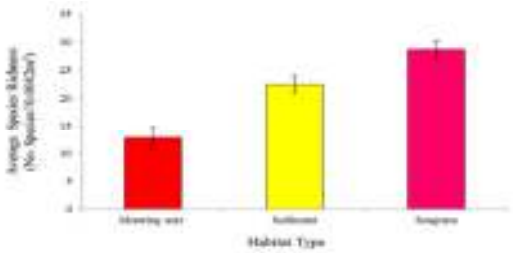


Figure 7. Average infauna species count (No. of species/0.0042m^3) within each of the habitat types (±SE) sampled within the Porthdinllaen (Figure from Stamp 2012).

Vulnerability of the seagrass at Porthdinllaen

To support the long-term survival and resilience of seagrass at Porthdinllaen in the face of global environmental issues (e.g. climate change and sea level rise) the manageable immediate threats that these sensitive marine habitats face from damaging anthropogenic activities need to be addressed [93, 94]. Experimental and observational studies on marine ecosystems maintain that healthy balanced ecosystems are more resilient to large scale changes such as elevated sea surface temperature or severe storms [93]. Simply put, the immediate threats facing seagrass meadows in Porthdinllaen and across Wales must be managed to improve chances of marine ecosystem resilience to larger (global-scale) phenomena such as climate change and its associated impacts.

For context, ecological resilience is "*the capacity of an ecosystem to absorb repeated disturbances or shocks and adapt to change without fundamentally switching to an alternative stable state*" [95]. Resilience therefore relates to how an ecosystem resists stressors and how it recovers from loss or degradation (resilience = resistance and recovery). In Porthdinllaen this means reducing the impacts of the multiple stressors that are known to be present (see Table 4). These stressors need to be managed to allow the seagrass meadow some resilience not just to deal with larger scale issues such as climate change but also the problems of disease and the increasing prevalence of invasive species.

Cumulative threats to seagrass

Over the last century, seagrasses have become increasingly affected by human activities, illustrated by severe declines in habitat or species loss that are often characterized by sudden change [4, 5]. Whilst much is known about how individual stressors (e.g. poor water quality) can affect seagrass, the cumulative impact of more than one stressor remains largely unstudied. At Porthdinllaen, multiple potential stressors are present, and although the potential threat posed by each stressor individually is understood, how the stressors interact and their cumulative impacts, is not.

The Irish Sea has been highlighted by a global analysis of cumulative stressors as already being highly impacted as a result of anthropogenic activity [96]. Understanding of cumulative impacts in marine ecosystems is generally poorly understood, however there is evidence from meta-analysis of cumulative impacts at a global scale of the potential for additive and synergistic interactions between different stressors [97] e.g. poor water quality exacerbating the existing effects of a degraded food web [64].

An understanding of the current threats and impacts to seagrass at Porthdinllaen, coupled with the growing knowledge of how cumulative impacts potentially further undermine the resilience of seagrass ecosystems, serves to highlight that management action needs to be undertaken to safeguard the seagrass meadow at Porthdinllaen in the long term.

Recovery potential

The capacity of *Z. marina* to recover after disturbance and loss depends upon a range of biological and environmental factors. Numerous studies have explicitly tried to understand the processes that lead to recovery. As disturbance is a natural structuring process within seagrass meadows it is not surprising to learn that recovery is sometimes readily observed [98-101]. Although recovery is usually possible from short-term small scale disturbance, there are many instances where recovery of seagrass has been unsuccessful [4], particularly where meadows have been subject to severe and widespread disturbance. One explanation for this may be that the system has become locked into an alternative stable state [102]. Such a change is most likely when the system is already under cumulative anthropogenic stress and doesn't have the resilience to facilitate recovery, or if the scale of the disturbance is sufficient to alter the physic-chemical environment of the meadow beyond the limits of what is suitable for the species. Recent studies on *Z. marina,* for example, illustrate how seagrass recovery can be hampered by the presence of elevated nutrients [103].

The failure of seagrass to recover, even following the removal of a primary stressor, is likely to be the result of the seagrass meadow shifting to what ecologists refer to as an 'alternative stable state' (effectively a new habitat type) of high turbidity, increased suspended sediment and anoxic sediments [104]; conditions effectively unsuitable to facilitate seagrass survival and recovery. When systems are healthy and are in a balanced ecological state their capacity to avoid shifting to an 'alternative stable state' is greatly increased as they are able to recover from loss. However, when multiple anthropogenic pressures cause the slow incremental degradation of seagrass health (such as anchor and mooring damage, poor water quality and altered food-webs) the meadow becomes weakened, losses become unrecoverable and the system rapidly slips into an 'alternative stable state' of anoxic mud.

When seagrass does fail to recover restoration is a possibility however this is difficult and costly. There have been many extensive and costly attempts to restore seagrass meadows owing to the widespread loss of *Z. marina* throughout the North Atlantic. Although there are now a number of successful restoration projects up and running, unfortunately the majority have failed and in most cases it is not clear what caused the failure. It is becoming increasingly accepted that, in order to succeed, there is a need for projects to run at large scale [105]. Specific methods that have worked in the past have involved the use of seeds from a donor meadow [106]. It is important to note that if seagrass were to be lost at Porthdinllaen there is no guarantee that any attempts at restoration would succeed.

Research for acceptable conservation and management solutions

Seagrass friendly moorings

The ecological impacts of fixed moorings on seagrass meadows are well documented at Porthdinllaen and elsewhere. Solutions to solving this problem are unfortunately less well understood, particularly with respect to developing seagrass friendly mooring systems in sites of high tidal range.

A process of stakeholder engagement and discussion commenced in 2010 and as a result information searches have been established and research projects developed with the aim of providing simple, affordable and realistic seagrass friendly alternatives to the moorings systems currently in use. A summary report of the initial options available for changing the moorings to less damaging systems was commissioned and proposed a series of different system available commercially [16]. A specific research project is underway, managed by the Pen Llŷn a'r Sarnau SAC Officer, to develop simple alternative mooring systems that are acceptable to all users whilst not damaging seagrass. This project will involve working with a marine engineer to develop the ideas and the SAC Officer will be reporting on this work later in 2017.

Proposed snorkel trail

The seagrass at Porthdinllaen also provides a tourist opportunity. Currently the numbers of visitors to the bay coming exclusively for snorkelling or diving are minimal; however there are numerous local businesses that could benefit from an increase in such tourist numbers (e.g. pubs, cafes, restaurants, accommodation, outdoor activity companies). A survey by the North Wales Wildlife Trust found that there is extensive interest from people throughout the area in expanding such snorkelling opportunities on the Llŷn Peninsula [107]. The Pen Llŷn a'r Sarnau SAC seagrass steering group developed a collaborative SEACAMS project with Swansea University and some local businesses to investigate the viability of a snorkel trail at Porthdinllaen. This was seen as a means of sustainably enhancing the value of the natural resources at the site to the local population. The snorkel trail study characterised the key features (species present, habitat type, environment, access safety) of ten near shore sites spread across the whole of Porthdinllaen [108]. The report concludes that Porthdinllaen provides extensive seagrass and rocky habitats that make excellent sites for snorkelling by visitors and tourists. Although it doesn't actually propose a means of developing the trail it provides valuable information about where a trail could potentially be established. The report noted the presence of a diverse array of species, many of which are of great interest to visitors and states that "of particular interest to visitors are the spider crab (*MaJa squinado*), Greater Pipefish (*Sygnathus acus*) and the Fifteen-spined Stickleback (*Spinachia spinachia*)".

The development of such a trail has yet to commence however various organisations have used the information to undertake snorkel safaris at Porthdinllaen.

Evidence gaps

The present review highlights that we have growing understanding of the ecological and economic value (ecosystem services) of the seagrass meadow at Porthdinllaen, its distribution and the factors affecting it. However this body of knowledge is far from complete. The following areas are significant evidence gaps to facilitating the future management of the seagrass meadow:

Thresholds

This present review highlights a growing understanding of the presence of a wide range of factors leading to the loss, damage and possible deterioration of seagrass, however the exact mechanisms of how these drivers may damage the seagrass meadow remain poorly understood. We need to understand the thresholds at which these factors may result in significant seagrass loss. For example we do not fully understand the frequency and intensity of physical disturbance that results in large scale seagrass loss; we just know that physical disturbance is resulting in seagrass loss in localised areas. We also don't know the point at which seagrass is damaged by poor water quality but we know that seagrasses are being subjected to elevated nutrients. Given the increasing level of anthropogenic stress at the site and the looming problems of climate change an understanding of the system's ability to deal with future stressors is required to inform future management actions.

Understanding change

In order to manage the site in the long-term it is vital that we understand the natural cycles of intra and inter annual variability that allows their separation from the impacts of anthropogenic damage. We do not currently have an understanding of what these natural changes are and there magnitude. The Pen Llŷn a'r Sarnau SAC seagrass steering group commissioned a series of studies to determine the most effective means of monitoring the long-term change in the seagrass at Porthdinllaen [78]. The review proposed methods for annual and/or seasonal monitoring of fixed sites within the intertidal and subtidal areas using tried and tested methodologies from seagrass studies globally. The authors also recommended the periodic mapping (using low costs rapid techniques) of the seagrass meadow to fully understand the spatial changes that occur over time. This programme of monitoring needs to be commenced.

There is a lot of anecdotal information about the historical change in the seagrass at Porthdinllaen, but this information has never been corroborated by means of conducting detailed studies using accepted techniques in quantifying local ecological knowledge (LEK) and historical ecology [109, 110]. There exists considerable potential knowledge from non-traditional scientific sources that requires quantifying so that it can be used for the management of the seagrass at Porthdinllaen.

Ecosystem services

The majority of the biological information collected about the site to date has focussed around fish nursery habitat use and invertebrate biodiversity of the site. We need to understand more about how the biodiversity of the site contributes to providing other ecosystem services such as beach stability, nutrient cycling and carbon storage. We also need to understand more about species of high conservation importance that use (or potentially have used in the past) resources at the site (e.g. bird species, seahorses, long-lived bivalves).

Reducing the impact of fixed boat moorings

Whilst we know that fixed moorings significantly damage seagrass we don't yet know the intricacies of this loss and how variations in mooring design and small modifications influence this damage. More information and research is required into how fixed moorings can be made to be less environmentally damaging to seagrass.

Seagrass recovery and restoration

Seagrass at Porthdinllaen is being damaged, and options exist to halt this loss and provide opportunities for ecosystem recovery. The capacity of seagrass to recover after loss is not ubiquitous. We currently have insufficient knowledge of the seagrass at Porthdinllaen to determine whether or not seagrass at the site can recover from loss and whether intervention in the form of restoration may be required in the long-term to ensure full seagrass recovery.

Conclusions

The bay at Porthdinllaen is of considerable ecological, tourist, cultural and industrial importance. The bay is widely used on a daily basis and particularly during warm weather is a hive of activity.

The site supports extensive seagrass meadows that are of significant value across scales from local to national and international.

Available evidence suggests that these meadows are under threat from multiple anthropogenic impacts and the then Countryside Council for Wales declared has identified the meadow as being in unfavourable condition.

More information is required with respect to the ecological mechanisms of the impacts on the seagrass bed, and initiation of a long term monitoring programme is recommended to facilitate improved understanding of the long-term change in the seagrass at the site. There is also a need to map the seagrass providing high resolution data across both the intertidal and subtidal areas.

Finding a means to sustainably manage the site and its ecological resources, whilst facilitating its continued use by stakeholders is of prime concern to the statutory authorities and specifically the Pen Llŷn a'r Sarnau SAC seagrass steering group. There are legal obligations to conserve and protect the seagrass bed at Porthdinllaen through the duties on Welsh Government and statutory bodies in relation to the SAC, SSSI and seagrass as a priority biodiversity habitat. Sustainable use solutions exist as evidenced by a growing body of scientific studies. These solutions could simultaneously support both seagrass protection and continued use of the site by stakeholders.

Given the factors threating the seagrass at this site, the recognised ecosystem service value of the seagrass meadows at Porthdinllaen, and our still limited understanding of the thresholds and tipping points that lead to undesirable ecological states with limited ecosystem service provision, this review concludes that actions to halt and reverse seagrass damage are urgently required.

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