

Investigation into the decline of the Maerl bed in the Pembrokeshire Marine (PM) Special Area of Conservation



Report No: 976

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Report series: Marine and Coastal Evidence Reports

Report number: 976

Publication date: June 2026

Title: Investigation into the decline of the Maerl bed in the Pembrokeshire Marine (PM) Special Area of Conservation

Author: Ratcliffe, F.C.

Technical editor: Ratcliffe, F.C. and Sannassy, J.

Quality assurance: Tier 3

Contributors: Camplin, M., Goudge, H., Lincoln, H. Lindenbaum, C. Lough, N., Pauls, L.

Peer reviewers: Camplin, M., Grant, L., Jakobsen, K., Pauls, L., Ramsay, K., Sannassy, J., and Winterton, A.

Approved by: Winterton, A., Pauls, L.

Restrictions: None

Distribution list (core)

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Recommended citation for this volume

Ratcliffe, F.C., 2026. Investigation into the decline of the Maerl bed in the Pembrokeshire Marine (PM) Special Area of Conservation. NRW Evidence Report No: 976, 93pp, National Resources Wales, Cardiff.

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Crynodeb gweithredol

Gwelodd gwely maerl Aberdaugleddau ostyngiad o 71% yn helaethrwydd maerl byw rhwng 2005 a 2017, gan ysgogi ymchwiliad i'r achosion sylfaenol a'r pwysau parhaus a allai fod yn atal ei adferiad. Mae'r adroddiad hwn yn cyflwyno canfyddiadau'r ymchwiliad hwnnw, gan nodi effeithiau hanesyddol a phwysau amgylcheddol cyfredol.

Methodoleg

Nodwyd y prif bwysau sy'n effeithio ar wely maerl Aberdaugleddau ac fe'i harchwiliwyd yn nhermau amseru, dwyster, amllder a graddfa ofodol. Yna rhestrwyd y pwysau hyn o'r risg uchaf i'r risg isaf. Defnyddiwyd canfyddiadau'r asesiad hwn i bennu camau rheoli priodol ar gyfer y safle ac i dynnu sylw at unrhyw ofynion monitro ychwanegol.

Achosion y dirywiad

Nid yw'r data monitro yn dangos unrhyw ddirywiad cyson yng nghyflwr y maerl rhwng 2017 a 2023; felly mae'r dystiolaeth yn awgrymu bod y prif effeithiau a arweiniodd at y dirywiad yng ngwely'r maerl wedi digwydd cyn 2017 ac nad ydynt bellach yn weithredol. Fodd bynnag, nodwyd dau fath o bwysau fel y rhai a gyfrannodd fwyaf sylweddol at y dirywiad cychwynnol:

- Gwaddodiad/Claddu
- Difrod Ffisegol (crafiadau, treiddiad, aflonyddu'r is-wyneb)

Rhwystrau i adferiad: pwysau parhaus

Er bod y prif weithgareddau niweidiol wedi dod i ben, mae'n bosib bod nifer o fathau o bwysau'n dal i fod yn rhwystrau i adferiad:

- Cyfoethogiad Organig
- Cyfoethogiad gan Faethynnau
- Rhywogaethau Estron Goresgynnol: *Crepidula fornicata*
- Solidau Crog (Clirder y Dŵr)
- Dadocsigeniad
- Macroalgâu (Mygu/Cysgodi)

Argymhellion rheoli

Er bod effeithiau hanesyddol yn debygol o fod yn gyfrifol am y dirywiad cychwynnol, rhwystrir adferiad y maerl gan bwysau parhaus, llawer ohonynt yn gydgyssylltiedig. Dylai'r mesurau rheoli ganolbwyntio ar liniaru'r rhwystrau hyn trwy ddull cydgysylltiedig ar draws y dalgylch. Ymysg y meysydd blaenoriaeth ar gyfer ymyrryd mae:

- Lleihau **cyfoethogiad organig a gan faethynnau** o darddleuedd pwynt (e.e. dŵr gwastraff) a gwasgaredig (e.e. dŵr ffo amaethyddol)
- Lleihau **solidau crog** i wella clirder y dŵr

- Monitro a mynd i'r afael â **dadocsigeniad** mewn gwaddod a drwy'r golofn ddŵr ble cafodd ei nodi.
- Monitro'r llenyddiaeth ar gyfer dulliau newydd o gael gwared ar **rywogaethau estron goresgynnol (*Crepidula fornicata*)** a'u rhoi ar waith lle bo hynny'n briodol.
- Monitro a lleihau **mygu a chysgodi macroalgaid** ble cafodd ei nodi.

Bydd adferiad effeithiol y gwely maerl yn dibynnu ar reolaeth amgylcheddol integredig ar draws y dalgylch a chamau wedi'u targedu i leihau'r pwysau hyn.

Executive summary

The Milford Haven maerl bed underwent a 71% decline in abundance of live maerl between 2005 and 2017, prompting an investigation into the underlying causes and ongoing pressures that may be inhibiting its recovery. This report presents the findings of that investigation, identifying both historic impacts and current environmental pressures.

Methodology

The main pressures affecting the Milford Haven maerl bed were identified and examined in terms of timing, intensity, frequency, and spatial scale. These pressures were then ranked from highest to lowest risk. The findings from this assessment were used to determine appropriate management actions for the site and to highlight any additional monitoring requirements.

Causes of decline

Monitoring data show no consistent ongoing decline in maerl condition between 2017 and 2023; hence evidence suggests that the primary impacts leading to the maerl bed's deterioration occurred prior to 2017 and are no longer active. Two pressures were identified as the most significant contributors to the initial decline:

- Sedimentation/Burial
- Physical Damage (Abrasion, Penetration, Disturbance of Substratum)

Barriers to recovery: ongoing pressures

Although the primary damaging activities have ceased, several pressures may continue to act as barriers to recovery:

- Organic Enrichment
- Nutrient Enrichment
- Invasive Non-Native Species (INNS): *Crepidula fornicata*
- Suspended Solids (Water Clarity)

- Deoxygenation
- Macroalgae (Smothering/Shading)

Management recommendations

While historic impacts are likely responsible for the initial decline, recovery is hindered by ongoing pressures, many of which are interlinked. Management measures should focus on mitigating these barriers through a coordinated, catchment-wide approach. Priority areas for intervention include:

- Reducing **organic and nutrient enrichment** from both point (e.g. wastewater) and diffuse (e.g. agricultural runoff) sources
- Reducing **suspended solids** to improve water clarity
- Monitoring and addressing **deoxygenation** in sediment and water column where identified.
- Monitoring literature for new methods of removal of **INNS (*Crepidula fornicata*)** and implementing where appropriate.
- Monitoring and reducing **macroalgal smothering and shading** where identified.

Effective recovery of the maerl bed will depend on catchment wide, integrated environmental management and targeted actions to reduce these pressures.

General introduction

This report presents an investigation into the decline in the condition of the Milford Haven maerl bed, conducted as part of the Nature Networks (NN) 2025 programme. It outlines the background, rationale, findings, and management recommendations resulting from the investigation. The NN initiative is a Welsh Government-funded, multi-year program aimed at improving the condition of protected sites across Wales, addressing both the nature and climate emergencies. As part of this program, the 'Investigation Into Declines in Benthic Habitats and Species' project seeks to identify the causes behind significant declines observed in certain benthic habitats and species, particularly those within the Marine Protected Areas (MPA) Network in Wales, such as maerl.

Maerl is a term used to describe nodule-forming calcareous red algae. In Britain, five species of maerl are recognised: *Phymatolithon calcareum*, *Phymatolithon lusitanicum*, *Lithothamnion corallioides*, *Lithothamnion glaciale*, and *Lithothamnion erinaceum* (Bunker and Ratcliffe, *in press*). Maerl nodules are fragile, slow-growing (0.1 mm to 1.5 mm per annum), and long-lived (Blake and Maggs, 2003; Bosence and Wilson, 2003). These nodules aggregate on the seabed to form maerl beds, typically in areas of clear seawater and moderate tidal flow, where they are less susceptible to siltation (Wilson et al., 2004). Maerl beds support a diverse community of flora and fauna, including algae that grow on the nodules and species that inhabit the interstitial spaces between them or burrow into the coarse gravel beneath (Bunker and Ratcliffe, *in press*).

Due to their fragility, maerl beds are easily damaged (Grall and Hall-Spencer, 2025) and are considered irreplaceable habitats in England, as well as being classified as vulnerable on the European Red List (Tillin et al., 2022). These habitats take hundreds of years to develop, and some beds may be 4,000 to 6,000 years old (Birkett et al., 1998). Maerl nodules themselves have lifespans exceeding 100 years (Foster, 2001) and are slow to recruit, rendering them a non-renewable resource. Once damaged, fragmented, or killed, maerl has almost no ability to recover, and its resilience is considered "very low" (Perry et al., 2017).

Maerl is found throughout Europe, including the Mediterranean and along the Atlantic coast from Portugal to Norway (Barbera et al., 2003). However, it is rare in the English Channel, Irish Sea, North Sea, and Baltic Sea (Grall and Hall-Spencer, 2025; Jenkins et al., 2025a). In Europe, many maerl beds are in poor or declining condition due to pressures from extraction, fishing, mariculture, dredging, invasive non-native species (INNS), and climate change (Hall-Spencer et al., 2010). As a result, maerl beds are listed under Section 7 of the Environment (Wales) Act 2016 (formerly the NERC Act 2008) and recognized as a threatened and declining habitat by OSPAR (1998).

The Milford Haven maerl bed is located within the Pembrokeshire Marine Special Area of Conservation (SAC) and is a part of the 'large shallow inlets and bays' as well as the 'estuaries' designated features of the site (Jackson-Bué et al., 2025). Maerl is also a Section 7 habitat and *L. corallinoides* and *P. calcareum* are Section 7 species (Environment (Wales) Act, 2016). The first known recording of maerl in the area was during the 1978-79 SWBSS Milford Haven Survey, where the survey summary recorded 'a

bed of sparse maerl' (JNCC, 2018). Station descriptions included a 'slope of clean sand with 100% coverage of maerl' west of the Esso Jetty. The habitat at that site was classified as 'maerl bed leading to sand with *Laminaria saccharina*, with occasional *Zostera*'. While the exact age of the bed is unknown, fossil maerl collected from Stack Rock within the bed area has been dated to between 184 BC and 12 AD (Blake et al., 2007).

L. corallioides which dominates the bed, is nationally scarce in British waters. The Milford Haven maerl bed also hosts a range of rare algal taxa, several of which are considered endemic to maerl habitats and absent from other benthic environments (Bunker & Ratcliffe, *in press*). The bed has a mosaic structure, with patches of live maerl interspersed with dead maerl fragments, situated on fine sandy substrates (Bunker & Ratcliffe, *in press*). Fossil maerl is present in deeper sediment layers, indicating the long-term persistence with a sample radiocarbon-dated to between 184 BC and 12 AD (Bunker and Ratcliffe, *in press*), affirming the ancient origin of this biogenic structure (Blake, 2005). In addition to its ancient origins, genetic analysis has revealed that the maerl in this bed is genetically diverse with a high number of clonal lineages, mostly derived from a single ancestral population and is isolated from other populations in the United Kingdom (Jenkins et al., 2025a). This indicates that the bed is a unique habitat, unreplicated in terms of genetic background elsewhere, with great importance to local biodiversity.

Between 2005 and 2017 the maerl bed underwent a pronounced deterioration in ecological condition, characterized by a 71% decline in the percentage cover of live maerl and shifts in the composition of associated benthic fauna. This observed decline has triggered the present investigation.

Objectives of this report

This report brings together historical and newly collected data to:

- Provide background on the current ecological status (monitoring) and history of the site.
- Identify pressures or combinations of pressures that have led to the decline in maerl abundance and degradation at this site between 2005 and 2017.
- Rank the impact of pressures from highest to lowest risk.
- Inform future conservation and management strategies to either halt the decline or promote recovery of maerl and protect the ecological function of the site.

The following sections will address these objectives.

Background - monitoring and current status

The maerl bed is situated within Milford Haven and part of it lies beneath the South Hook Liquid Natural Gas (LNG) jetty (Figure 1). The site ranges from 3 to 6m in depth and is subjected to moderate tidal flow. Since the discovery of the bed, there have been a series of diver and drop down video surveys to monitor the condition and extent of the bed (Figure 2, Table 1). Development of the South Hook LNG Terminal between 2005 and 2008 also resulted in several years of impact assessment and impact monitoring that included diver surveys, drop-down video (DDV), and one remotely operated vehicle (ROV) survey (RPS, 2006).

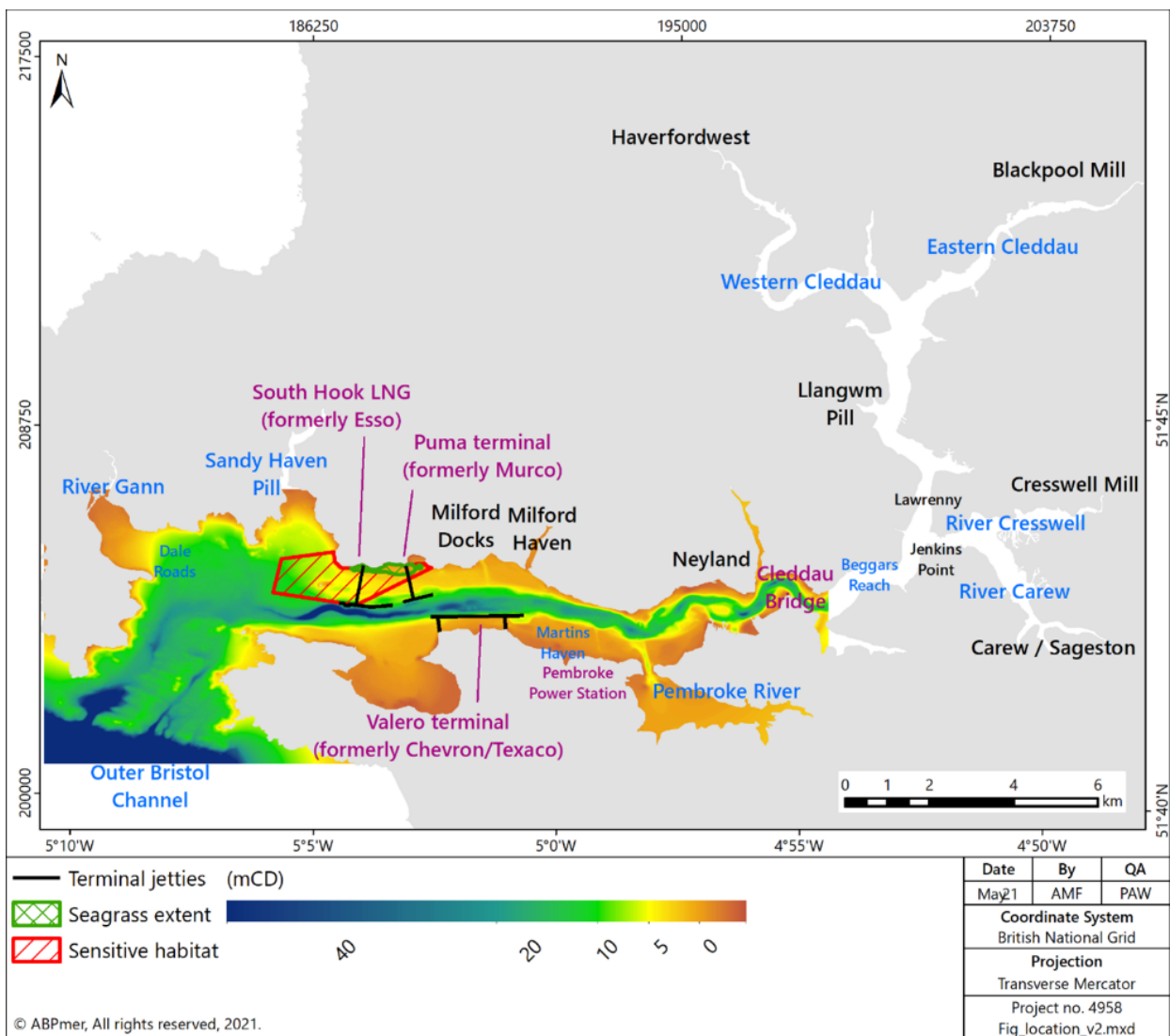


Figure 1: The location of the Maerl bed (highlighted by the sensitive habitat box) and bathymetry in Milford Haven, reproduced from ABPmer, NRW Evidence Report 551 (unpublished report).



Figure 2: Maerl monitoring sites around South Hook LNG jetty (former Esso terminal) surveyed by Natural Resources Wales (NRW) and RPS from 2004 to 2023.

Table 1: Maerl bed condition surveys carried out from 2004 – 2023. Dive (CCW/NRW 6 sites) = diver surveys – 6 sites/6 quadrats and cores per site. Dive (RPS 3x yr) = diver surveys, two transects each with 5 stations (6 quadrats/cores per station). DDV = dropdown video (approx. 630 drops per survey). ROV (RPS) = remotely operated vehicle survey.

| Year | Survey type | Reference |
|------|--------------------|--|
| 2005 | Dive (CCW 6 sites) | Bunker, F.St.P.D.; Camplin, M.D., 2007. A study of the Milford Haven maerl bed in 2005 using drop down video and diving. (CCW Science Report No. 769). |
| 2005 | DDV (CCW) | Bunker, F.St.P.D.; Camplin, M.D., 2007. A study of the Milford Haven maerl bed in 2005 using drop down video and diving. (CCW Science Report No. 769). |
| 2005 | DDV (RPS) | Wilson, S.; Bunker, A., 2004. Maerl survey May 2004 at South Hook LNG, Milford Haven. For South LNG / RPS Planning, Transport & Environment. |
| 2005 | ROV (RPS) | RPS, 2006. ROV Maerl Survey. South Hook For Besixkier J.V. JER2580R200905JE v1.1. 20th September 2005. |

| Year | Survey type | Reference |
|------|--------------------|--|
| 2005 | Dive (RPS 3x yr) | RPS, 2008a. Maerl Monitoring- Winter 2005 to Spring 2008 South Hook Jetty, Milford Haven. For BeSixKier/CB&I. JER2580R080901NS v4. 1st September 2008. |
| 2006 | Dive (RPS 3x yr) | RPS, 2008b. Maerl Monitoring- Winter 2005 to Summer 2008 South Hook Jetty, Milford Haven For BeSixKier/CB&I. JER2580R081223KL v3. 23rd December 2008. |
| 2007 | Dive (RPS 3x yr) | RPS, 2008b. Maerl Monitoring- Winter 2005 to Summer 2008 South Hook Jetty, Milford Haven For BeSixKier/CB&I. JER2580R081223KL v3. 23rd December 2008. |
| 2008 | Dive (RPS 3x yr) | RPS, 2008b. Maerl Monitoring- Winter 2005 to Summer 2008 South Hook Jetty, Milford Haven For BeSixKier/CB&I. JER2580R081223KL v3. 23rd December 2008. |
| 2010 | Dive (CCW 6 sites) | Bunker, F.St.P.D., 2011. Monitoring of a maerl bed in the Milford Haven waterway Pembrokeshire 2010. (CCW Science Report No. 979). |
| 2016 | Dive (NRW 6 sites) | Bunker, F. St. P. D., Díaz-Tapia, P. and Maggs, C. A., <i>in press</i> . Monitoring a maerl bed in Milford Haven between 2005 and 2016. (NRW Evidence Report No: 213). |
| 2017 | DDV (NRW) | Moore, J., Mercer, T., and Bunker, F. St. P., <i>in press</i> . Monitoring Survey of Maerl in Milford Haven Waterway, 2017 |
| 2023 | Dive (NRW 6 sites) | Bunker, F., Ratcliffe, F., <i>in press</i> . Maerl Bed monitoring in Milford Haven, Wales using diving between 2005 and 2023 (NRW Evidence Report No 882). |
| 2023 | DDV (NRW) | Mercer, T., Bunker, F.S., D., Ratcliffe, F.C., Camplin, M., <i>in press</i> . Milford Haven maerl bed drop down video survey, 2023. (NRW Evidence Report No: 880). |



Figure 3: Percentage of live maerl from 2005-2023 assessed by drop down video surveys in Milford Haven (Mercer et al., *in press*). Map is copyrighted as follows: © Hawlfraint y Goron a hawliau cronfa ddata 2025 Arolwg Ordnans AC0000849444 © Crown copyright and database rights 2025 Ordnance Survey AC0000849444.

The 2023 drop-down video survey represents the most recent extent and abundance data available of maerl habitat in Milford Haven. A grid of 628 stations was surveyed using comparable method to surveys carried out in the same area in 2005 and 2017. The proportion of stations where live maerl was recorded remained fairly constant, at approximately 20%, across all three surveys. However, the average percentage cover of live maerl recorded over the years fell from 5.7% to 1.3% (Figure 3), whilst the percentage of stations recording dead maerl increased by 50%. Note, there was no decrease in live maerl detected by DDV between 2017 and 2023 (Mercer et al., *in press*). Voronoi metrics indicated that between the 2005 baseline and the most recent 2023 analysis, there was a reduction of 71% in the area of live maerl (Mercer et al., *in press*).

The abundance (assessed as % cover) of live maerl at the 6 dive study sites also indicated a similar decline since the start of the maerl monitoring programme although no further decline was detected between 2016 and 2023 (Figure 5, Bunker & Ratcliffe, *in press*). The slipper limpet (*C. fornicata*), a non-native invasive species, was found to be present at approximately 30% of stations in both 2016 and 2023 (Figure 6), with an average cover of 3% across the survey area. Recording of live *C. fornicata* was undertaken in 2023 for the first time and they were recorded as present in 6% of the screenshots analysed (Mercer et al., *in press*). Dive surveys also detected an increase in abundance of *C. fornicata* between 2005 and 2010 (Figure 4), however a subsequent decline between 2016 and 2023 was also noted (Bunker and Ratcliffe, *in press*).

Further analysis of dive survey data indicates that infauna species richness declined between 2005 and 2010 and increased in 2016 and infauna community composition was significantly different between each year surveyed. Epibiota community composition was distinct between all years, with the exception of 2005 and 2010, with trajectories indicating directional change in community composition. The number of epibiota taxa recorded *in situ* varied between sites and years with no distinct overall pattern emerging, except that the number of taxa recorded in 2023 was higher at all sites apart from one (Site 410) (Bunker & Ratcliffe, *in press*). Five epiflora species endemic to maerl or particularly associated with the Milford Haven maerl bed were recorded during dive surveys. These species declined between 2010 and 2016 but increased in abundance between 2016 and 2023. Interestingly, sediment granulometry did not change between years, and further investigation into sediment dynamics at the site is needed to ascertain if changes in silt composition have occurred (Bunker and Ratcliffe, *in press*).

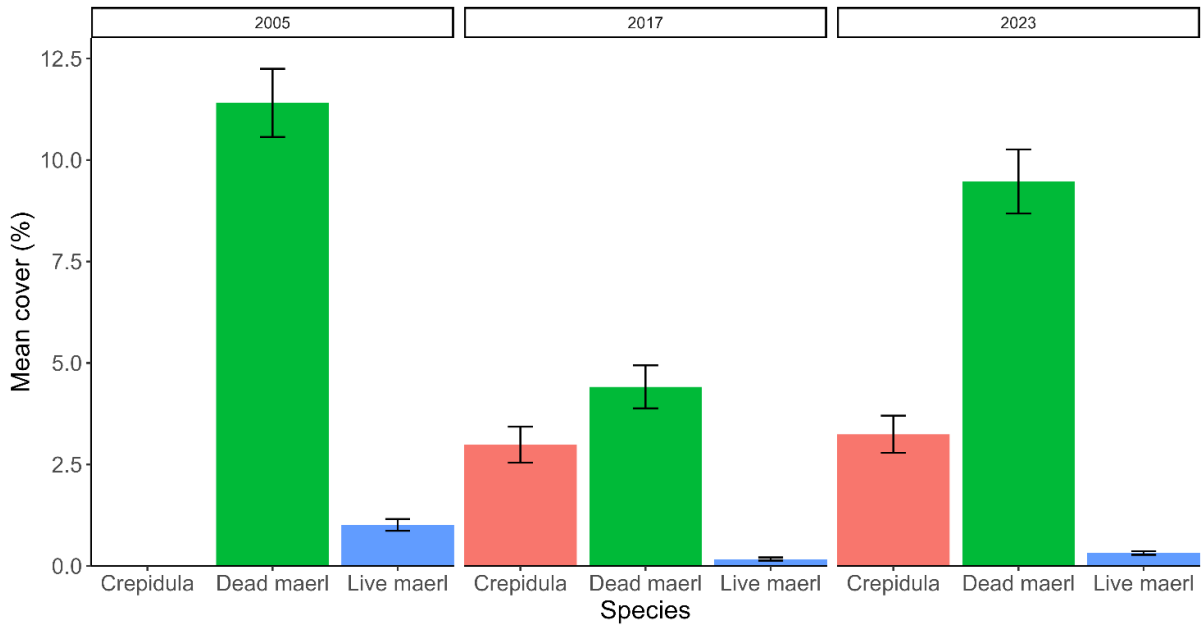


Figure 4: Mean (\pm standard error) % cover of live maerl, dead maerl and *Crepidula fornicata* surveyed by drop down video in Milford Haven from 2005 – 2023. Note, *Crepidula fornicata* was not quantified in 2005 (reproduced from Mercer et al., *in press*).

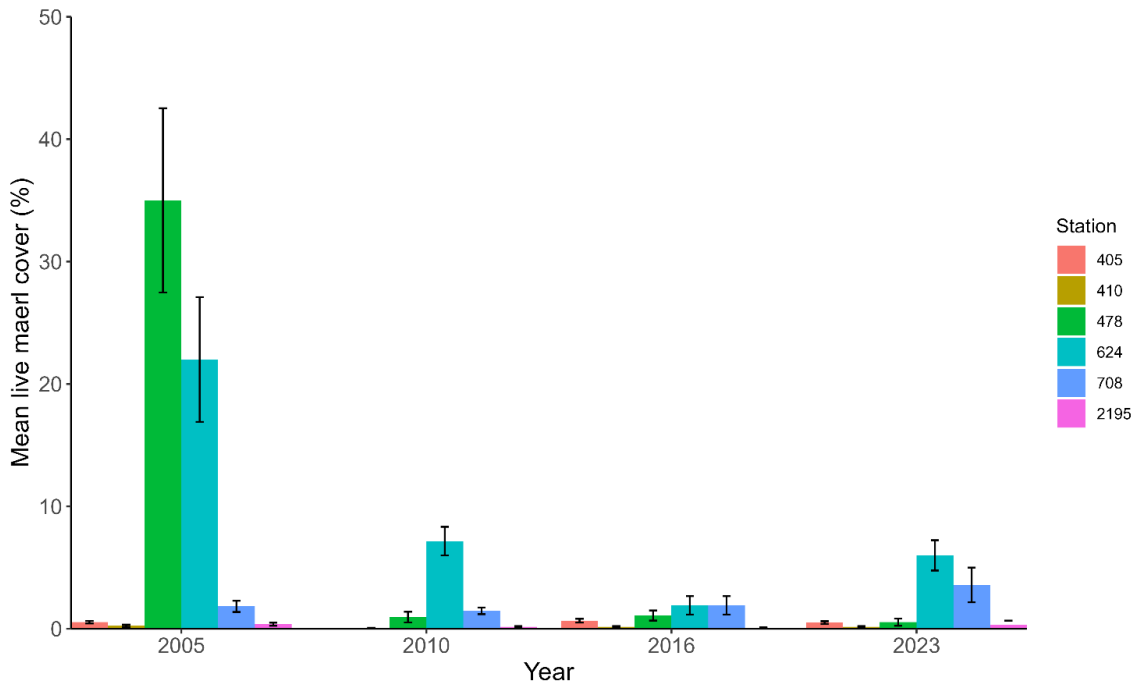


Figure 5: Mean (\pm standard error) % cover of live maerl at 6 dive stations (6 quadrats per station) from 2005 – 2023 within the Milford Haven maerl bed ($n = 36$ per year, reproduced from Bunker & Ratcliffe, *in press*).

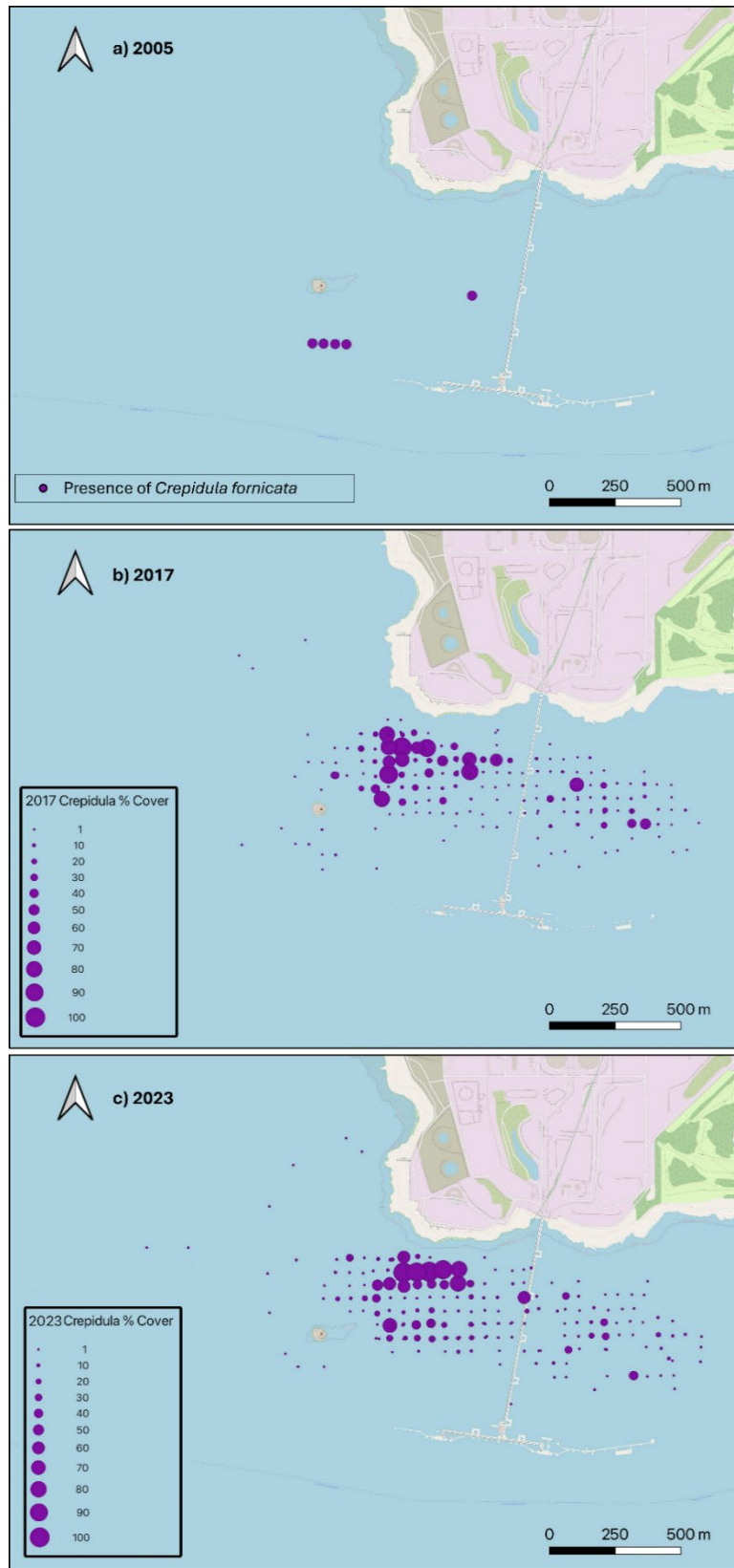


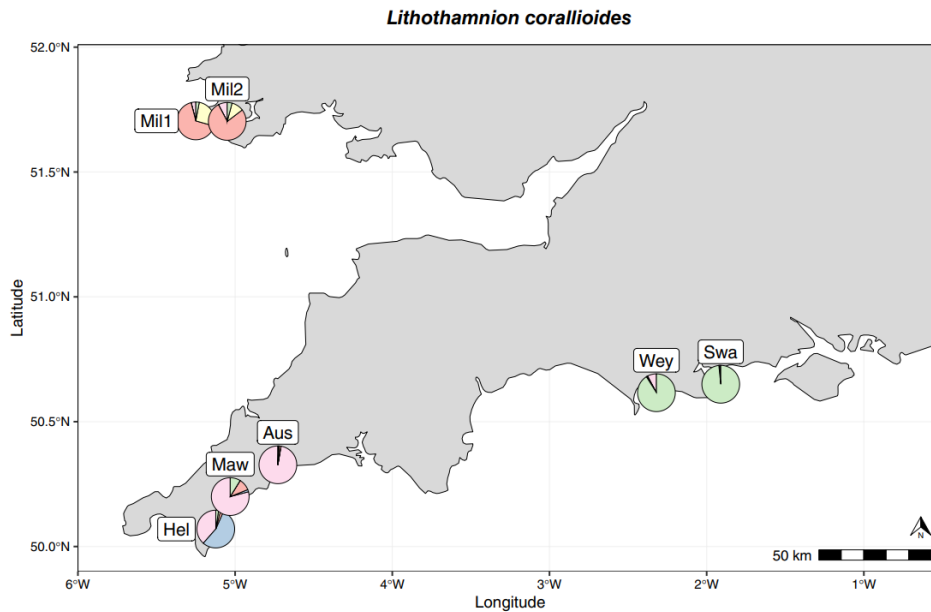
Figure 6: Changes in *Crepidula fornicata* cover from 2005 – 2023. a) Presence of *C. fornicata* in 2005 from dive surveys; b) - c) Increase in *Crepidula fornicata* cover from 2017

to 2023, assessed by drop down video surveys in Milford Haven maerl bed (Mercer et al., *in press*). Note that *C. fornicata* percentage cover was not assessed in 2005, however presence was noted in dive notes in some quadrats. Map is copyrighted as follows: © Hawlfraint y Goron a hawliau cronfa ddata 2025 Arolwg Ordnans AC0000849444 © Crown copyright and database rights 2025 Ordnance Survey AC0000849444. Reproduced from Mercer et al., *in press*.

Genetic background

A comprehensive understanding of the genetic structure and connectivity between maerl bed sites is essential to inform effective management and potential restoration strategies. This includes identifying levels of genetic diversity, population differentiation, and gene flow, which can underpin resilience and recovery potential. Jenkins et al. (2025), in collaboration with NRW, used genomics to investigate the population structure and spatial distribution of genetic diversity in two key maerl-forming species found along sheltered coasts of western Europe, *P. calcareum* and *L. corallioides*. Only *L. corallioides* was found in Milford Haven, which revealed a population that is genetically diverse with a high number of clonal lineages and is isolated from other populations in England (Figure 7, Jenkins et al., 2025).

In Milford Haven, individuals from two sites (sampling locations were either side of the South Hook Jetty), are mostly derived from a single ancestral population (red cluster), but with some admixture (the merging of multiple previously separated populations, resulting in a mixed genetic background) with other sites (Figure 7), and an additional distinct ancestral population (yellow cluster) that composed the genetic make-up for four individuals (Figure 7, Jenkins et al., 2025).



C

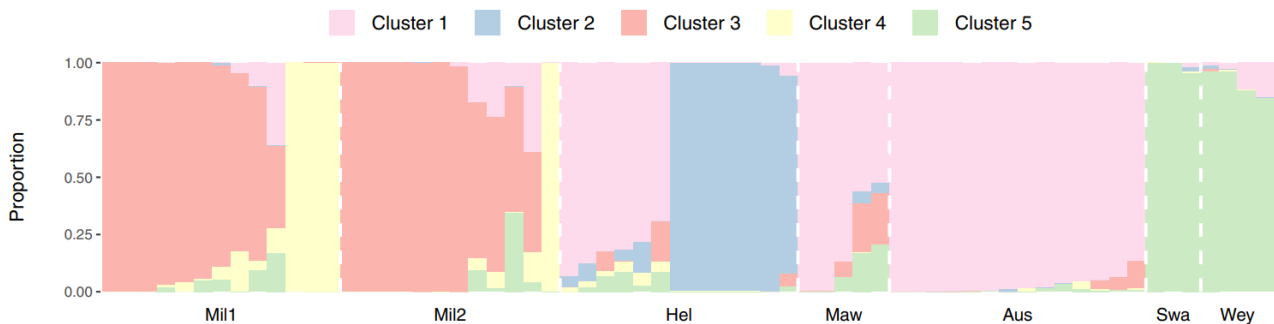


Figure 7: *Lithothamnion corallioides* admixture map and structure plot. The admixture map (top panel) shows pie charts on a zoomed in map of south-west England and southern Wales, where each pie represents the average admixture proportion across all individuals for a given cluster at a location. The structure plot (bottom panel) show the same admixture data but per individual, where each bar represents the proportion of their genome derived from each K source ancestral population (Reproduced from Jenkins et al., 2025).

Overview of activities in Milford Haven with potential impacts on the Maerl Bed

The Milford Haven Waterway, within which the maerl bed is located, is the largest deep-water estuary and natural harbour in Wales, extending 22 miles. It is a dynamic and heavily developed system that supports extensive commercial and urban activity. Functioning as a major deep-water shipping port, the estuary hosts significant petrochemical infrastructure. Since the 1960s, industrial development in the area has been closely tied to the oil and gas sector. In addition to its role in energy transport and processing, the port also serves as a ferry terminal for Irish Ferries and hub for recreational activities, industrial waste disposal, and power generation, including operations at Pembroke Power Station.

Petrochemical industry

In the 1960s, oil refineries were established along the Milford Haven Waterway, capitalising on the port's status as one of the world's deepest natural harbours. Its depth and sheltered conditions made it ideally suited for accommodating large crude oil tankers, facilitating the import of substantial volumes of petroleum for refining into various fuel products. This industrial development contributed significantly to regional economic growth, providing employment opportunities and supporting local infrastructure (Heley et al., 2015).

However, the expansion of the oil industry also introduced considerable environmental risk. On 15 February 1996, the oil tanker *Sea Empress*, enroute to the Texaco Refinery, ran aground on rocks near St Anne's Head at the entrance to Milford Haven. The incident resulted in a major oil spill, releasing thousands of tonnes of crude oil into the marine environment. Other major industrial accidents have occurred, including explosions at the Amoco terminal in 1983, Texaco in 1994, and Chevron in 2011 (Milford Waterfront, 2025).

In the early 2000s, the Milford Haven Waterway diversified its energy infrastructure with the introduction of liquefied natural gas (LNG) operations. Two LNG terminals—Dragon LNG and South Hook LNG—were constructed/refurbished to receive and process gas transported by large-scale LNG carriers. These facilities have since positioned Milford Haven as a critical hub in the UK's natural gas supply chain (Milford Waterfront, 2025).

Catchment level water quality

The Milford Haven Waterway is a ria estuary (drowned river valley) comprising a central channel with numerous shallow embayments, tributaries, and pills. It is the largest estuary in Wales, with a catchment covering much of Pembrokeshire. For Water Environment (Water Framework Directive (WFD)) (England and Wales) Regulations 2017 classification, it is divided into two water bodies: Milford Haven Inner (transitional) and Milford Haven Outer (coastal). The entire waterway lies within the Pembrokeshire Marine Special Area of Conservation, designated under the EU Habitats Directive for its nationally important habitats and species, all of which are vulnerable to water quality degradation from pollution (Haines and Edwards, 2016).

Nutrient enrichment has been identified as a key threat to the ecological integrity of Pembrokeshire Marine Special Area of Conservation. Agriculture is considered the main source of dissolved inorganic nitrogen (DIN). Increasing concern has been raised over opportunistic macroalgal blooms on intertidal mudflats and sandflats in the waterway's sheltered bays and inlets. In response, Milford Haven Inner has been designated a sensitive (eutrophic) area under the Urban Wastewater Treatment Regulations (Welsh Government, 2025a).

Construction

Of note is the construction of the South Hook LNG Jetty. The jetty located above the maerl bed was originally built for the Esso Oil Refinery and Marine Terminal in 1957 (McKay and Springer, 1999). Built by a workforce of 3,500, the jetty became operational in 1960 as part

of the Esso Refinery (McKay and Springer, 1999). By the 1960s, Milford Haven had emerged as the largest oil port in Europe (McKay and Springer, 1999). The Esso site at South Hook was closed around 1980 and had been dismantled by 1983 (Coflein, 2021).

Between 2005 and 2010, the jetty was refurbished and converted into a liquid natural gas (LNG) terminal, with the majority of the construction occurring within the first two years, resulting in several construction activities, including but not limited to:

- Drilling of seabed
- Cutting out and removal of existing jetty structures (steel and concrete)
- Piling
- Shot blasting
- Land development with runoff
- Vessel traffic
- Jack-up/spud barges, anchors and chains
- Sediment plumes generated from above activities

Other significant construction included the Dragon LNG development (2004-2009) and the Petroplus tank storage (both at Waterston) and the construction of the Pembroke Power Station (2009-2012).

Dredging (capital/maintenance) – shipping and navigation

Capital and maintenance dredging has occurred within the Haven since the 1960s. Since 2005 and the initial monitoring surveys of the maerl bed, dredging has continued in order to meet the growing demands of shipping and industrial activities. Capital dredging, which involves deepening and widening channels, has facilitated the accommodation of larger vessels, particularly for the oil and gas sectors, while maintenance dredging ensures the continued navigability of existing channels (Figure 8). Key berthing facilities and jetties near the maerl bed, such as the South Hook LNG terminal, South Hook LNG channel, Puma Energy, and Valero Refinery, have undergone both capital and maintenance dredging since the start of maerl monitoring (Figure 8).

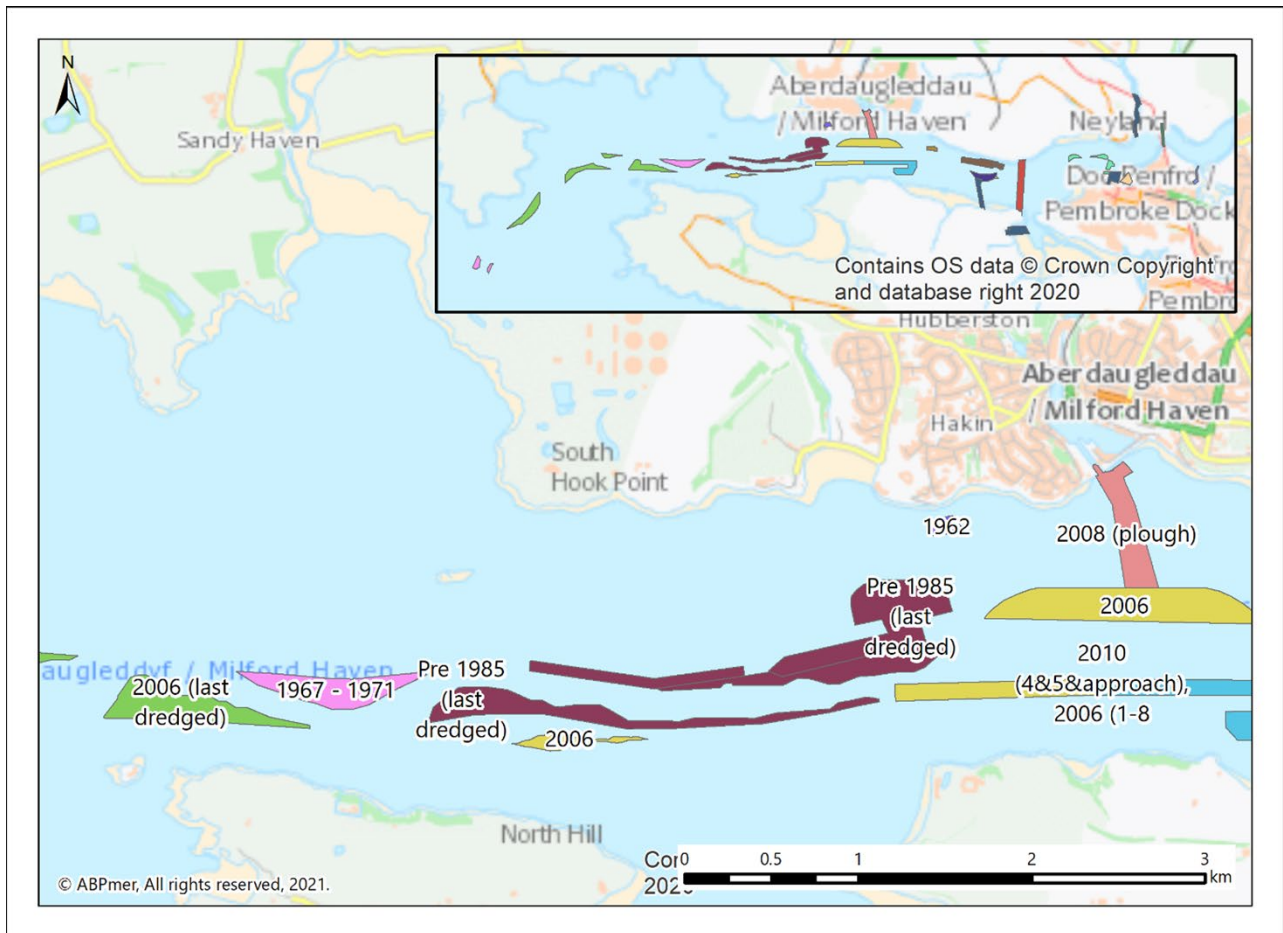


Figure 8: Map of dredging history within Milford Haven from 1962 – 2010 (ABPmer, NRW Evidence Report 551 (unpublished report)). Original data: Milford Haven Port Authority, 2021.

Additional activities will be discussed with the relevant pressures.

Pressure assessment methodology

The period of decline for this investigation was identified as 2005 to 2017, due to lack of sufficient quantitative data for the site before 2005 and the lack of a further decline detected in the 2023 survey. Early surveys described the bed as ‘sparse’ (JNCC, 2018), however, we do not have comparable quantitative data to ascertain how abundances changed between the 1970s and 2005, and a decline may have occurred during that time period.

The purpose of the pressures assessment was to identify the main pressures affecting the Milford Haven maerl bed, and to examine each pressure in terms of its timing, intensity, frequency, and spatial scale. These pressures were then ranked from highest to lowest risk. The findings from this assessment were used to determine appropriate management actions for the site and to highlight any additional monitoring requirements.

Initially, potential pressures were identified using The Marine Life Information Network (MarLIN) marine evidence-based sensitivity assessment (MarESA) (Tyler-Walters et al., 2023), carried out for the species *Lithothamnium corralioides* (Perry et al., 2017). Since the MarESA assessments are generic and not site-specific, this list of pressures was then reviewed to identify pressures relevant to the area of concern – in this case Milford Haven (occurring between 2005 and 2017 – the period in which we have sufficient maerl abundance data for this investigation), and pressures that were not relevant to the investigation were removed from the list. Where a known pressure in the area did not have a corresponding MarESA pressure, this was flagged and the pressure assessed. A spreadsheet of these pressures was generated, and an extensive literature review was then conducted building on the MarESA evidence base, covering both the sensitivity of the species and the history of the pressure in the area. The impacts of the identified pressures were scored and ranked to assess their relative risk to maerl bed resilience (see Table 2). Impact scoring was based on five criteria: timing, intensity, frequency, spatial scale, and species sensitivity, each evaluated on a four-point scale. These scores were then multiplied to generate an overall risk score. A confidence rating (low, medium, high) was also assigned to reflect the strength and availability of supporting evidence. These assessments, including the evidence base and pressure evaluations, were presented during an internal workshop, where both the pressure scores and confidence ratings were reviewed and validated by a panel of internal NRW experts, including site officers, benthic specialists, and water quality specialists.

Table 2. Pressure impact scoring definitions.

| Impact score criteria | Definition |
|-----------------------|---|
| Timing | Likelihood of a pressure occurring during the decline period (2005-2017) 1 = only outside the time period 2 = mostly outside the time period (including continuous pressures that occurred before and after the decline period as well as throughout) 3 = mostly within the time period (including pressures present before and/or after for a limited time duration) 4 = only within the time period |
| Intensity | Relative magnitude of the pressure. 1 = very low intensity, 2 = low intensity, 3 = high intensity, 4 = very high intensity |

| Impact score criteria | Definition |
|------------------------|---|
| Frequency | <p>How often the pressure recurs over time</p> <p>1 = One off/short term event, 2 = Frequently for a short duration or infrequently over a longer period, 3 = Frequent (may be intermittent but ongoing), 4 = Continuous</p> |
| Spatial scale | <p>The proportion of the feature affected by the pressure</p> <p>1 = <10% of the maerl bed 2 = >10 - <50% of the maerl bed 3 = >50 - 80% of the maerl bed 4 = 80% -100% of the maerl bed</p> |
| Sensitivity of species | <p>The likelihood of change when a pressure is applied to a feature. This reflects the feature's ability to tolerate or resist change, and its capacity to recover from impact:</p> <p>1 = Not sensitive 2 = Low sensitivity 3 = Medium sensitivity 4 = High sensitivity</p> |
| Risk | <p>Timing x Intensity x Frequency x Spatial scale x Sensitivity of species</p> |

Pressures

Sedimentation/burial

Definition of pressure: This pressure refers to the settling out of silt/sediments suspended in the water column causing deposition of fine material on the seabed.

Sensitivity of species

The sensitivity assessment classified maerl beds' resistance to sedimentation as "none," with resilience rated as "very low" and overall sensitivity as "high" (Perry et al., 2017). This evaluation was based on a scenario where up to 5 cm of fine material is added to the seabed in a single event. Tank experiments have shown that smothering by fine sediment is a primary anthropogenic threat to maerl beds (Wilson et al., 2004). The particle size of sediment is critical in determining its impact. Fine anoxic sediments, for instance, have more rapid and lethal effects compared to burial or light deprivation in coarse sediments. In one study, *P. calcareum*, similar species to *L. corallioides*, survived for up to four weeks under 4 cm or 8 cm of clean coarse sand or maerl gravel but died within two weeks when exposed to anoxic muddy sand (Wilson et al., 2004).

Moreover, sediment may accumulate in the open matrix of the maerl bed and become trapped, potentially resulting in higher deposition rates compared to surrounding habitats. Although field observations suggest that sedimentation negatively impacts maerl beds, additional tank experiments are needed to separate the effects of anoxia from those of particle size and clarify the mechanisms behind mortality. Wilson et al. (2004) proposed that the hydrogen sulphide content in muddy sand is the primary harmful factor during burial. Therefore, mortality observed after scallop dredging for example (Hall-Spencer and Moore, 2000) is likely due to a combination of physical and chemical burial effects, rather than a lack of light alone (Wilson et al., 2004).

Evidence of sedimentation/burial at the maerl bed

South Hook LNG Jetty construction, operation and refurbishment

At the time of the initial construction of the Esso jetty in the late 1950s, the presence of the maerl bed was unknown, and no surveys or impact assessments were conducted. Based on the scale and nature of works carried out during the refurbishment, it can be inferred that the original jetty construction—undertaken with far fewer, if any, environmental controls—would likely have caused significant seabed damage through abrasion, penetration, and disturbance. These activities would have suspended and redistributed sediments, leading to deposition and burial that likely affected the broader area of the maerl bed.



Figure 9: Scale of refurbishment of the South Hook LNG jetty. Photo: Mike Camplin (April, 2006).

The original jetty was refurbished between 2006 and 2008 (Figure 9). Prior to the refurbishment and conversion into a liquid natural gas (LNG) terminal, the presence of the maerl bed was known, and advice on potential impacts and the need for a Habitats Regulations Assessment was provided to the Regulator. The construction proceeded and sediment plumes were observed (Figure 10) resulting in likely deposition of fine sediment in the area, both from construction activities and vessel traffic (Figure 10). In addition to plumes, direct burial of maerl occurred from penetration of piling, jack-up spud legs, anchors and chain. Direct deposition of cuttings and shot blasted material (concrete and coal tar) from pile refurbishment also occurred. These impacts are discussed further under 'Physical damage: Abrasion/Penetration/Disturbance of Substratum'.

A further consequence of the jetty's refurbishment was the increased vessel traffic associated with construction in the area, which would have resulted in increased prop wash which may cause seabed abrasion and sediment suspension/resettling, especially at shallow depths. Note that vessel traffic will have been reduced after construction and is now limited to a single 'small boat passage' under the jetty.

In addition to the jetty works, it is likely that there were peak periods of sediment runoff that occurred during and after extensive ground works carried out between 2003 and 2005 at the South Hook LNG site which included contaminated land at former Esso refinery site (Little et al., 2015a). Concentrations of sediment contaminants peaked in the Haven in 2007 and are likely to be related, in part, to this runoff (but see dredging section below) (Little et al., 2015a) (Figure 11).

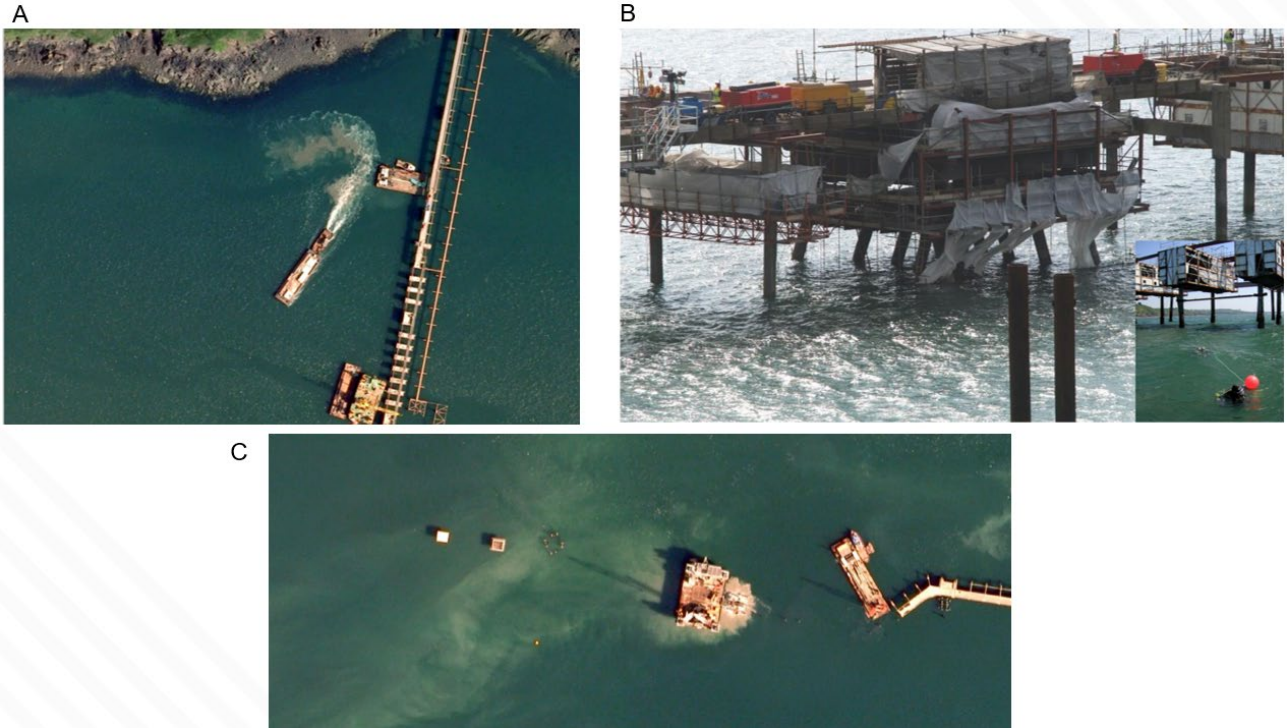


Figure 10: South Hook LNG jetty construction in Milford Haven. A) barges and jack-up barges operating in the area (Google Earth, 2006). B) damage to coverings designed to prevent shot blasted material entering the sea (Photo: Mike Camplin, 2006). C) sediment plumes generated from barges and jack-up barges at end of jetty (Google Earth, 2006).



Figure 11: The extent of the South Hook LNG land works in 2006 (Google Earth, 2006).

Observed impacts of jetty refurbishment:

Several maerl surveys were conducted during the jetty refurbishment period, including remotely operated vehicle (ROV) surveys (RPS, 2006), drop-down video (DDV) surveys (CCW, Mercer et al., *in press*), and diver surveys (Bunker & Ratcliffe, *in press*; RPS, 2008a,b). A 71% decline in live maerl area (% cover) was observed between 2005 and 2017 (Figure 4, Mercer et al., *in press*). While no DDV survey took place directly after the jetty refurbishment, diver surveys were carried out, detecting a mean decrease of 34% and 25% in live maerl at the monitoring sites with most abundant maerl in 2005 (site 478 and 624 respectively, Figure 5, Bunker & Ratcliffe, *in press*). In addition, declines in maerl cover close to the jetty (for station map see Figure 2) were also detected by RPS who undertook monitoring to determine jetty related impacts (Figure 12, RPS, 2008a,b).

A summary of additional findings relevant to the refurbishment time period is provided below:

RPS diver surveys (RPS, 2008a,b):

- A slight increase in silt was observed across the survey area since the summer of 2008 (RPS, 2008a,b).
- Marked decline in live maerl % cover at stations 3 and 5, adjacent to the jetty (Figure 2, Figure 12).
- A decrease in species richness and diversity was observed in areas directly impacted by construction as well as the wider survey area.

CCW/NRW diver surveys (Bunker and Ratcliffe, *in press*):

- Diversity indices (Margalef's and Simpson's) and species richness data showed a marked decline in infaunal diversity and richness between 2005 and 2010, coinciding with the main period of jetty refurbishment (Figure 12).
- Community composition differed significantly across all survey years, indicating ongoing shifts in benthic assemblages.
- Trophic structure changed over time, with a sharp decline in both surface and subsurface deposit feeders between 2005 and 2010, followed by a substantial increase in 2016 and a slight decline again in 2023, potentially linked to *C. fornicata* abundance trends (Figure 4). The initial decline coincided with a broader reduction in infaunal diversity and abundance, though the specific drivers remain unclear. The subsequent rise aligns with an increase in abundance of *C. fornicata* whose presence is associated with sediment trapping and pseudofaeces accumulation (for details see section 'Invasive Non-native Species').
- While particle size analysis (PSA) results did not show a consistent increase in fine sediment, it is likely that diver-observed silt was underrepresented in PSA cores, potentially due to resuspension during sampling.
- Stations with the highest *C. fornicata* densities and live maerl presence (stations 478, 624, and 708, Figure 6) consistently exhibited the highest proportions of fine sediment.

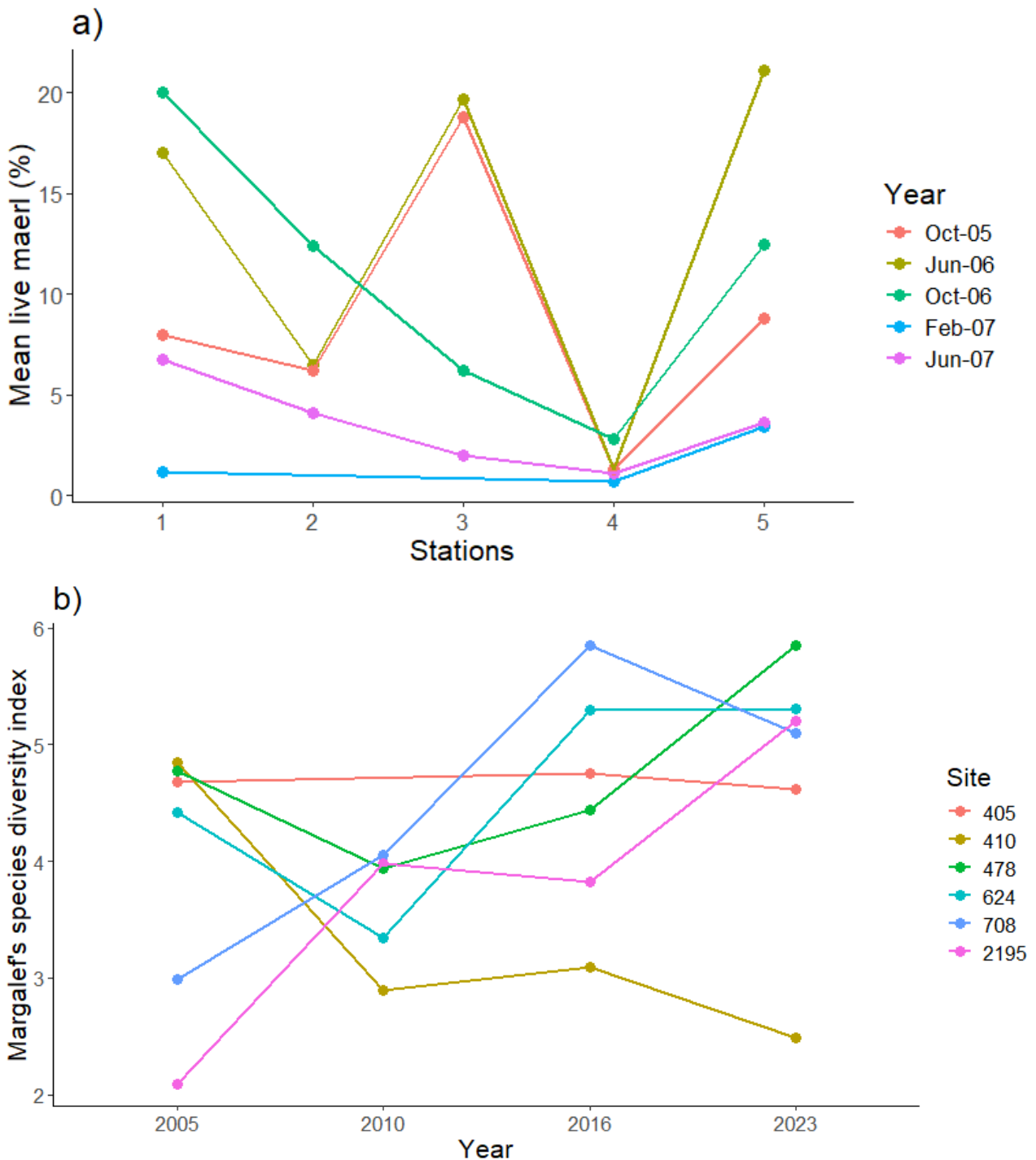


Figure 12: Change in live maerl cover and species diversity from 2005 – 2023. a) RPS data showing decline in live maerl cover from 2005 to 2007 at 5 stations spread on either side of the South Hook jetty (stations 3 and 4 being closest to the Jetty, see Figure 2) and b) Margalef's species diversity index showing variation in species richness within the epibiota community from 2005 to 2023 across the 6 permanent monitoring stations in the Milford Haven maerl bed (for station locations see Figure 2).

Dredging – capital and maintenance

Dredging activities may also have contributed to sediment deposition on the maerl bed. Direct measurements of sediment deposition on the maerl bed during dredging campaigns have not been conducted, and this has been identified as an area for future research. However, we can identify the most likely dredging campaigns that may have affected the bed.

- 2006. Capital dredging of the South Hook Channel Widening (32,000m³ dredged material) – trailer suction hopper dredge (Milford Haven Port Authority, 2021) .
- 2006. Large scale maintenance dredging of Valero Facility - trailer suction hopper dredge (Milford Haven Port Authority, 2021).
- 2009 to 2012. Construction of Pembroke Power Station. In autumn 2010, the power station outfall was reinstated through dredging, followed by dredging and reinstatement of the intake and Ro-Ro approach channel between 2010 and 2011.

The above campaigns are likely to have caused the release of suspended materials into the water column due to seabed agitation and dredge hopper over wash, as well as subsequent deposition of dredged materials on the seabed. This is supported by Little et al., (2015a, 2016) who noted that a Haven-wide peak in concentrations of sediment polycyclic aromatic hydrocarbons (PAHs), metals and other contaminants occurred in late 2007, following intense dredging in 2006, indicating widespread sediment deposition.

In addition to larger campaigns, maintenance dredging is conducted regularly; however, sedimentation rates at the South Hook and Puma Energy jetties have remained relatively low. These berths are situated within the natural deep channel of Milford Haven, where water movement is sufficient to limit the accumulation of fine sediments. As a result, only minimal maintenance dredging has been required since the initial capital dredging campaign (Milford Haven Port Authority, 2021).

At Neyland, maintenance dredging is carried out annually during winter (Little et al., 2015a; Milford Haven Port Authority, 2021). Initial tracer studies showed sediment from Neyland rapidly spread and deposited up and down the estuary (ETS, 2002). However, a later report concluded that the sediment plume dispersion is unlikely to extend far enough to impact the maerl bed located downstream (Fulford et al., 2021).

The fate of sediment mobilised by plough dredging in the Milford Haven dock channel remains uncertain and warrants further investigation. Locations of dredging activity are illustrated in Figure 8.

Non-anthropogenic sources and new evidence

There are several additional sources of sedimentation in the Haven. For further information, see 'Suspended solids (water clarity) pressure'. Please note, uncertainties persist regarding sediment transport and, in particular, deposition within the Haven.

Therefore, NRW is currently conducting both a modelling study and deploying instrumentation, to measure turbidity/deposition to enhance our understanding.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of sedimentation/burial on the maerl bed (Table 3). A timing score of 4 was assigned because the activities of concern took place during the period under investigation. Intensity was rated as 4 due to the scale of construction involved. A frequency score of 2 was given because these activities occurred over a limited period. A spatial scale of impact score of 4 was assigned, as some activities, such as the jetty refurbishment, occurred directly within the maerl bed. Additionally, other activities, although indirect, could have impacted large portion of the maerl bed through sediment deposition resulting from dredging. A sensitivity score of 4 was assigned, reflecting maerl beds' very low resistance to sedimentation, very low resilience, and overall high sensitivity. The confidence score was high due to the amount of data and photographic evidence available for the assessment.

Table 3: Assessment for **sedimentation/burial** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2017); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature's susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 4 | 4 | 2 | 4 | 4 | 512 | High |

Physical damage: abrasion/penetration/disturbance of substratum

Definition of pressure: Physical disturbance or abrasion of the substratum surface, leading to damage of surface features such as species and physical structures within the habitat.

Sensitivity of species

The sensitivity assessment classified maerl beds' resistance to physical damage: abrasion/penetration/disturbance of substratum as "none," with resilience rated as "very low" and overall sensitivity as "high" (Perry et al., 2017).

Maerl beds, are highly sensitive to physical disturbances, which can significantly impact their structure, function and biodiversity. While physical disturbance resulting in

fragmentation of *L. corallioides*, may not directly kill it, subsequent mortality is likely due to burial and reduced water flow from compaction and sedimentation (Hall-Spencer and Moore, 2000; Bernard et al., 2019). For example, experimental studies showed that a single scallop dredge pass could bury and kill 70% of living maerl in its path, while resuspended sand and silt smothered maerl over a wide area (up to 15 m from the dredged track) (Hall-Spencer and Moore, 2000). Additionally, abrasion may break up *L. corallioides* nodules, making them more susceptible to displacement by wave action, thus reducing structural heterogeneity and biodiversity (Kamenos et al., 2003).

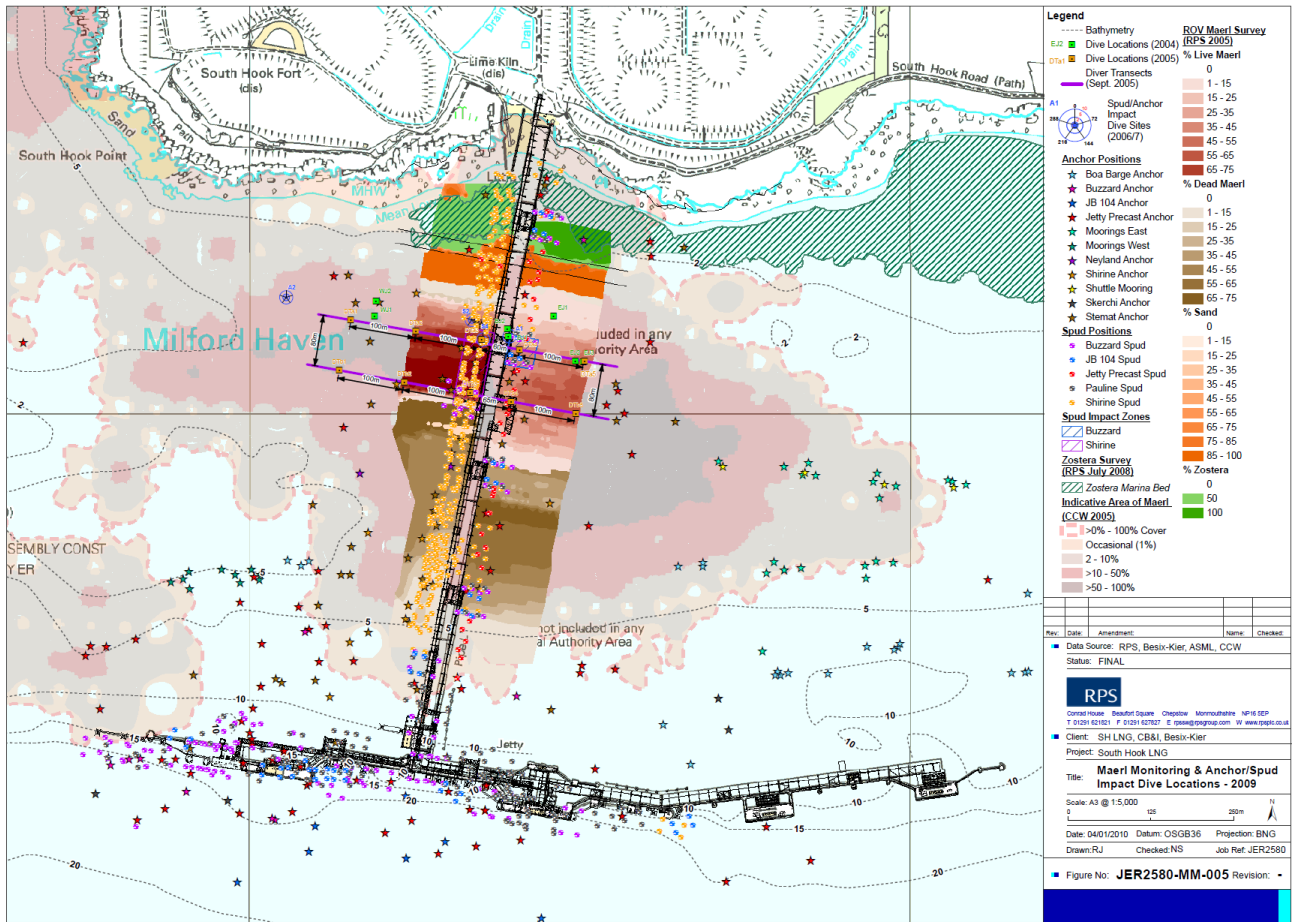
Evidence of physical damage (abrasion/ penetration/ disturbance of substratum) at the maerl bed

The construction of the original jetty on the maerl bed occurred before monitoring began, so its impact remains unquantified. However, evidence from the refurbishment and similar events at other locations suggest that the impact on the bed would have been extensive. The refurbishment of the jetty at South Hook LNG terminal between 2005 and 2010 caused significant abrasion of the seabed due to various activities, including seabed drilling and the use of jack-up spuds, anchors, and chains. The construction impacted a large portion of the maerl bed, particularly areas with high maerl percentage cover.

Of note, a large number of spud legs were recorded (Figure 13, Figure 14), with legs of larger barges measuring 4m in diameter and those of smaller barges measuring 60cm in diameter, causing direct burial (Figure 10), with secondary impacts of displaced sediment and sediment plumes (Figure 10). Each barge required multiple anchors and associated chains, increasing the area of abrasion. In addition, there are multiple reports from divers that maerl was buried during this process (pers. comms. ASML, Mike Camplin), with significant overturning of seabed sediments observed. Underwater imagery (Figure 15) showed that displaced bed sediments from inserted spud legs buried surface maerl and brought fine sediments to the surface.



Figure 13: Jack-up barges. Photo: M. Camplin (April, 2006).



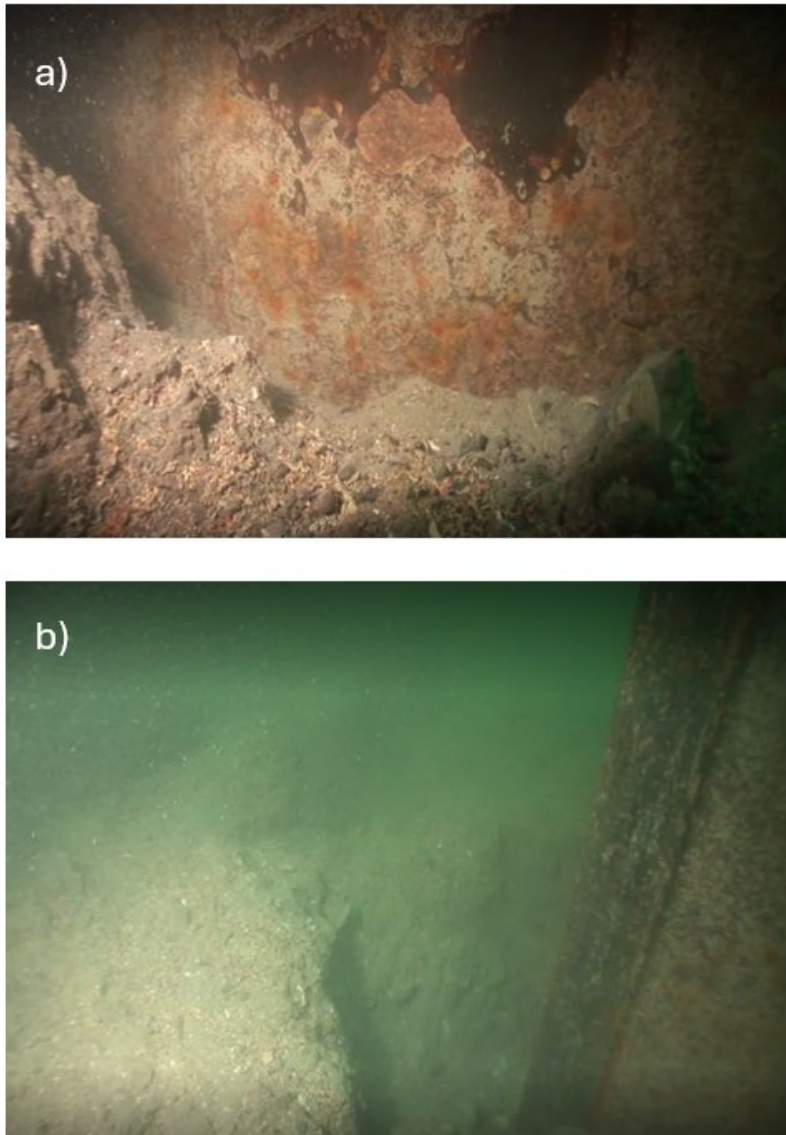


Figure 15: Still photographs from diver video of a spud leg from the South Hook Jetty refurbishment. a) partially buried maerl rhodolith fragments adjacent to spud leg. b) overturned sediment with buried maerl. Spud legs measured 4x4m in cross section (Video: Francis Bunker, ASML, 2006).

In addition to the jetty refurbishment, scallop dredging also occurred on the bed in 2006 (and possibly in the years prior), causing direct abrasion, for details see pressure 'physical damage: scallop dredging'. There are also many secondary pressures linked to abrasion, such as increased suspended solids, sedimentation and burial and hydrocarbon contamination from coal tar. Please see relevant pressures sections for details.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of Physical damage (Abrasion/ Penetration/ Disturbance of the substratum) on the maerl bed (Table 4). A timing score of 4 was assigned because the activities of concern took place during the period under investigation. Intensity was rated as 4 due to the scale of construction involved. A frequency score of 2 was given because these activities occurred over a limited period. A spatial scale of impact score of 2 was assigned, as the directly impacted area of the seabed was limited. A sensitivity score of 4 reflected maerl's very low resistance to abrasion, penetration, or disturbance of the substratum, as well as very low resilience. This combination results in an overall high sensitivity. The confidence in this score was high, due to the substantial amount of data and photographic evidence available to support the assessment.

Table 4: Assessment for **physical damage: Abrasion/ Penetration/ Disturbance of Substratum** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature's susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 4 | 4 | 2 | 2 | 4 | 256 | High |

Organic enrichment

Definition of pressure: Organic enrichment refers to an increase in organic material above 'natural' levels, resulting in organisms no longer being limited by the availability of organic carbon and typically resulting in negative environmental effects. Sources include dead biota, faecal matter, sewage, domestic and industrial wastes, aquaculture, and agricultural runoff. For the purposes of this report, enrichment from *C. fornicata* presence is not considered in this section.

Sensitivity of species

The sensitivity assessment classified maerl beds' resistance to organic enrichment as "none," with resilience rated as "very low" and overall sensitivity as "high" (Perry et al., 2017).

While few studies have directly examined the impact of organic enrichment on *L. corallioides*, this pressure is likely to act in combination with several associated pressures known to negatively affect maerl survival, such as increased sedimentation, elevated hydrogen sulphide levels, and smothering by macroalgae (Grall and Hall-Spencer, 2003).

Notably, organic enrichment acts in combination with deposition of particulate matter/sediment on the bed, closely linking this pressure to sediment deposition.

Sediment grain size plays a key role in regulating oxygen diffusion in benthic environments. Coarse-grained sediments (e.g., sands) allow greater oxygen penetration due to higher porosity and permeability, while fine-grained sediments (e.g., silts and clays) restrict diffusion, promoting hypoxic or anoxic conditions closer to the sediment–water interface (Levin et al., 2009).

As oxygen becomes limited—either from restricted diffusion or elevated biological oxygen demand (BOD)—microbial communities shift from aerobic respiration to anaerobic metabolism. Under these conditions, sulphate-reducing bacteria dominate, producing hydrogen sulphide (H₂S) as a byproduct (Deng et al., 2018). H₂S is toxic and contributes to the characteristic black colouration and odour of anoxic sediments.

This process is often intensified by increased organic input from elevated primary productivity, typically driven by nutrient enrichment. As algal and plant biomass settles and decomposes, microbial respiration increases, further depleting oxygen and accelerating H₂S formation (Bali and Gueddari, 2019).

Evidence from other maerl beds supports these concerns. In the Bay of Brest, the accumulation of sewage and urban effluent has been shown to clog the interstitial spaces between thalli leading to a decline in biodiversity, heightened siltation, increases in abundance and biomass of opportunistic species, and the loss of sensitive species (Grall and Hall-Spencer, 2003). In some cases, this pressure has caused a shift from dense maerl beds to mud, with buried maerl fragments (BIOMAERL team, 1998). Furthermore, comparisons between maerl beds beneath salmon farms and unimpacted beds indicate that the former exhibited clear signs of organic enrichment and significantly lower biodiversity (Hall-Spencer et al., 2006).

Evidence of organic enrichment at the maerl bed

Please note the presence of *C. fornicata* is a direct local source of organic enrichment at the site, however it is assessed under pressure ‘Invasive non-native species (INNS).’

Organic enrichment of sediment has not been directly measured at the maerl bed, however there are multiple potential sources of organic enrichment in the Haven. Nutrient analysis for WFD investigations indicate that there are mixed sources of pollutants, which would be likely to contribute to availability of organic carbon in the system. The major confirmed source of nutrient input in Milford Haven Outer was linked to agricultural land runoff, with all other sources considered minor contributors (Lock et al., 2025a).

Opportunistic macroalgae could be an additional source of organic enrichment at the site. The inner part of the estuary fails to meet WFD standards (Lock et al., 2025b) for its levels of opportunistic macroalgae and, while the outer Haven meets WFD standards for this criterion, there are additional localised areas of excessive opportunistic macroalgae in that area (Lock et al., 2025a). Excessive algal growth in the estuary system leads to increased organic enrichment due to the algal die back and decomposition and transport of these

materials within the estuarine system. Macroalgal abundance has not been quantified subtidally within the maerl bed or the wider area, however increased algae presence on the maerl bed during the summer months has been noted by divers (ASML pers. comm. 2023). Given that an abundance of macroalgae, particularly if decaying, could contribute a short-term influx of organic matter to the bed, this source of enrichment cannot be ruled out as a potential contributor to this pressure.

An excess of organic matter could lead to anoxic sediment conditions, which have been demonstrated to cause high mortality of maerl thalli (Wilson et al., 2004), as well as changes to infaunal community composition (Hall-Spencer et al., 2006). Localised sediment anoxia may occur in areas dominated by fine-grained sediments rich in organic matter. This is due to the limited oxygen diffusion capacity of compact sediments and the elevated biological oxygen demand (BOD) associated with microbial decomposition of organic material.

A Sediment Profile Imaging project assessed mean apparent redox potential discontinuity (aRPD) (i.e. boundary between oxidising and reducing conditions) at stations throughout Milford Haven and the maerl bed in 2012 (Carey et al., 2015). The shallower (smaller) the aRPD reading, the closer anoxic conditions are to the sediment surface and the higher the potential for adverse effects (for further information on impacts on maerl, see pressure 'De-oxygenation'). The majority of stations within the bed did not have a clear aRPD reading (this could be due to sediment or biological disturbance, sediment properties or technical/operational issues). However, a subsample had aRPD readings between 2.1cm and 4.3cm (Carey et al., 2015). Further data on sediment oxygen levels is needed for a robust assessment.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of organic enrichment on the maerl bed (Table 5). A timing score of 2 was assigned due to effluent releases in the Haven occurring before and after as well as throughout the period under investigation. An intensity score of 2 was given based available evidence on nutrient status of the waterbodies, although specific site level evidence is lacking. Frequency and spatial scale scores of 4 were assigned due to this pressure occurring regularly and throughout the area and a sensitivity score of 4 was assigned based on literature evidence, such as studies of the Bay of Brest. However, due to data gaps, this pressure is assessed with medium confidence. Please note, it is not possible to separate the impacts of organic and nutrient enrichment with the current data available.

Table 5: Assessment for **organic enrichment** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 2 | 2 | 4 | 4 | 4 | 256 | Medium |

Nutrient enrichment

Definition of pressure: Nutrient enrichment refers to elevated levels of nitrogen, phosphorus, silicon, and iron in a waterbody. For additional information please see ‘Organic enrichment’ pressure.

Sensitivity of species

The MarLIN sensitivity assessment for this pressure is incomplete (Perry et al., 2017). Nutrient enrichment is linked to multiple secondary factors such as organic enrichment, suspended solids and deoxygenation. For literature on these secondary impacts please refer to the relevant pressures sections of this report. None the less, levels in the estuary exceed levels needed for good status under the Water Framework Directive and secondary effects are apparent, as discussed below.

Evidence of nutrient enrichment at the maerl bed

Milford Haven Inner has been designated by Welsh Government as a sensitive area (eutrophic) under the Urban Wastewater Treatment Regulations 2003 (Welsh Government, 2025b).

The Water Framework Directive (WFD) investigation indicated that the Milford Haven Outer coastal waterbody, which includes the maerl bed, failed to meet the Dissolved Inorganic Nitrogen (DIN) standard in 2015 (Cycle 2) and 2021 (Cycle 3) (Lock et al., 2025a). The primary contributor of DIN to the Milford Haven Outer waterbody has been identified as diffuse sources linked to farming activity, with significant contributions likely coming from agricultural land runoff. Further investigation is needed to better understand the specific sources of DIN from agricultural practices and to pinpoint the inputs into the catchment area that are preventing the waterbody from achieving good status. Additionally, point source pollution from sewage treatment works has been confirmed as a source of DIN, while intermittent sewage discharges are considered a probable source, and unsewered domestic sewage is also suspected to contribute (Lock et al., 2025a).

It should be noted that there is a direct input of Nitrogen from the end of the South Hook jetty, directly adjacent to the bed, resulting from output from the Submerged Combustion Vaporisers used by the plant as well as other site water runoff (Simpson, 2006).

Milford Haven Outer is adjacent to Milford Haven Inner, which has been designated by Welsh Government as a sensitive area (eutrophic) under the Urban Wastewater Treatment Regulations (Welsh Government, 2025a). In addition, the catchment area draining into the Haven was recommended for designation as a Nitrate Vulnerable Zone (NVZs) under the provisions of the EC Nitrates Directive (91/676/EEC) (Haines and Edwards, 2016), now covered under The Water Resources (Control of Agricultural Pollution) (Wales) Regulations 2021 (Welsh Government, 2021). However, it should be noted that these conditions occurred before the period under investigation (Edwards, 2005). This weakens the case for their causing the current rapid decline observed, although it cannot be ruled out that a tipping point may have been reached.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of nutrient enrichment on the maerl bed (Table 6). A timing score of 2 was assigned due to high levels of nutrients in the Haven occurring before and after as well as throughout the period under investigation as demonstrated by WFD assessments. An intensity score of 2 was given due available evidence on nutrient status of the waterbodies, although specific site level evidence is lacking. Frequency and spatial scale scores of 4 were assigned due to this pressure occurring regularly and throughout the area and a sensitivity score of 4 was assigned based on literature evidence, mainly from the Bay of Brest. However, due to data gaps, this pressure is assessed with medium confidence. Please note, it is not possible to separate the impacts of organic and nutrient enrichment with the current data available.

Table 6: Assessment for **nutrient enrichment** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 2 | 2 | 4 | 4 | 4 | 256 | Medium |

Invasive Non-native Species (INNS): *Crepidula fornicata*

Definition of pressure: The direct or indirect introduction or spread of invasive non-indigenous species. In this context, the species of concern is *Crepidula fornicata* (American slipper limpet).

Sensitivity of species

The sensitivity assessment classified maerl beds' resistance to INNS, specifically *C. fornicata* as "none," with resilience rated as "very low" and overall sensitivity as "high" (Perry et al., 2017).

The invasion of *C. fornicata* poses significant threats to maerl beds, disrupting ecosystem function and affecting biodiversity (Hall-Spencer et al., 2003). *C. fornicata* competes with native species for space within maerl beds. Their presence results in direct deposition pseudofaeces which contain both inorganic material (silt, sand, grit etc) and organic matter. These fine particles clog interstitial spaces in the sediments and reduce oxygen diffusion between maerl thalli (Martin et al., 2007). Additional dissolved metabolites from these gastropods act as a fertiliser, stimulating growth of microphytobenthic biofilms (Androuin et al., 2018).

In France, Grall & Hall-Spencer (2003) observed that maerl beds in Brittany had dense aggregations of *C. fornicata*, resulting in high mortality of thalli and clogging the bed with silt and pseudofaeces, changing the associated community and rendering bivalve fishing nearly impossible. In the Bay of Saint-Brieuc, Thouzeau (1989) found high densities of *C. fornicata* (up to 400 individuals per m²) on maerl beds, later surveys showing that 4 km² of maerl has been smothered by *C. fornicata* (Hamon and Blanchard, 1994). While *C. fornicata* infestation in maerl beds is generally lower than adjacent areas (up to 100 individuals per m²), some beds are surrounded by dense *C. fornicata* populations and may soon be smothered (Chauvaud et al., 2000).

Evidence of INNS at the maerl bed

C. fornicata was first observed in the Milford Haven Waterway in 1953 (Bohn et al., 2015) and surveys conducted in 2009 and 2010 revealed dense aggregations, particularly in the shallow subtidal and low intertidal zones. *C. fornicata* was observed on the maerl bed in DDV footage from 2005, although abundance data were not recorded. In 2016 and 2023, percentage cover was assessed for all camera drops. Up to 30% of the stations contained *C. fornicata*, with some stations showing 100% cover (Table 7).

Table 7: Summary of changes in *C. fornicata* abundance and occurrence on maerl bed from 2005 through 2017 to 2023 in Milford Haven (Mercer et al., *in press*). NR- not recorded.

| Survey area metrics | 2005 | 2017 | 2023 |
|---|------|-------|-------|
| Max % <i>C. fornicata</i> recorded at a station | NR | 100 | 100 |
| Average % <i>C. fornicata</i> - within survey area | NR | 2.98 | 3.24 |
| Average % <i>C. fornicata</i> – within the <i>C. fornicata</i> bed (>10%) | NR | 37.24 | 35.24 |
| Percentage of stations with <i>C. fornicata</i> * | 0.65 | 27.2 | 29 |
| Number of stations with live <i>C. fornicata</i> seen | NR | NR | 39 |
| Percentage of stations with >1% cover <i>C. fornicata</i> | NR | 22.83 | 27.59 |
| Percentage of stations with >50% cover <i>C. fornicata</i> | NR | 1.93 | 1.83 |

* *C. fornicata* was mentioned 5 times in the notes section of the recording forms in 2005, but it may have been inconsistently recorded and therefore this figure should be treated with a considerable degree of caution.

During dive surveys, *C. fornicata* first became conspicuous in 2010 and showed an increase at all sites in 2016, particularly at the most prominent maerl sites. However, by 2023, live *C. fornicata* declined at all sites (Table 7, Figure 16). This decline in 2023 may eventually lead to a reduction of sedimentation caused by the gastropods themselves, however, the quantity of dead shells remaining could have a smothering effect and trap additional sediment (Bunker and Ratcliffe, *in press*). Interestingly, Androuin (2018) suggested that a dead *C. fornicata* bed showed trophic complexity similar to that of maerl beds and dive survey data indicated that there was no decline in infaunal diversity in 2023, despite the cover of dead shell (Bunker and Ratcliffe, *in press*).

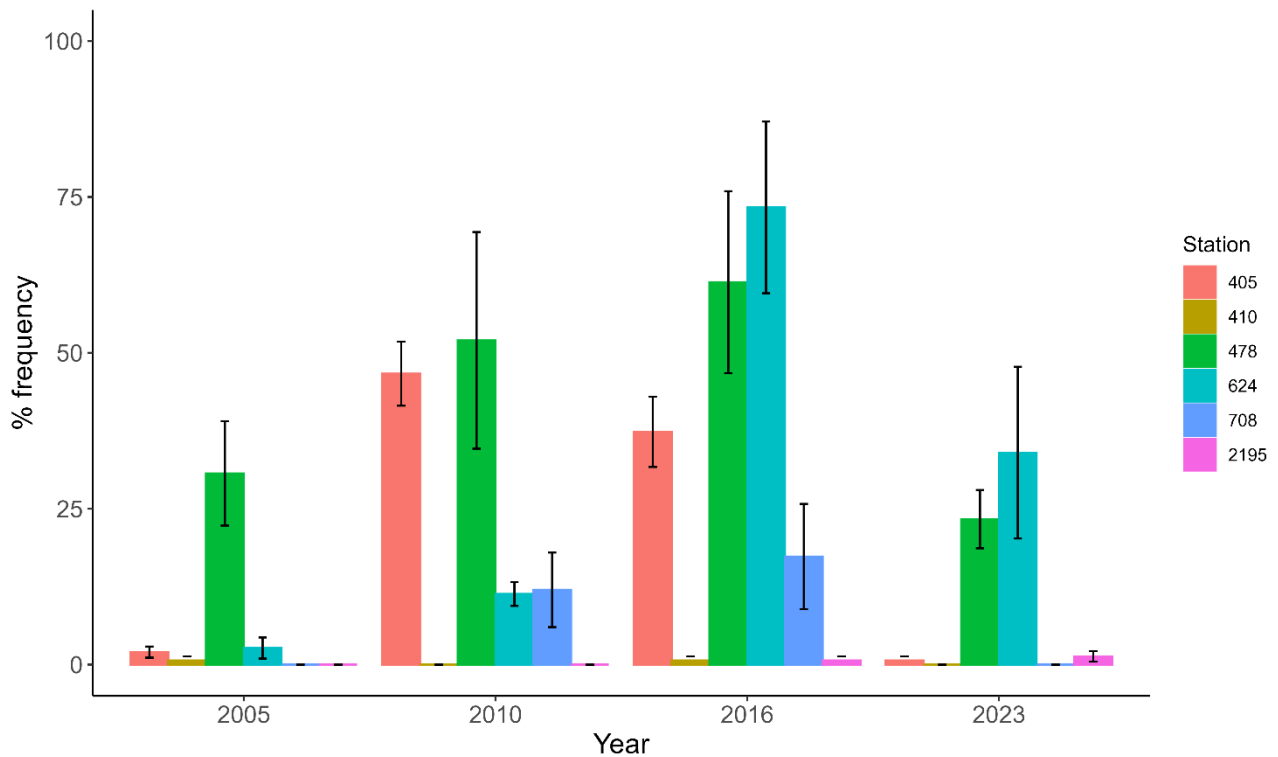


Figure 16: Percentage frequency of *Crepidula fornicata* at six dive sampling stations from 2005 – 2023 at the maerl bed in Milford Haven. At each station, *C. fornicata* was recorded in situ from 6 randomly placed 0.25 m² quadrats, subdivided into 10 x 10 cm grid squares (a total of 25 cells) (reproduced from Bunker and Ratcliffe, *in press*).

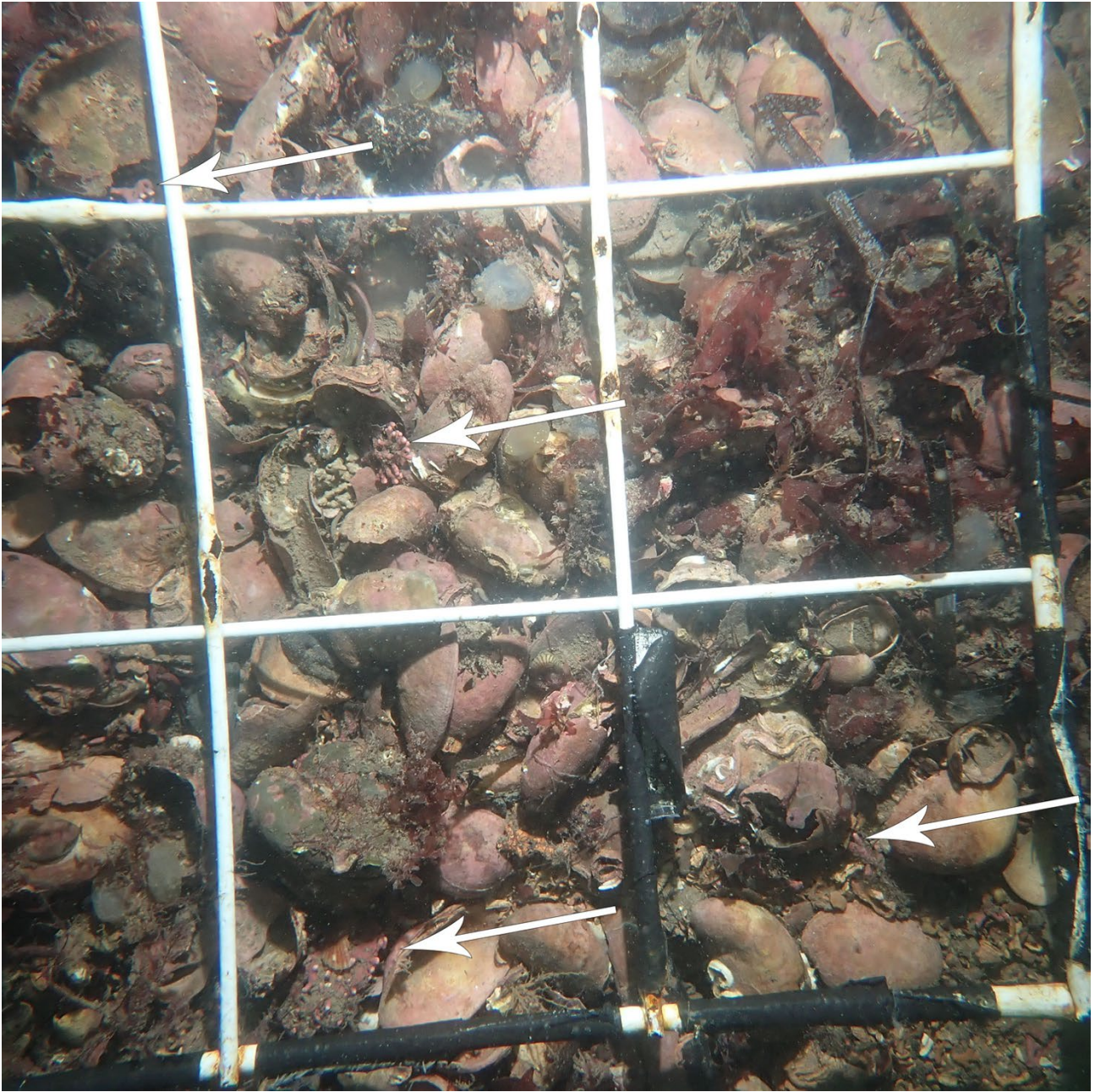


Figure 17: Abundant dead *C. fornicata* shell from quadrat 1 at site 624 (NRW Diver survey, 2023). Arrows point to maerl medallions, many of which were underneath the loose shells. (reproduced from Bunker & Ratcliffe, *in press*, photo by Jon Moore).

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of INNS (*C. fornicata*) on the maerl bed (Table 8). A timing score of 4 was assigned because the increase in prevalence took place during the period under investigation. Intensity was rated as 2 due to observed densities of *C. fornicata*. A frequency score of 4 was given because this occurred throughout the period. A spatial scale of impact score of 2 was assigned, as up to 30% of the area was impacted. A sensitivity score of 4 was assigned, reflecting that maerl beds have no resistance, very low resilience, and overall high sensitivity to *C. fornicata* invasions. The confidence score was medium due the amount of data available for the assessment.

Table 8: Assessment for **INNS: *Crepidula fornicata*** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 4 | 2 | 4 | 2 | 4 | 256 | Medium |

Suspended solids (water clarity)

Definition of pressure: Changes in turbidity (water clarity) due to changes in sediment & organic particulate matter concentrations.

Sensitivity of species

The MarLIN sensitivity assessment classified *L. corallioides* resistance to changes in water clarity (benchmark: A change in one rank on the WFD (Water Framework Directive) scale e.g. from clear to intermediate for one year) to be “medium” and the resilience is “very low”, with an overall sensitivity of “medium” (Perry et al., 2017).

While the irradiance requirements of maerl species are not known and they are generally considered as low-light adapted (Dutertre et al., 2015; Wilson et al., 2004), a decrease in light levels would impact the ability of *L. corallioides* to photosynthesise and would therefore reduce productivity and fitness. This is especially true if the species is found at the lower end of its depth range (>10m) where light levels are more likely to be a limiting factor (Dutertre et al., 2015). In addition, suspended solids in the water column could increase scour, potentially resulting in high mortality in early post-settlement algal stages and prevents the settlement of propagules (Vadas et al., 1992). Further to limiting access

to light, any settlement of particles could also limit gaseous exchange (Hall-Spencer and Moore, 2000).

Evidence of changes in suspended solids at the maerl bed

There are multiple sources of suspended solids in the Haven. Agricultural and forestry management practices in the river catchments may have increased runoff in the period under investigation. Nutrient and organic matter inputs also influence this pressure (for full discussion please see pressures 'organic enrichment' and 'Nutrient enrichment'). In addition, historic temporary, activity-dependent increases will have occurred during activities that resulted in disturbance of the seabed within the maerl bed – see all pressures relating to 'physical damage'. In addition, suspended solid concentrations fluctuate daily with the tidal cycle, as well as wave parameters, and port related operations.

To start to quantify these changes a YSI EXO2 multiparameter Sonde was deployed at the maerl bed by NRW (Nature Networks funded) between July 2023 and March 2024 (Figure 18) and data were analysed, with wave and river level data (Dale and Mandipe, *in press*). To assess the tidal / daily relationships between parameters, Spearman's Rank correlation coefficients (r values between -1 and +1, where a value of +1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation and 0 indicates no correlation) were calculated. River level, indicated by a strong negative correlation with salinity ($r = -0.701$) and positive correlation with water level (Western Cleddau: $r = 0.668$, Eastern Cleddau: $r = 0.669$) had the strongest relationship with turbidity at the site (Table 9, Figure 18). This relationship was maintained following the application of one-, two- and three-day offsets to the data, indicating sediment transported into Milford Haven during periods of high river discharge might have a considerable residency time. During the flood tidal stage, suspended sediment concentration typically increased at first, before decreasing and remaining low during high water. The amount of the sediment in suspension also increased during the ebb tide, which was usually when suspended sediment concentrations peaked (Figure 20). This peak tended to occur between four to five hours after high water (Dale and Mandipe, *in press*).

Please note, however, that this is a preliminary analysis and there are other variables that were not assessed such flow from additional rivers in the catchment, wind direction and strength and wave action over mud flats and it is possible that some of these factors correlate with rainfall and therefore river flow.

It was not possible to determine the influence of dredging on shorter-term variations in suspended sediment from this sonde deployment, with similar patterns and trends being observed regardless of whether dredging was taking place (Dale and Mandipe, *in press*). To evaluate further the potential influence of dredging, alongside other factors such as vessel movements, NRW is conducting further modelling/data collection. It is also noteworthy that an increase in suspended sediment concentration may not result in increased sediment deposition, although this could not be assessed from the available sonde data (Dale and Mandipe, *in press*).

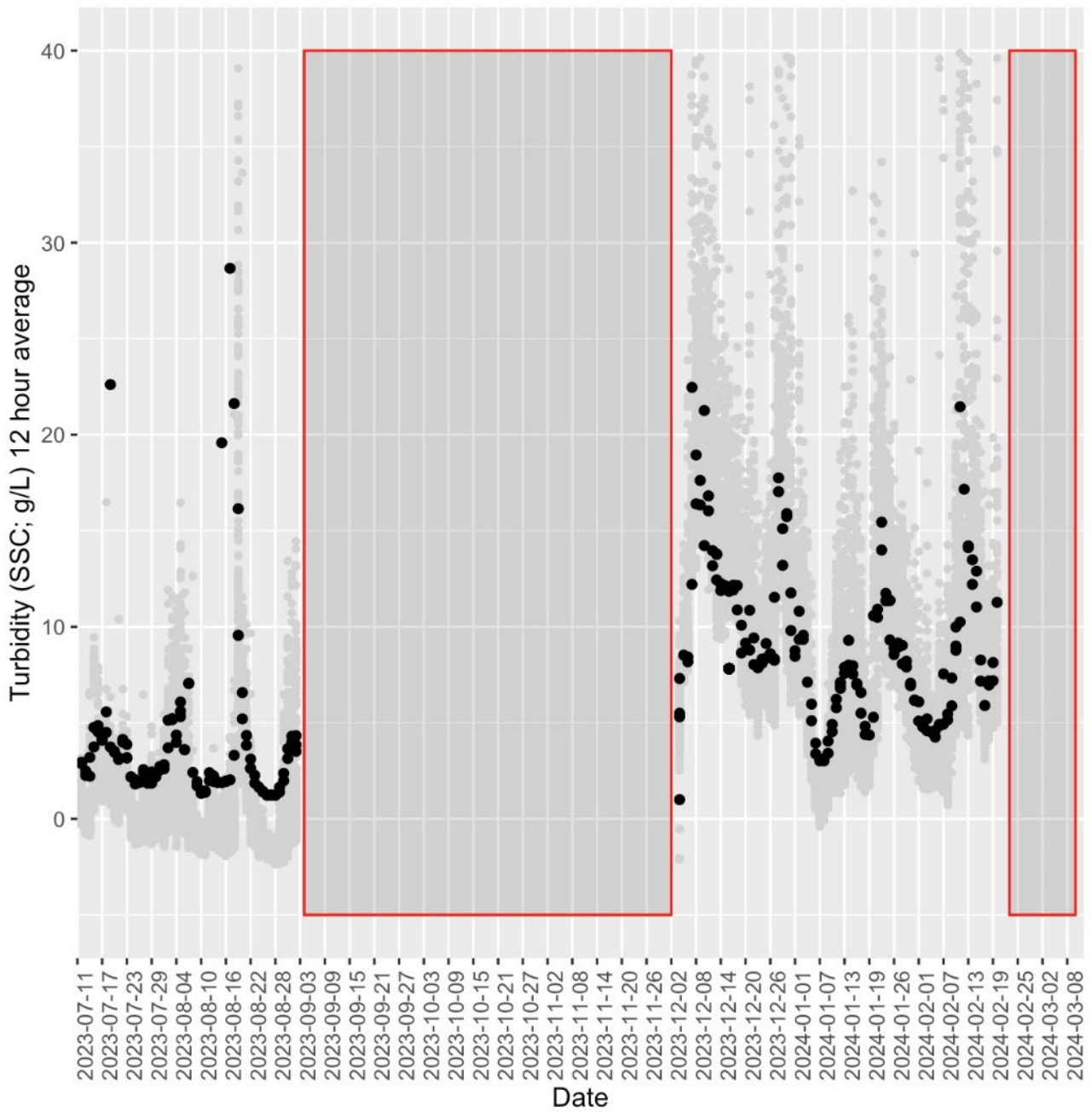


Figure 18: Turbidity at the Milford Haven maerl bed between July 2023 and February 2024. Suspended sediment concentration is indicated by black dots. The original dataset of Optical Backscatter Measurements of turbidity, collected at a 10-minute logging frequency, is plotted in grey. Periods when erroneous data were detected and removed are indicated by the red box (reproduced from Dale and Mandipe, *in press*).

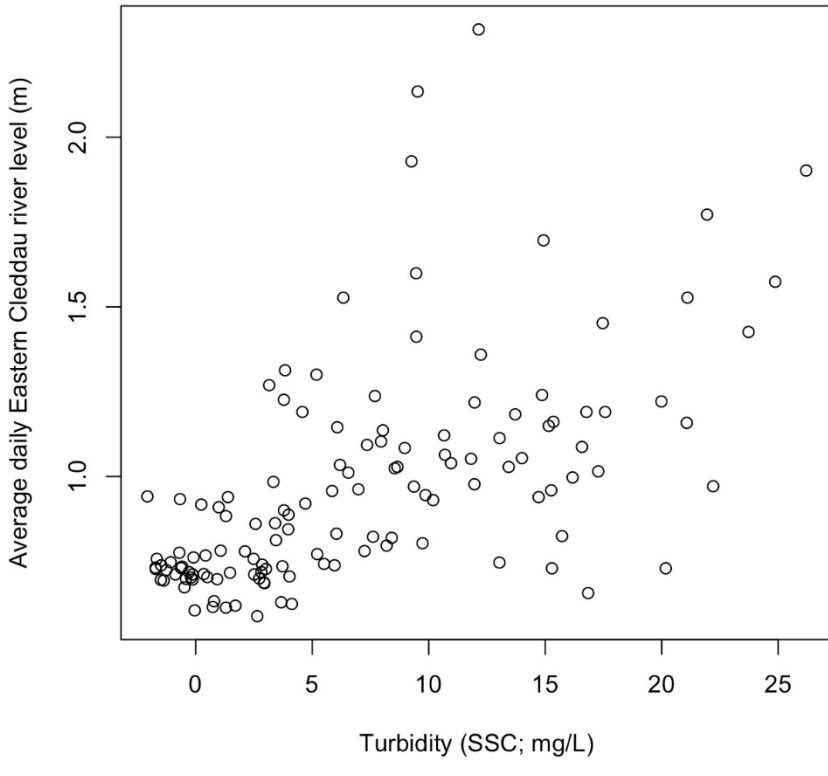
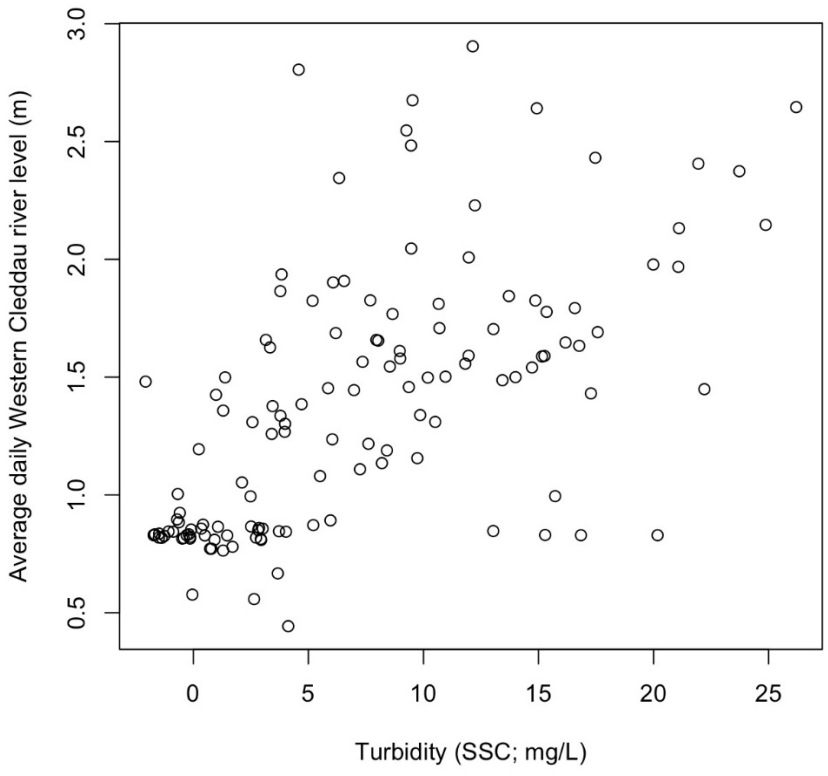


Figure 19: Average daily water level (m) in the Western Cleddau at Haverfordwest (*top*) and Eastern Cleddau at Canaston Bridge (*bottom*) (NRW, 2025a) and suspended

sediment concentration (SSC; mg/L) at the Milford Haven maerl bed. Reproduced from Dale & Mandiye, *in press*.

Table 9: Spearman's Rank Correlation Coefficient's for measured parameters in respect to suspended sediment concentration (r values between -1 and +1, where a value of +1 indicates a perfect positive correlation, -1 indicates a perfect negative correlation and 0 indicates no correlation). All coefficients were statistically significant at the 95% confidence level. Data from Dale & Mandiye, *in press*.

| Parameter | Temporal resolution | Correlation coefficient (r) |
|--|----------------------------|------------------------------------|
| Maximum Water Level (m) | Tidal | -0.159 |
| Salinity (PSU) | Tidal | -0.701 |
| Turbot Bank Maximum Wave Height | Tidal | 0.493 |
| Turbot Bank Wave Frequency | Tidal | -0.256 |
| Mid Channel Rock Maximum Wave Height | Tidal | 0.431 |
| Mid Channel Rock Wave Frequency | Tidal | -0.052 |
| Western Cleddau Average River Level (m) | Daily | 0.668 |
| Western Cleddau Average River Level (m) one day offset | Daily | 0.639 |
| Western Cleddau Average River Level (m) two day offset | Daily | 0.630 |
| Western Cleddau Average River Level (m) three day offset | Daily | 0.642 |
| Eastern Cleddau Average River Level (m) | Daily | 0.669 |
| Eastern Cleddau Average River Level (m) one day offset | Daily | 0.624 |

| Parameter | Temporal resolution | Correlation coefficient (r) |
|--|---------------------|-----------------------------|
| Eastern Cleddau Average River Level (m) two day offset | Daily | 0.613 |
| Eastern Cleddau Average River Level (m) three day offset | Daily | 0.608 |

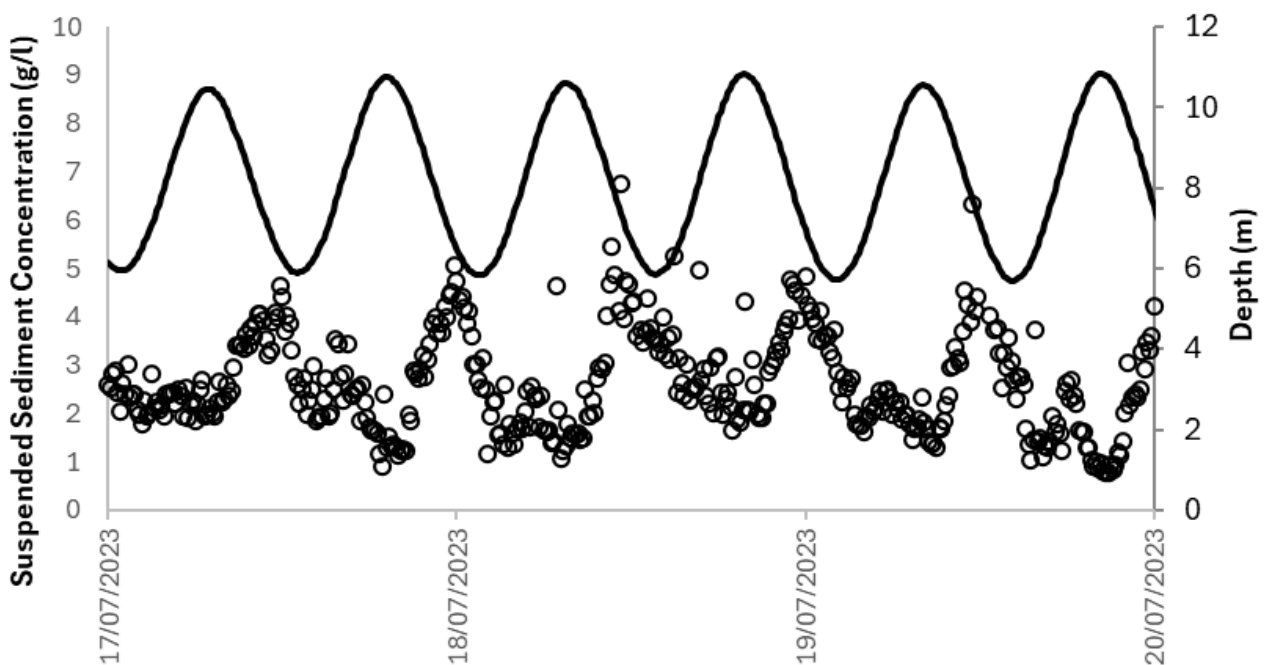


Figure 20: Variations in suspended sediment concentration (circles, (g/l)) and depth (solid line, m) across six tides from 17th July 2023 to 20th July 2023 as measured by a YSI EXO2 multiparameter Sonde deployed at the Milford Haven maerl bed. Reproduced from Dale & Mandipe, *in press*.

If light availability were a primary structuring factor, without the influence of other pressures, the pattern of maerl decline would likely show a clear zonation based on depth. Areas with the greatest loss of maerl would be expected in deeper zones with lower light availability. This has not been observed, however, given the likelihood for combined pressures to be driving maerl distribution at the site, the influence of structure based on light levels could potentially be masked. Further analysis would be needed to ascertain if the fluctuations of light (and sediment concentrations) at the site are sufficient to limit maerl growth.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of suspended solids and water clarity on the maerl bed (Table 10). A timing score of 3 was assigned because this pressure would have been present during the period under investigation, however it is also likely to have been present in the preceding time period. Intensity was rated as 2 due to the limited intensity. A frequency score of 2 was given because sediment levels fluctuate. A spatial scale of impact score of 4 was assigned because this would impact the entire site. A sensitivity score of 3 was assigned, reflecting maerl beds' 'medium' sensitivity to changes in water clarity. The confidence score was medium due the amount of turbidity data available for the site.

Table 10: Assessment for **Suspended solids (water clarity)** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature's susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------------|------------|
| 3 | 2 | 2 | 4 | 3 | 144 | Medium |

De-oxygenation (reduction in oxygen) in sediment or water column

Definition of pressure: A reduction oxygen levels in water or substrate (sediment), either temporarily or permanently, due to anthropogenic activities.

Sensitivity of species

This pressure is closely linked to sedimentation and burial, as the depth of the oxic zone/aRPD in sediments is influenced by sedimentation rate, organic matter flux, particle size and mixing processes. Please see relevant pressures sections for full details.

The sensitivity assessment classifies maerl beds' resistance to de-oxygenation as "low," with resilience rated as "very low" and overall sensitivity as "high" (Perry et al., 2017). The evidence indicates that maerl and its associated community are highly sensitive to deoxygenation and anoxia. However, these effects may be mitigated in areas with strong water flow, where deoxygenating conditions in the water column are likely to be short-lived (Perry et al., 2017).

Deoxygenation of seabed sediments is expected to have more severe effects. Laboratory studies by Wilson et al. (2004) found that burial in black muddy sand with an odour of hydrogen sulphide was fatal to live maerl. Thalli placed on the sediment surface or buried by 0.25 cm and 2 cm of sediment all died within two weeks (Wilson et al., 2004). These conditions would also negatively impact infaunal assemblages (Hall-Spencer et al., 2006).

The impact of deoxygenation on maerl beds has been primarily studied in relation to fish farm aquaculture. Eutrophication from aquaculture has been identified as a major factor in the decline of maerl beds in the North East Atlantic (Hall-Spencer et al., 2010). Near fish farms in Orkney, much of the maerl was found dead and clogged with black, sulphurous, anoxic silt. In contrast, high-energy environments like Shetland showed more live maerl, likely transported by rough weather and forming large ripples (Hall-Spencer et al., 2006).

Evidence of de-oxygenation at the maerl bed

Water Framework Directive assessments indicate no evidence of deoxygenation in the water column at the site. All three overlapping WFD waterbodies were classified with a High status for dissolved oxygen in the 2024 cycle 3 interim classification (Pembrokeshire South, Milford Haven Outer and Milford Haven Inner) (Jackson-Bué et al., 2025).

Oxygen levels within the sediments of the maerl bed have not been measured and this gap in evidence is a priority for future research. Limited evidence of an aRPD layer close to the surface can be observed from an SPI imaging survey, (see pressure 'Organic enrichment' for SPI imaging study).

To fill this evidence gap, it is recommended that, in addition to direct measurements of dissolved oxygen and the depth of the oxic zone (aRPD), sediment microbiome samples be collected and analysed for bacteria that thrive in anoxic conditions, including sulphur-reducing bacteria. If sediment anoxia or shallow aRPD layers are observed and the presence of sulphide compounds (to be confirmed) are detected in the maerl bed, they could help explain some of the observed decline in the condition of the bed, although historical data is currently unavailable. Short term deoxygenation from, for example, the settling of decaying opportunistic macro algae cannot be ruled out. Given the sensitivity of the species, a short period of deoxygenation could have catastrophic consequences.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of deoxygenation on the maerl bed (Table 11). The deoxygenation assessment assigned the following scores: a timing score of 3 indicating that the activities occurred mostly within a relevant timeframe; an intensity score of 1, reflecting the gaps in evidence for this pressure; a frequency score of 3, as the occurrence would be frequent (may be intermittent but ongoing); a spatial scale score of 4, due to both direct and indirect impacts on the entirety of the maerl bed; and a sensitivity score of 4, reflecting the high sensitivity of maerl beds to deoxygenation. The confidence score, however, was low and more data is needed.

Table 11: Assessment for **deoxygenation** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------------|------------|
| 3 | 1 | 3 | 4 | 4 | 144 | Low |

Macroalgae: smothering/shading

Definition of pressure: changes in the abundance of macroalgal species which may cause smothering/shading.

Sensitivity of species

There is no MarLIN category specific to macroalgal smothering/shading, however this pressure relates to ‘Nutrient enrichment’, ‘Organic enrichment’. See ‘Suspended solids (water clarity) for discussion on light levels.

Both competitive and facilitative relationships with macroalgae can be observed in maerl beds (McCoy and Kamenos, 2015). These habitats host over 150 macroalgal species (Birkett et al., 1998), many of which play dual roles in structuring the maerl bed ecosystem. In temperate intertidal and shallow subtidal zones, maerl species may benefit from shading provided by macroalgal canopies, which can moderate light and temperature conditions (Qui-Minet et al., 2022). At the same time, they compete with larger macrophytes for light and space for attachment (Cobacho et al., 2018).

Several macroalgal species are considered endemic to maerl habitats, indicating a degree of ecological specialization (Helias et al., 2024). However, under altered environmental conditions—such as those driven by eutrophication—these relationships can shift. For instance, macroalgal epiphytes may proliferate on maerl surfaces, benefiting from reduced competition and increased nutrient availability, to the detriment of the maerl algae themselves (Qui-Minet et al., 2019).

Recent findings from the Bay of Brest indicate that macroalgal biomass varies significantly with eutrophication status, with the highest biomass observed at highly eutrophic sites and the lowest at unimpacted ones. Seasonal peaks in biomass—particularly in late summer—were observed across all conditions, with community composition differing by nutrient status: unimpacted sites were dominated by attached cartilaginous red algae (e.g. *Chondria dasyphylla*), whereas highly eutrophic sites were characterized by free-living species such as *Halopithys incurva* (Helias et al., 2024).

Interestingly, in one study, no positive relationship was observed between nutrient enrichment and macroalgal epiphyte abundance, but epiphyte abundance was higher at stations with lower maerl biomass. (Qui-Minet et al., 2019).

Evidence of changes in/to macro algal smothering/shading at the maerl bed

There are well documented issues with intertidal opportunistic macroalgae in the Haven. While the macroalgae classifications for ‘Milford Haven Outer’ are Cycle 2 (2015) ‘good’ (98%) and Cycle 3 (2021) ‘good’ (99%) (Lock et al., 2025a), there are photographic records of localised dense opportunistic macroalgal growth associated with freshwater inputs in the more sheltered bays and inlets, including Sandy Haven, near to the maerl bed. In addition, ‘Milford Haven Inner transitional waterbody’ has failed to meet WFD standards for the opportunistic macroalgae element (classified ‘moderate’, 2013 (interim), 2015, 2018 and 2021).

There is limited information as to whether issues persist in subtidal areas, however, since they are directly linked to DIN and organic inputs, known to occur in the area, there is potential for increased algal growth in the subtidal. During dropdown video surveys (see section ‘Monitoring and Current Status’), macroalgal cover obscured a portion of images in the 2023 survey (Mercer et al., *in press*). However, because surveys did not take place at the same time of year in previous years (and algal cover is highly seasonal) it is not possible to do a temporal analysis to ascertain an increase over time. Dive survey data provides algal abundances at 36 quadrats across the site and was consistently surveyed during the summer months, however overall trends for smothering are not possible to ascertain from this data (Figure 21).

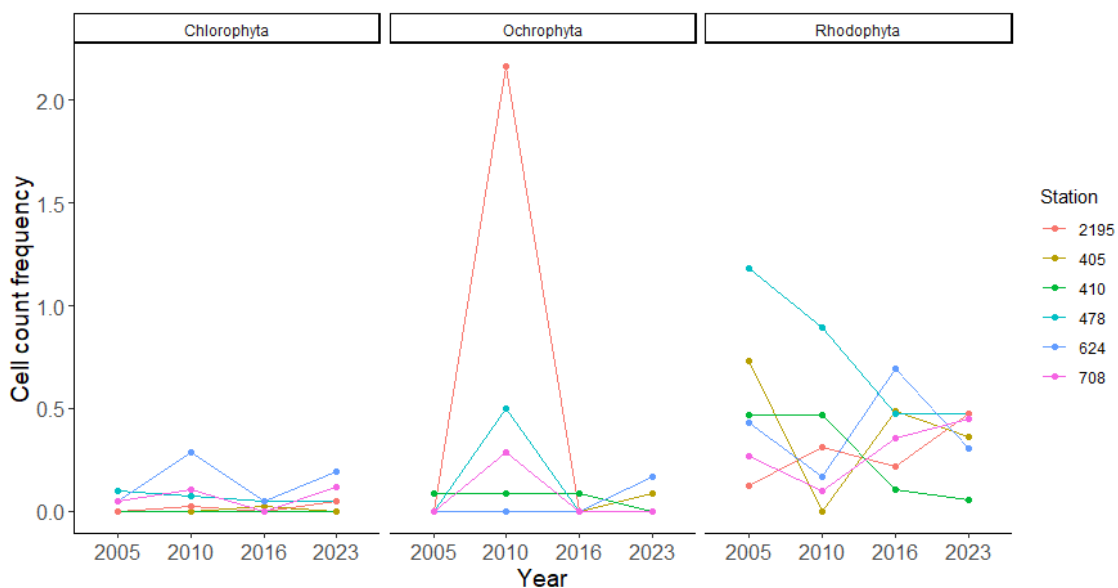


Figure 21: Changes in cell count frequency of macroalgal phyla: Chlorophyta, Ochrophyta and Rhodophyta from 2005 – 2023 monitored at NRW diver stations at the Milford Haven maerl bed (Bunker and Ratcliffe, *in press*).

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of macroalgae (smothering/shading) on the maerl bed (Table 12). A timing score of 3 was assigned because this pressure would have been present during much of the period under investigation. Intensity was rated as 2 due to the limited impact and need for further evidence. A frequency score of 3 was given due to seasonal variation. A spatial scale of impact score of 3 was assigned because of assumed patchiness in algal cover at the site. A sensitivity score of 2 was assigned, reflecting the complexity of interactions (some positive and some negative) between algal cover and maerl species. Confidence was low as more data is needed for the site.

Table 12: Assessment for **Macroalgae: smothering/shading** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 3 | 2 | 3 | 3 | 2 | 108 | Low |

Hydrocarbon contamination

Definition of pressure: hydrocarbon presence in water column and sediment at the site.

Sensitivity of species

Perry et al. (2017) classified resistance of coralline algae to oil as ‘Low,’ resilience and sensitivity as ‘Medium,’ with confidence in the assessment at ‘Medium’ due to variability between studies. However, they classified resistance of maerl-forming species and maerl habitat to oil spills as ‘Low,’ resilience as ‘Very low,’ and sensitivity as ‘High,’ with ‘Low’ confidence due to lack of direct evidence.

Limited evidence of petrochemical hydrocarbons on maerl-forming species or maerl beds has been found for this report. However, in the intertidal, changes in macroalgal abundance, (including *Corallina elongata* and *Lithophyllum incrustans*) were quantified along the Basque coast after the Prestige oil spill and found no significant differences between oiled and non-oiled sites over a period of 2 years (Díez et al., 2009). In contrast, after the Dounreay oil spill on the north coast of Scotland, 100% of *Lithothamnion* cover was bleached, and dead rodoliths of *Lithothamnion* were observed in lower shore rock pools (Bowman, 1978). Close to the Milford Haven maerl bed, encrusting coralline algae, including *Lithothamnion incrustans*, *Phymatolithon purpureum*, and *Corallina officinalis*, were bleached in West Angle Bay immediately following the Sea Empress oil spill but recovered quickly, (Crump et al., 1999).

While the subtidal location of maerl beds may offer some protection from surface spills, studies indicate that the Deepwater Horizon (DWH) oil spill on deep (50-77 m) rhodolith beds in the Gulf of Mexico, resulted in bleaching of the rhodoliths (encrusting species included *Lithophyllum* sp., *Lithothamnion* sp., *Mesophyllum* sp., and *Porolithon* sp.) (Felder et al., 2014; Fredericq et al., 2014).

Evidence on the effects of PAHs on maerl-forming species or maerl beds is limited, with mixed findings from intertidal studies—some reporting impacts and others noting recovery. While subtidal maerl beds may be somewhat protected from surface spills, the Deepwater Horizon (DWH) oil spill resulted in bleaching of rhodolith beds and associated encrusting species, highlighting the potential for oil spills to affect these ecosystems.

Evidence of Hydrocarbon contamination at the maerl bed

The Milford Haven is heavily industrialised, importing a large proportion of the UK’s oil and gas. In 1996, the Sea Empress oil tanker ran aground as it entered the Milford Haven Waterway. Six days later, after 72,000 tons of Forties Blend North Sea crude oil was spilt, the tanker refloated and was towed to the end of the South Hook LNG jetty at the maerl bed site. The tanker then continued to spill oil at the site (Little et al., 2015b).

During the South Hook jetty refurbishment, shot blasting of coal tar from the old jetty piles was deposited on the seabed (Figure 22), resulting in a further source of hydrocarbons on the bed. It should be noted that the coal tar deposition coincides with the period under investigation, in contrast to the Sea Empress spill, which occurred a decade prior.

Grab sampling surveys (2018 Milford Haven inlets monitoring sediment survey NRW), indicate that polycyclic aromatic hydrocarbons (PAH) were present at higher levels in two of the four maerl bed samples, in comparison to other areas of the Haven (Table 13, Figure 23). It should be noted that survey data for the maerl bed is limited to a single time point (2018) and 6 grab samples.

The Sea Empress spill occurred nearly a decade before the period under investigation, making it unlikely to have directly contributed to the observed decline, unless sediment-bound PAHs are causing ongoing effects. There is no available information on the impact of coal tar deposits on maerl beds; however, coal tar deposition on the bed occurred during the period of concern and has been documented. While both Sea Empress spill and coal tar deposition could have contributed to PAH concentrations at the site, timings of the decline align more closely with coal tar deposition. It should be noted that the link between concentrations in sediment and maerl fitness is yet to be established.

Table 13: Concentrations of analytes at the maerl bed during the 2018 NRW Milford Haven sediment survey. Units = ug/kg. All analytes were analysed as dry weight at 120 degrees C. For monitoring station location map see Figure 2.

| Analyte name | MAERL St. 405 | MAERL St. 410 | MAERL St. 478 | MAERL St. 624 | MAERL St. 708 | MAERL St. 2195 |
|----------------|---------------|---------------|---------------|---------------|---------------|----------------|
| Benzo(e)pyrene | 24.1 | 17.3 | 39.2 | 180.0 | 314.0 | 364.0 |
| C1 Naphthalene | 32.6 | 22.0 | 68.5 | 279.0 | 614.0 | 293.0 |

| Analyte name | MAERL St. 405 | MAERL St. 410 | MAERL St. 478 | MAERL St. 624 | MAERL St. 708 | MAERL St. 2195 |
|-------------------------|------------------|------------------|------------------|------------------|------------------|-------------------|
| C1 Phenanthrene | 30.4 | 21.8 | 58.2 | 251.0 | 366.0 | 392.0 |
| C2 Naphthalene | 30.1 | 19.5 | 77.8 | 233.0 | 362.0 | 246.0 |
| C3 Naphthalene | 19.5 | 12.2 | 38.1 | 149.0 | 157.0 | 133.0 |
| Perylene | 8.8 | 6.4 | 13.8 | 56.5 | 113.0 | 141.0 |
| Acenaphthene | 3.7 | 4.0 | 6.2 | 39.2 | 360.0 | 337.0 |
| Acenaphthylene | 1.9 | 1.4 | 3.4 | 15.7 | 20.3 | 22.9 |
| Anthracene | 5.9 | 4.7 | 12.6 | 57.2 | 84.6 | 232.0 |
| Benzo(a)anthracene | 17.9 | 14.5 | 27.5 | 124.0 | 366.0 | 506.0 |
| Benzo(a)pyrene | 23.9 | 17.1 | 35.9 | 149.0 | 430.0 | 523.0 |
| Benzo(b)fluoranthene | 34.3 | 24.0 | 55.3 | 253.0 | 470.0 | 528.0 |
| Benzo(ghi)perylene | 23.8 | 17.2 | 38.5 | 170.0 | 280.0 | 321.0 |
| Benzo(k)fluoranthene | 13.5 | 10.0 | 16.8 | 92.6 | 227.0 | 219.0 |
| Chrysene | 27.3 | 21.1 | 47.2 | 199.0 | 529.0 | 566.0 |
| Dibenzo(ah)anthracene | 6.0 | 4.2 | 10.1 | 43.2 | 72.2 | 90.1 |
| Fluoranthene | 34.8 | 26.3 | 53.7 | 266.0 | 1130.0 | 1190.0 |
| Fluorene | 7.7 | 6.8 | 15.0 | 84.9 | 275.0 | 292.0 |
| Indeno(1,2,3-c,d)pyrene | 23.8 | 19.5 | 43.9 | 189.0 | 320.0 | 365.0 |
| Naphthalene | 17.2 | 10.1 | 35.1 | 154.0 | 324.0 | 130.0 |
| Phenanthrene | 28.4 | 22.8 | 46.9 | 249.0 | 875.0 | 914.0 |
| Pyrene | 28.1 | 19.9 | 43.0 | 208.0 | 869.0 | 912.0 |

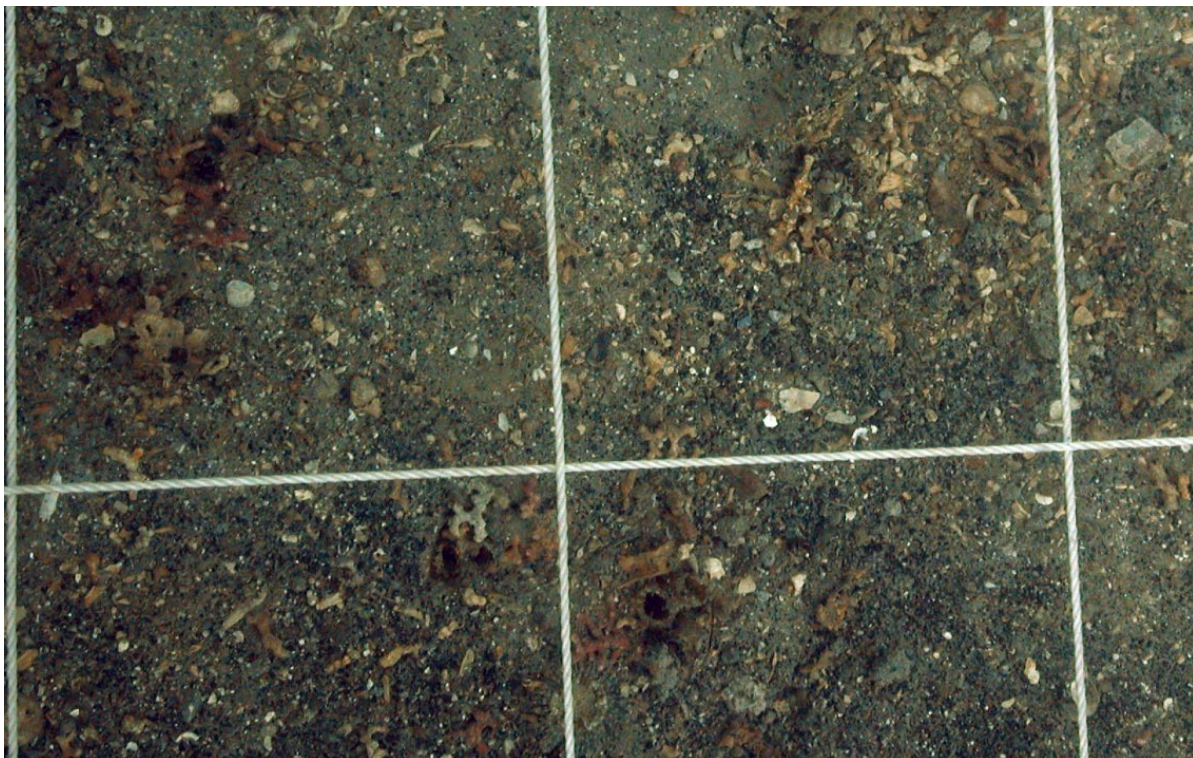


Figure 22: Shot blasted coal tar (black and grey material) on the Milford Haven maerl bed. Photo Francis Bunker, ASML Ltd, 2006.

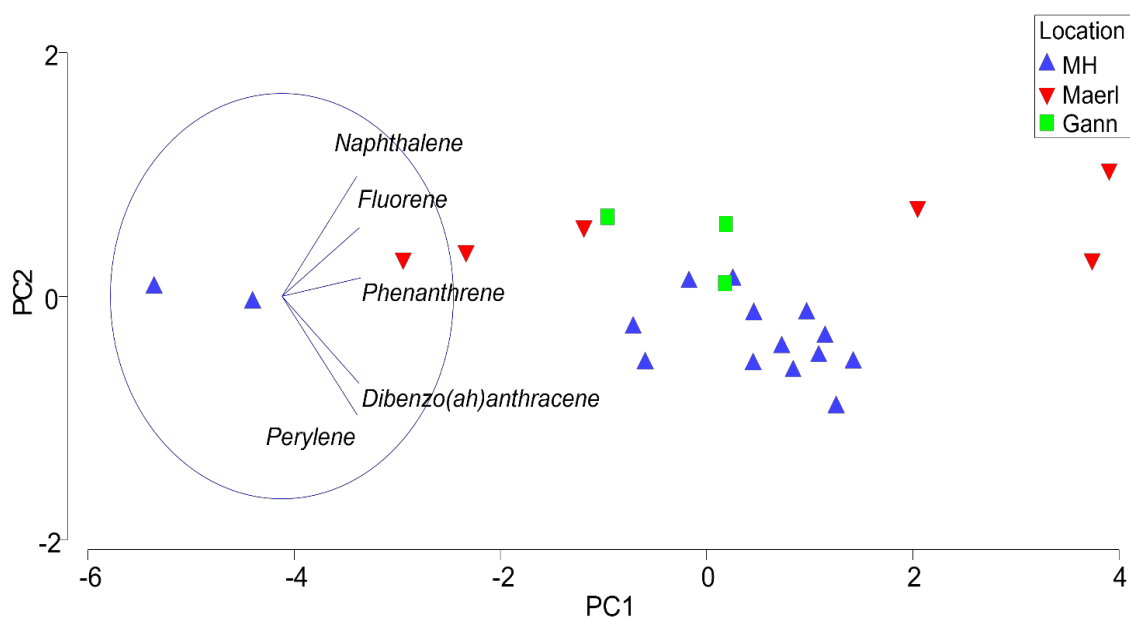


Figure 23: Principal component analysis of polycyclic aromatic hydrocarbons (PAHs) composition from 54 sample grabs in Milford Haven in 2018, showing clustering of PAHs across 3 locations (the Gann, the maerl bed and the wider Milford Haven Waterway), based on Euclidean distance of log transformed normalised data. Vectors show PAHs that significantly contributed to the patterns on the ordination. Data: 2018 NRW Milford Haven sediment survey.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of hydrocarbons on the maerl bed (Table 14). A timing score of 3 was assigned because the shot blasting took place within period under investigation, however previous contamination at the site (Sea Empress) occurred prior to the period under investigation. Intensity was rated as 3 due to the direct deposition of material (coal tar) on the site. A frequency score of 2 was given because these activities occurred over a limited period. A spatial scale of impact score of 2 was assigned, as it impacted a limited portion of the bed. A sensitivity score of 3 was assigned, reflecting maerl beds' low resistance to hydrocarbon contamination, very low resilience, and overall high sensitivity. Confidence was low due to data gaps. Tank experiments are recommended to reassess maerl sensitivity to the various elements of this pressure.

Table 14: Assessment for **hydrocarbons: Sea Empress spill/smaller spills** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure;

frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature's susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------------|------------|
| 3 | 3 | 2 | 2 | 3 | 108 | Low |

Physical damage: scallop dredging

Definition of pressure: King Scallop dredge on Maerl

Sensitivity of species

The sensitivity assessment classified maerl beds' resistance to removal of non-target species (for example scallop dredging) as "low," with resilience rated as "very low" and overall sensitivity as "high" (Perry et al., 2017). Scallop dredging causes significant seabed abrasion, burial of maerl thalli, and resuspension of seabed sediments. In experimental studies, it was reported that a single pass of a scallop dredge through a maerl bed could bury and kill up to 70% of the living maerl in its path (Hall-Spencer and Moore, 2000). Additionally, the dredge re-suspended sand and silt, which then settled over a wide area—up to 15 meters from the dredged track—smothering the remaining living maerl (Hall-Spencer and Moore, 2000). Even a single pass (tow of 3 dredges), resulted in sedimentation on the surrounding maerl bed which was still measurable 4 years post disturbance (Hall-Spencer and Moore, 2000). Due to the impacts involved (abrasion, penetration, sedimentation, burial – see pressures above) trawling has been recognised as one of the main anthropogenic hazards for live maerl (Hall-Spencer and Moore, 2000; Wilson et al., 2004; Tauran et al., 2020).

Evidence of scallop dredging at the maerl bed

Dredging for scallops with a single dredge was observed on the maerl bed in 2006 in the densest area of live maerl at the time (personal communication M. Camplin, November 2006). Although records of the number of tows, vessels etc are lacking, it is possible that more than one dredging event occurred.

Dredging for scallops in Milford Haven was subsequently banned under the Scallop Fishing (Wales) (No.2) Order 2010 (S.I. 2010 No. 269 (W.33)). Therefore, while dredging occurred during the monitoring period/period under investigation, this pressure is not thought to be ongoing.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of physical damage (scallop dredging) on the maerl bed (Table 15). A timing score of 3 was assigned because the activities of concern took place during the period under investigation, although ceased by 2010 and likely occurred before the period under investigation for which we have quantitative data. Intensity was rated as 4 due to the severity of impact from dredges. A frequency score of 1 was given because these activities occurred over a limited period and no longer occur. A spatial scale of impact score of 2 was assigned, as the directly impacted area of the maerl bed was limited, although unquantified. A sensitivity score of 4 was assigned, reflecting maerl beds' very low resistance to dredging (abrasion/ penetration/ burial), very low resilience, and overall high sensitivity. The confidence score was low due the lack of quantitative data.

Table 15: Assessment for **physical damage: scallop dredging** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature's susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 3 | 4 | 1 | 2 | 4 | 96 | Low |

Physical damage fishing/recreation: potting/anchoring

Definition of pressure: Use of pots (lobster, crab, whelk) and anchors directly within the maerl bed site. *Fishers can have multiple strings of pots deployed at any one time* (Seafish, 2020).

Sensitivity of species

There is no directly comparable MarLIN pressure for potting/anchoring. It should be noted that the damage caused by static gears such as pots and anchors are less likely less severe than towed fishing gears, however, placement and hauling of pots and anchors could cause surface disturbance and abrasion, impacting both maerl and associated fauna (JNCC and Natural England, 2011; Walmsley et al., 2015). Where pots are fixed in strings, the retrieval of pots, or incidences of rough weather, could lead to ropes, pots and anchors dragging over the bed, increasing potential damage (Macdonald et al., 1996; *Evidence*, 2010; JNCC and Natural England, 2011; Gall et al., 2020). This would be further

exacerbated during spring tides, which could cause pots to move further on the seabed (Eno et al., 2001; Sørensen et al., 2015; Stephenson et al., 2015).

The impacts of anchoring would vary depending on the type and size of the anchor, the conditions in which the anchors are set or hauled, and the length of the chain used (Sørensen et al., 2015). The potential for anchor dragging would be influenced by the same factors that affect potting impacts.

Evidence of potting/anchoring at the maerl bed

The 2020 whelk order restricts the permitted commercial whelk potting around the maerl bed and seagrass beds, but does not restrict recreational whelk potting – although it is understood that recreational whelk potting is very limited/nil in this area and elsewhere around the coast. Other potting (predominantly crab and lobster) is currently unrestricted. Penetrating anchors associated with whelk potting are also prohibited on the seagrass beds adjacent to the maerl bed (Inshore Fishery Legislation, 2011).

In addition, a voluntary "no anchoring" zone has been established over the maerl bed in Milford Haven to minimize the direct physical impact of anchoring on the seabed (Pembrokeshire Marine Special Area of Conservation, 2014).

Despite these measures, potting has been regularly observed on the maerl bed throughout 2024 (pers. comm. Frances Ratcliffe, 2024), although the extent, number of pots and type of pots has not been verified.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of fishing/recreation (potting/anchoring) on the maerl bed (Table 16). A timing score of 3 was assigned because the activities of concern have been likely ongoing throughout the period of investigation but may be intermittent. Intensity was rated as 2 due to intermittent nature of the activity. A frequency score of 3 was given because these activities may have not have occurred at all time points during the period in question. A spatial scale of impact score of 1 was assigned, as the direct footprint of these gears is spatially limited. A sensitivity score of 4 was assigned, reflecting maerl beds' low resistance, very low resilience, and overall high sensitivity to associated pressures of penetration and abrasion.

Table 16. Assessment for **physical damage from fishing/recreation: potting/anchoring** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature's susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
|--------|-----------|-----------|---------------|------------------------|------|------------|

| | | | | | | |
|---|---|---|---|---|----|--------|
| 3 | 2 | 3 | 1 | 4 | 72 | Medium |
|---|---|---|---|---|----|--------|

Synthetic compounds (pesticides/biocides/antifoul)

Definition of pressure: Exposure of marine species or habitat to one or more relevant contaminants via uncontrolled releases or incidental spills (Perry et al., 2017).

Sensitivity of species

There is no assessment for synthetic compounds available from the MarLIN sensitivity assessment (Perry et al., 2017) and published literature on their effects specifically on maerl species is limited. However, a few relevant studies are outlined below:

The antifouling biocide/herbicide diuron (N'-(3,4-Dichlorophenyl)- N,N-dimethylurea – tested alone and in combination with sedimentation) is known to inhibit photosynthesis and survival of a crustose coralline algae, *Porolithon onkodes* (Harrington et al., 2005; McCoy and Kamenos, 2015). However, this effect was reversible: after transfer into uncontaminated seawater for a period of 4 days, photosynthetic efficiency values reverted to control values (Harrington et al., 2005). In contrast, Dimethyl sulphoxide (DMSO compounds) from sunscreen was found not to impact photosynthesis in *Lithothamnion spp* (MacVicar et al., 2022).

A study evaluating the environmental impact of chlorination in power station abstraction systems have shown that even low concentrations of residual chlorine (0.02–0.1 mg/L) can affect marine phytoplankton communities (Vannoni et al., 2021). These effects include reductions in biomass, shifts in species composition, and a disproportionate impact on smaller phytoplankton such as picophytoplankton. Sensitive groups include Prasinophyceae, Cyanobacteria, and Chlorophyceae, with diatoms like *Skeletonema marinoi* and *Asterionellopsis glacialis* also showing high sensitivity. Although photosynthetic activity in affected communities may recover within 48 hours, these findings suggest that chlorination can cause short-term ecological disruptions, particularly in the mixing zone near discharge points (Vannoni et al., 2021). While the authors are not aware of any direct studies on maerl, it is possible that photosynthetic activity would also be impacted.

Exposure to hydrogen peroxide (H₂O₂) has also been shown to negatively impact photosynthesis and cause bleaching in maerl (Legrand et al., 2022). After 28 days, full recovery of photosynthetic ability was observed, however, there was evidence of two- to four-times more bleaching in thalli treated in comparison to controls. This indicates that despite the recovery of some photosynthetic function, persistent damages occurred to structural integrity of thalli, which may considerably increase the vulnerability of coralline algae to further exposure to stressors (Legrand et al., 2022).

The limited available literature suggests that synthetic compounds must be assessed individually—both in isolation and in combination with other stressors—to understand their specific impacts on maerl species. Additionally, species-specific recovery potential following exposure requires further investigation.

Evidence of Synthetic compounds (Pesticides/biocides/antifoul) at the maerl bed

Up to 2007, diuron was among several herbicides frequently detected in surface waters across England and Wales (Defra, 2012). However, due to growing environmental concerns—particularly its persistence and high mobility in aquatic environments—its use in the UK amenity sector was withdrawn in 2007 (Annex I of Council Directive 91/414/EEC, European Commission, 2007). While diuron may have been in use in Wales during the early 2000s, it was largely phased out by 2005. While this may have been a stressor prior to the investigation period, it is unlikely to have contributed to the observed decline during the period under investigation.

Pembroke Power Station uses chlorination as part of its cooling water system to control biofouling, which is a common practice in coastal and estuarine power stations. Chlorination is applied during the abstraction and return of seawater used for cooling, which also involves the emission of heat and residual chemicals. Chlorination-by-product (CBP) concentrations in water samples from the power station and Milford Haven have remained consistently low compared to levels reported at other coastal and estuarine power stations using once-through cooling (Jacobs, 2023).

Due to the industrial nature of the Haven, it is likely that many synthetic compounds are present in the waterway. However, damage would be concentration dependent, and potentially reversible, depending on the compound in question, and the amount of exposure time.

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of synthetic compounds (Pesticides/biocides/antifoul) on the maerl bed (Table 17). A timing score of 2 was assigned because this pressure would have been present intermittently during the period under investigation. Intensity was rated as 2 due to the combination of factors needed for this pressure to cause an impact. A frequency score of 2 was given because compound concentrations would be variable. A spatial scale of impact score of 4 was assigned because this would impact the entire site. A sensitivity score of 2 was assigned, reflecting that, in many cases, this pressure would be non-lethal, and recovery may be possible. Confidence in this assessment was low due to the limited evidence available.

Table 17: Assessment for **synthetic compounds (Pesticides/biocides/antifoul)** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the

proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 2 | 2 | 2 | 4 | 2 | 64 | Low |

Transitional elements & organometal pollution

Definition of pressure: Exposure of marine species or habitat to one or more relevant contaminants via uncontrolled releases or incidental spills.

Sensitivity of species

The MarLIN assessment concluded that there was insufficient literature available to evaluate the impact of metal pollution on *L. corallioides* (Perry et al., 2017). No studies specifically addressing this species were found for this report. However, a tank-based experiment on the photosynthetic activity of *P. calcareum* examined the effects of a single dose of a heavy metal mixture (Zn:Pb:Ni:Cu:Cd in a 37:16:14:11:1 ratio) (Wilson et al., 2004, Figure 24). The concentration of cadmium ranged from 0.174 to 174 ppb, and the results showed a significant reduction in photosynthetic capacity (as indicated by F_v/F_m values, which reflect a decrease in Photosystem II activity). The species, however, recovered quickly depending on the concentration of metals. Exposure to heavy metal ions is likely to impose a fitness cost as evidenced by the antioxidant responses observed in various algae species (Nowicka, 2022). In most cases, exposure to toxic concentrations of heavy metal salts resulted in oxidative stress. Acclimation to this stress was typically accompanied by increased levels of low-molecular-weight antioxidants and enhanced activity of antioxidant enzymes (Nowicka, 2022). However, a range of protective and adaptive mechanisms have been documented – for full discussion see Nowicka (2022).

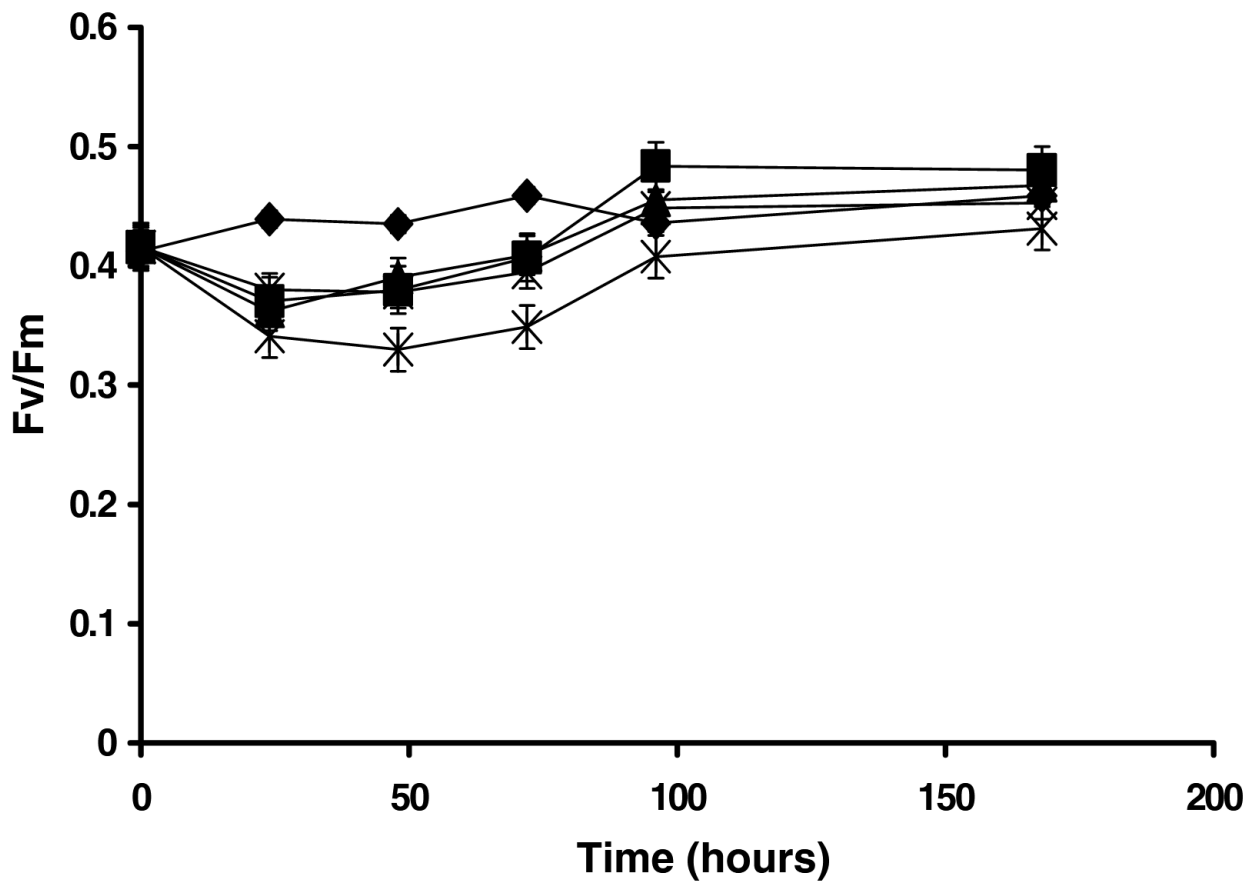


Figure 24: The effect of various concentrations of a heavy metal model effluent (expressed as ml of effluent per litre of seawater: diamonds, control; squares, 0.12; triangles, 1.2; x, 12; star, 120) upon the F_v/F_m of *P. calcareum* at 9°C (reproduced from Wilson et al., 2004).

Evidence of transitional elements & organometal pollution at the maerl bed

The only metal detected in the grab sampling (2018 Milford Haven inlets monitoring sediment survey NRW) at levels exceeding threshold effects level (TEL) was mercury (Table 18). However, the sample size is small. No analytes exceeded the probable effects level (PEL). Milford Haven Outer has failed for mercury in previous WFD cycles (Lock et al., 2025a, however the concentration is now declining (NRW, unpublished data). Tributyltin (TBT) also failed in previous Cycles however, monitoring for TBT has now ceased so current data is not available.

Table 18: Transitional elements and organometal concentrations at 5 sites in the Milford Haven maerl bed, surveyed in 2018 (NRW Milford Haven sediment survey). TEL = threshold effects level. PEL probable effects level. All analytes were measured in mg/kg

| Analyte (Dry Wt) | Maerl St. 410 | Maerl St. 478 | Maerl St. 624 | Maerl St. 708 | Maerl St. 2195 | TEL | PEL |
|------------------|---------------|---------------|---------------|---------------|----------------|------|-----|
| Mercury | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.13 | 0.7 |
| Cadmium | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.7 | 4.2 |
| Chromium | 9.3 | 11.5 | 13.3 | 9.4 | 14.4 | 52.3 | 160 |
| Copper | 6.8 | 9.4 | 8.9 | 8.2 | 10.4 | 18.7 | 108 |
| Lead | 18.6 | 15.0 | 19.5 | 18.0 | 15.7 | 30.2 | 112 |
| Zinc | 45.8 | 47.4 | 61.6 | 60.2 | 64.5 | 124 | 271 |

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of transitional elements and organometals on the maerl bed (Table 19). A timing score of 2 was assigned because there is some evidence of metal pollution presence during the period under investigation. Intensity was rated as 2 due mercury exceeding TEL levels. A frequency score of 2 was given because more evidence is needed as to the behaviour of these elements within the bed. A spatial scale of impact score of 2 was assigned because not all sample sites were impacted. A sensitivity score of 2 was assigned, reflecting the observed impact and subsequent recovery in experimental settings (Perry et al., 2017). Confidence was low, reflecting limited data availability.

Table 19: Assessment for **transitional elements & organometal** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|-----------|------------|
| 2 | 2 | 2 | 2 | 2 | 32 | Low |

Introduction/presence of microbial pathogens

Definition of pressure: The introduction or presence of relevant microbial pathogens or metazoan disease vectors to the maerl bed.

Sensitivity of species

There is no assessment from MarLIN regarding the introduction of microbial pathogens or diseases, and the literature on their impacts on maerl species is limited (Perry et al., 2017). Coralline White Patch Disease has been documented in a rhodolith bed in the Egadi Islands (western Mediterranean) (Basso et al., 2018). In addition, studies of other crustose coralline red algae indicate that, like other marine organisms, these algae are susceptible to the current increase in marine disease outbreaks (Quéré et al., 2019). For example, white-band syndrome has also been observed in *Neogoniolithon brassica-florida* (a coralline algae) in the Mediterranean Sea, indicating that the disease threat has extended from tropical to temperate waters (Quéré et al., 2019). Evidence suggests that the impact of this disease is temperature dependent but can cause severe mortality in the right conditions. Furthermore, *Coralline Lethal Orange Disease*, which affects coralline algae in the Pacific, poses a potential threat to European maerl species. However, this disease has not been detected in Europe (Birkett et al., 1998). To date, no studies indicate the presence of disease in UK maerl beds, a potential area for future research.

Evidence of introduction/presence of microbial pathogens at the maerl bed

There is no current evidence of maerl disease at the Milford Haven maerl bed. However, to date, no surveys have collected data on disease and therefore indicate an evidence gap. Jenkins et al., (2025) in collaboration with NRW assessed microbiota communities in Milford Haven and compared them to other beds in Southern England (Figure 25:), providing preliminary data for further research. It would be beneficial for future monitoring to include indications of disease, and, if detected, the microbiome and the pathobiome of healthy and diseased tissue to be characterised and investigated for possible causes/management measures.

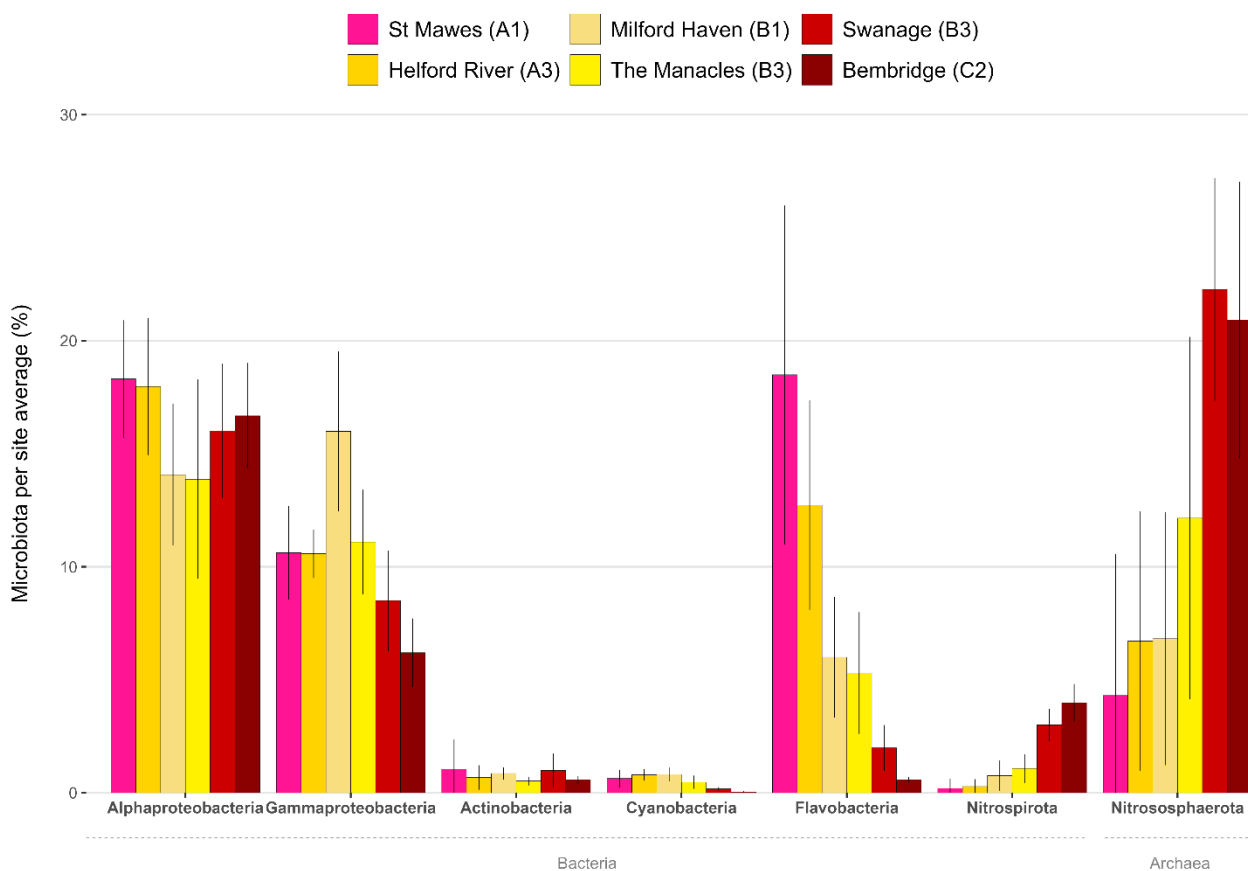


Figure 25: Microbiota community of maerl assessed using metagenomics. The mean average proportion of Bacteria or Archaea groups are presented for six locations; these locations broadly represent a gradient of maerl bed status from a dense, healthy maerl bed (St Mawes) to mostly dead scattered maerl (Bembridge). (Reproduced from Jenkins et al., 2025b).

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of the introduction of microbial pathogens on the maerl bed (Table 20). Timing, intensity and frequency scores of 1 were assigned because this pressure has not been detected. A spatial scale of impact score of 4 was assigned because this would impact the entire site. A sensitivity score of 4 was assigned because this pressure would be likely to have lethal impacts. Due to lack of data for this assessment, confidence was low.

Table 20: Assessment for **introduction of microbial pathogens** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 1 | 1 | 1 | 4 | 4 | 16 | Low |

Ocean acidification (reduction in pH)

Definition of pressure: The process by which increased atmospheric CO₂ is absorbed by seawater, leading to a reduction in pH, changes in carbonate chemistry, and potential harm to marine organisms, particularly calcifiers. MarLIN benchmark ‘middle emission scenario’: a decrease in pH of 0.15 (annual mean) at the site.

Sensitivity of species

The MarLIN assessment under the ‘middle emission scenario’ (see definition above) classified resistance and resilience as ‘high’ and therefore *L. corallioides* was “not sensitive” to ocean acidification at this benchmark level (Perry et al., 2017). Note that this pressure will become increasingly more relevant in future.

Surface ocean pH has declined by approximately 0.1 units (from 8.2 to 8.1) on average since the Industrial Revolution (Garcia-Soto et al., 2021). Coralline algae are considered particularly vulnerable to ocean acidification due to the solubility of their high magnesium-calcite skeletons (Martin and Hall-Spencer, 2017). Noisette et al. (2013) observed that under conditions expected for the middle emission scenario (550 $\mu\text{atm pCO}_2$), photosynthesis increased while calcification rates remained stable in *L. corallioides*. However, under the high emission scenario (1000 $\mu\text{atm pCO}_2$), photosynthesis remained unchanged compared to the control, but diel calcification rates experienced a sharp decline. Such changes in carbonate production would have severe implications for carbon and carbonate budgets in rhodolith beds (Noisette et al., 2013). In addition, changes in pH would affect ecological dynamics between coralline and non calcified algae as the energetic cost of calcification increases (McCoy and Kamenos, 2015).

Evidence of ocean acidification/reduction in pH at the maerl bed

There are few long-term high-quality observational time series of both chemical and biological data to identify biological changes (Findlay et al., 2025). The earliest data in the time-series from the Stonehaven and WCO – L4 recording stations starts in 2008, after maerl monitoring began (Findlay et al., 2025).

While ocean pH will continue to decrease in future, it is also thought that current levels of acidification may not cause direct observable changes (Birchenough et al., 2017). It is therefore unlikely that the decrease at the site is of sufficient magnitude to have caused an impact during the period under investigation. However, going forward, it is recommended that pH becomes part of monitoring plans at the site (Sordo et al., 2018).

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of ocean acidification (reduction in pH) on the maerl bed (Table 21). A Timing score of 2 was assigned due to the current reduction in pH being below benchmark level, intensity and frequency scores of 1 were assigned because this pressure has not been detected at a level to cause concern. A spatial scale of impact score of 4 was assigned because this would impact the entire site. A sensitivity score of 2 was assigned because this pressure at the current level would be unlikely to cause detectable impacts. The pressure will require reassessment and monitoring under future climate change scenarios.

Table 21: Assessment for **ocean acidification (reduction in pH)** pressure.

Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|-----------|------------|
| 2 | 1 | 1 | 4 | 2 | 16 | Medium |

Salinity decrease

Definition of pressure: A decrease in salinity outside the usual range/fluctuations within the Haven.

Sensitivity of species

The MarLIN assessment concluded that a decrease in salinity from 'full' to 'reduced' conditions is unlikely to cause significant harm (Perry et al., 2017). However, a decrease from 'reduced' to 'low' salinity could lead to reduced growth and potentially the death of maerl over the course of a year. Therefore, resistance is rated as 'Medium' with 'Low' confidence. Given the likely slow recovery, resilience is considered 'Very low,' resulting in an overall sensitivity rating of 'Medium.'

L. corallioides is commonly found in full salinity regimes. In laboratory experiments, salinity of *L. corallioides* specimens was gradually reduced from 33.5 ppt to 23 ppt for a month and then to 13 ppt for two weeks. Growth ceased at salinities below 24 ppt, but the species resumed growth and appeared healthy after being returned to full salinity (Adey and McKibbin, 1970). While low salinity was not lethal, it was found to hinder growth, particularly in enclosed estuaries with large streams (Adey and McKibbin, 1970). Similar effects have been observed in other maerl species (Wilson et al., 2004), however, responses are species specific, *Lithothamnion glaciale* was less tolerant to salinity

decrease than *Phymatolithon calcareum*. *P. calcarium* underwent a depression in the photosynthetic capacity at 15 psu, however acclimation to control values then occurred (Wilson et al., 2004).

Evidence of salinity decrease at the maerl bed

No major decreases in salinity have been detected, however, rainfall in the catchment and therefore river input leads to short term decreases in salinity, correlating with river levels and turbidity (Figure 26, Table 9). While *L. corralioides* is sensitive to decreases in salinity, and these occur in the Haven, the magnitude of decrease is unlikely to cause an impact. Given that salinity returns to full ocean levels after a decrease at the location and acclimation and recovery would be possible for the species, this pressure is unlikely to have had a major impact over the period under investigation.

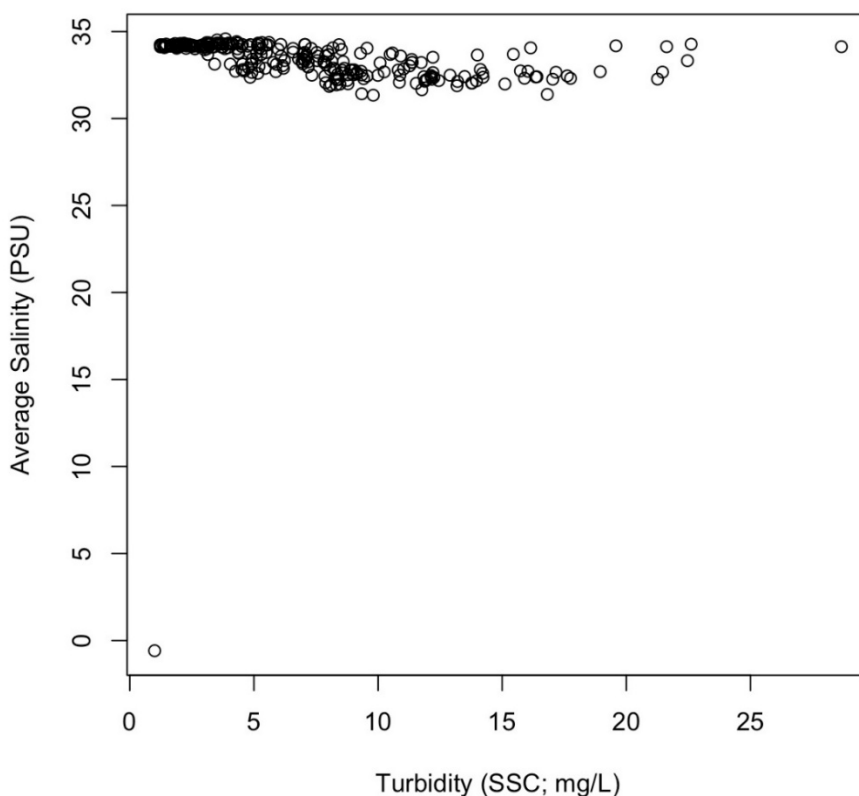


Figure 26: Tidal average salinity and suspended sediment concentration (SSC) at the Milford Haven maerl bed during the 2023/24 sonde deployment (Reproduced from Dale and Mandipe, *in press*).

Pressure assessment scores

The sensitivities and evidence described above were used to assess the impact of a salinity decrease on the maerl bed (Table 22). A timing score of 1 was assigned because there is no evidence of a change in salinity regime during the period under investigation. Intensity was rated as 1 due to the level of fluctuation observed (Figure 26). A frequency score of 1 was given because no events of sufficient magnitude have been reported. A spatial scale of impact score of 4 was assigned, as the whole area would be impacted. A sensitivity score of 2 was assigned, reflecting the ‘medium’ sensitivity (Perry, Jackson & Garrard, 2017). Confidence was medium due to data availability.

Table 22: Assessment for **salinity decrease** pressure. Scores range from 1 (low) to 4 (high). Timing = the likelihood that the pressure occurred during the decline period (2005–2016); intensity = the relative magnitude of the pressure; frequency = how often the pressure recurs over time; spatial scale = the proportion of the feature affected by the pressure. Sensitivity = a feature’s susceptibility to change and ability to recover under pressure. For detailed definitions, see Table 2.

| Timing | Intensity | Frequency | Spatial scale | Sensitivity of species | Risk | Confidence |
|--------|-----------|-----------|---------------|------------------------|------|------------|
| 1 | 1 | 1 | 4 | 2 | 8 | Medium |

Pembroke Power Station: thermal plume

Definition of pressure: increase in temperature directly linked to coolant system for Pembroke Power Station. Does not include climate driven temperature increases.

Sensitivity of species

The sensitivity assessment classified *L. corallioides* resistance to an increase in temperature as “high”, resilience as “high” and therefore “not sensitive” (Perry et al., 2017). The benchmark for this assessment is “a 5°C increase in temperature for one month, or 2°C for one year.” There have not been any incidences of an increase of this magnitude in Milford Haven over the investigation period, despite the coolant input from the Pembrokeshire Power Station (Figure 27). Therefore, this pressure will not be assessed further for the purposes of this report.

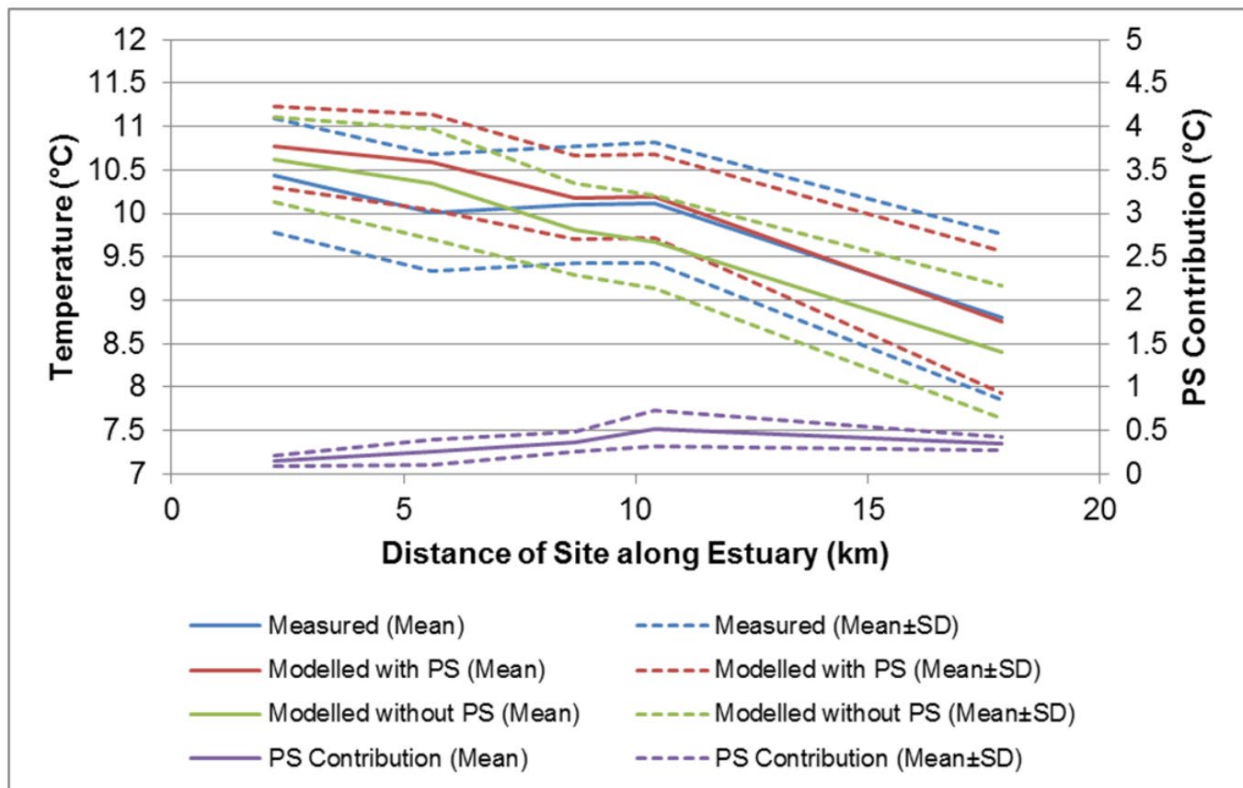


Figure 27: The distribution of measured and modelled power station (PS) contribution to the seawater temperature at near surface sites plotted against the distance of the sites along the estuary in December 2017 (Titan Environmental Surveys, 2018).

Temperature increase (climate driven)

Definition of pressure: increase of temperature at the site (MarLIN benchmark: A 5°C increase in temperature for one month, or 2°C for one year).

Sensitivity of species

The sensitivity assessment classified *L. corallioides* resistance to an increase in temperature as “high” resilience as “high” and therefore “not sensitive” (Perry et al., 2017). The benchmark for this assessment is “a 5°C increase in temperature for one month, or 2°C for one year.” There have not been any incidences of an increase of this magnitude in Milford Haven over the investigation period. Therefore, this pressure will not be assessed further for the purposes of this report. It should be noted that this pressure is expected to become increasingly relevant under future climate change scenarios.

Pressures summary table

Table 23: Pressures discussed in this report ranked from highest to lowest risk of causing the decline in maerl abundance at the Milford Haven maerl bed. INNS – invasive non-native species.

| Pressure | Risk | Confidence |
|---|------|------------|
| Sedimentation/burial | 512 | High |
| Physical damage: Abrasion/Penetration/Disturbance of Substratum | 256 | High |
| Organic enrichment | 256 | Medium |
| Nutrient enrichment | 256 | Medium |
| INNS: <i>Crepidula fornicata</i> | 256 | Medium |
| Suspended solids (water clarity) | 144 | Medium |
| Deoxygenation (reduction in oxygen) in sediment or water column | 144 | Low |
| Macroalgae: smothering/shading | 108 | Low |
| Hydrocarbon contamination | 108 | Low |
| Physical damage: scallop dredging | 96 | Low |
| Physical damage fishing/recreation: potting/anchoring | 72 | Medium |
| Synthetic compounds (Pesticides/biocides/antifoul) | 64 | Low |
| Transitional elements & organometal | 32 | Low |
| Introduction of microbial pathogens | 16 | Low |
| Ocean Acidification (reduction in pH) | 16 | Medium |
| Salinity decrease | 8 | Medium |

Discussion

The Milford Haven maerl bed represents a habitat of exceptional conservation value and constitutes Wales' only known true maerl bed, contributing to both the Large Shallow Inlets and Bays (LSIB) feature and associated estuarine habitats and communities of the Pembrokeshire Marine Special Area of Conservation (SAC) (NRW, 2018). This biogenic habitat supports a highly diverse assemblage of algae and invertebrate species, many of which colonise the structural matrix formed by live and dead maerl nodules. Even post-mortem, the maerl continues to provide a distinct ecological niche; however, the persistence and function of the habitat are contingent upon the continued presence of living maerl.

Pressures assessment

As demonstrated in this report, numerous environmental pressures affecting the maerl bed are interconnected—some acting as potential causal agents while others emerge as consequences. These pressures often operate in combination, with synergistic effects that amplify ecological degradation beyond the impact of individual stressors.

The scores generated for this report are to be used as a prioritisation exercise for further investigation and identification of management measures. Over time, and with further data and evidence gathering, priorities for investigation and management may change.

In future, rather than assessing pressures in isolation, an alternative and more holistic approach could be to use network analysis. This could build on this existing pressure assessment and illuminate underlying relationships among stressors and help identify critical nodes where management interventions could be most effective.

Decline period

While we lack quantitative data prior to 2005, survey records and site descriptions indicate that the bed was already considered *sparse* when first documented in the 1970s. At that time, however, some areas still supported up to 100% maerl cover, compared with a maximum of 40% recorded in 2005. Although we cannot exclude the possibility that activities such as scallop dredging or capital and maintenance dredging between the 1970s and 2005 contributed to a long-term decline, the period for which robust data are available shows a 71% reduction in abundance within just 12 years. A decline of this magnitude is unlikely to have occurred repeatedly throughout the bed's history and therefore warranted this focussed investigation.

Causes of the decline

Pressures:

1. Sedimentation/burial (risk score 512, confidence 'high')

2. Physical damage: abrasion, penetration, disturbance of substratum (risk score 256, confidence 'high')

Monitoring data indicate no consistent ongoing decline in maerl condition, suggesting that the primary impacts occurred before 2017 and are no longer active. The current exercise identified sedimentation/burial, followed by physical disturbance and abrasion, as the highest scoring pressures. Maerl is highly sensitive to sedimentation, burial and abrasion, with even short-term burial likely to cause high mortality, and recovery within the time frame of this investigation would be impossible. The refurbishment of the jetty at South Hook LNG terminal between 2005 and 2010 caused significant seabed damage due to activities including drilling and the use of jack-up spuds, anchors, and chains, all of which generated sedimentation and burial across the site. The scale of this construction was extensive, affecting large portions of the maerl bed, particularly areas with high maerl abundance. These activities led to direct mortality of live maerl and induced alterations in the structure and composition of associated faunal communities. Moreover, chemical contamination occurred, notably through the deposition of coal tar residues directly onto the seabed. These stressors are compounded by secondary impacts, such as elevated concentrations of suspended solids and reduced water clarity.

In addition to the jetty refurbishment, historic scallop dredging is likely to have caused direct mortality and damage to the integrity of the site. The impact of scallop dredges on maerl habitat is well documented (Hall-Spencer and Moore, 2000), however the extent of the activity on the Milford Haven maerl bed remains unclear.

Clearly there are lessons to be learned from this case with respect to considering these types of impacts on maerl. The findings of this report provide a useful evidence base to contribute to full assessment of the likely impacts of maerl as part of future regulatory decisions.

Barriers to recovery: ongoing pressures

Pressures:

3. Organic enrichment (score 256, confidence 'medium')
4. Nutrient enrichment (score 256, confidence 'medium')
5. INNS: *Crepidula fornicata* (score 256, confidence 'medium')
6. Suspended solids (water clarity) (score 144, confidence 'medium')
7. Deoxygenation (reduction in oxygen) in sediment or water column (score 144, confidence 'low')
8. Macroalgae: smothering/shading (score 108, confidence 'low')

Organic and nutrient enrichment are likely to adversely affect *L. corallioides*, particularly when combined with other pressures such as increased sedimentation, suspended solids

and macroalgal smothering. While there is evidence of conditions within the catchment that may lead to sediment deoxygenation at the site, direct measurements of sediment oxygen content are required for a comprehensive assessment. Catchment-wide issues with opportunistic macroalgae are well documented; however, their abundance in the subtidal zone or within the maerl bed has not been quantified. If increasing, this could contribute to smothering and shading effects. Additionally, the decomposition of opportunistic macroalgae in other areas of the Haven may contribute to organic enrichment through the transport of organic material within the estuarine system.

Maerl beds are highly sensitive to invasions of *C. fornicata* due to the combined pressures of smothering, sedimentation, and deoxygenation. *C. fornicata* threatens maerl habitats by outcompeting native species for space, smothering maerl thalli, and altering sediment structure, which disrupts ecosystem structure and function. While coverage of *C. fornicata* increased by 2017, live populations had declined across all sites by 2023. However, dead shells may continue to contribute to sediment smothering. Interestingly, despite the presence of dead shells, no decline in infaunal diversity was observed in 2023, and some studies suggest that dead *C. fornicata* beds may exhibit trophic complexity similar to that of maerl beds.

While it is likely that the decline itself was precipitated by historic pressures, there are multiple ongoing pressures still occurring at the site which may be limiting recovery and should be the target of management activities. However, it should be noted that even under ideal conditions, maerl recovery would be slow, due to its low growth rate.

Management measures

While historic impacts are likely to have caused the decline, management measures are recommended for pressures identified as barriers to recovery, as outlined in the previous section. These measures were identified by first noting the key obstacles to recovery and then evaluating potential actions to mitigate their impact.

Management measures should be focused on tackling barriers to recovery:

- Organic enrichment
- Nutrient enrichment
- INNS: *Crepidula fornicata*
- Suspended solids (water clarity)
- De-oxygenation
- Presence of macroalgae

Organic enrichment, nutrient enrichment, deoxygenation, and elevated suspended solids are closely interrelated environmental pressures. Effectively addressing these issues

requires a coordinated, catchment-wide management approach that targets both point sources (e.g. wastewater discharges) and diffuse sources (e.g. agricultural runoff).

Agricultural pollution is recognised as the primary contributor to organic and nutrient enrichment. The Control of Agricultural Pollution Regulations are designed to mitigate this impact. Combined storm overflows also contribute to pollutants entering the waterway and ensuring ongoing compliance and robust enforcement of these regulations is essential to improving water quality. In addition to this, nutrient neutrality (NRW, 2025b) is a specific measure used to manage the impact of new developments and water discharge permit proposals. It aims to ensure that such activities do not result in a net increase in nutrient levels for the duration of their authorisation. In Wales, nutrient neutrality applies to developments that discharge phosphorus into Special Areas of Conservation (SAC) rivers and ongoing compliance with this measure is essential. Currently, condition assessments of SAC features and WFD DIN assessments indicate widespread failures in the area (Jackson-Bué et al., 2025; Lock et al., 2025b, 2025a) and therefore targeted management measures need to be developed, by improving our understanding of specific agricultural activities contributing the highest levels of nutrients.

In addition to the above legislation, there are a number of projects and initiatives that look to reduce nutrient inputs into the Milford Haven catchment. For example, in 2024, on the Western Cleddau River, approximately 6,500 trees were planted along the riverbanks near its confluence with the Eastern Cleddau. These riparian woodlands function as buffer strips between agricultural land and the watercourse. By intercepting and absorbing excess nutrients from surface runoff, the vegetated corridors could help to mitigate nutrient pollution, reduce sediment input, and enhance overall water quality. It is recommended that similar projects are expanded to further reduce nutrient inputs in the Haven.

Further to catchment-wide interventions aimed at improving water quality, sedimentation and nutrient input resulting from the proliferation of *C. fornicata* presents a significant challenge. Due to the extreme sensitivity of maerl habitats to sedimentation, many commonly recommended control measures for *C. fornicata*—such as dredging and smothering—are unsuitable, as they risk causing irreversible physical damage to the substrate and associated biota. Currently, manual removal via hand collection is the only method potentially compatible with maerl conservation. However, the high population densities of *C. fornicata* at the site, combined with logistical constraints associated with diving operations, render this approach largely impractical. Furthermore, the species' extended planktonic larval phase increases the likelihood of recolonisation, particularly if removal efforts are incomplete or poorly timed (Dupont, 2004). The proliferation of *C. fornicata* is a threat to maerl habitats for which we have no obvious solution (Grall and Hall-Spencer, 2003). There is, therefore, an opportunity for novel methods of *C. fornicata* to be developed and trialled, bearing in mind feasibility of implementation.

Collaboration with the Port Authority to explore additional ways within their control to further safeguard the maerl bed would be worth pursuing. As an example, scheduling major vessel movements around high water, rather than low water, could help minimise disturbance. The sonde data collected as part of this project did not capture any major dredging events and was unable to detect a signal from the Neyland Marina dredging. Further data collection has been planned for winter 2025/26 along with a detailed, Haven

wide sediment modelling project to better understand sediment dynamics and potentially provide targeted management advice.

In addition, further investigation into subtidal algal abundance and macroalgae is needed, particularly in relation to sediment anoxia. Excessive algal growth could lead to smothering and subsequent oxygen depletion in sediments, the consequences of which could be damaging to the site. Understanding the dynamics between macroalgae proliferation and sediment oxygen levels would inform potential further management measures.

While a voluntary agreement is in place to manage anchoring and mooring within sensitive zones for the protection of subtidal seagrass and maerl in Milford Haven, raising awareness of the impacts of anchoring and potting activities on the maerl bed remains crucial. Strengthening outreach and education efforts would further support the protection of these vulnerable habitats.

Restoration may also be another avenue for the improvement of the site, however, due to maerl's sensitivity and extremely slow growth rate, restoration is particularly challenging, and so far, there is limited evidence of successful trials. It is recommended that efforts focus primarily on reducing the pressures that hinder natural recovery of the maerl bed. Ongoing monitoring of the scientific literature is important however, to identify and apply any emerging, effective restoration techniques, should they be developed.

Future monitoring priorities and evidence gaps

It is recommended that the time series of dive and drop-down video surveys be continued, with particular attention to maintaining methodological consistency to ensure comparability with previous data. This will enable robust long-term monitoring and reliable trend analysis. To support effective management of the maerl bed, targeted data collection is also recommended in the following key areas:

At the site level – in order of priority:

- **Organic and nutrient enrichment:** Identify the specific agricultural activities contributing the highest nutrient loads within the Haven, and determine which tributaries are responsible for the greatest nutrient inputs. This will help target mitigation efforts more effectively.
- **Sediment deposition:** Direct measurements of sediment accumulation on the maerl bed to assess ongoing smothering risk.
- **Hydrodynamics and sediment transport:** Modelling studies along with collection of fine-scale data on sediment dynamics and water movement to target management actions.
- **Macroalgal overgrowth:** Assessment of macroalgal smothering at the site, either from direct growth or from decaying intertidal algae.
- ***C. fornicata*** should continue to be monitored as part of the drop-down video maerl monitoring time series and removal trialled if appropriate methods were identified.

- **Sediment oxygenation:** In situ measurements of oxygen levels within sediments to evaluate hypoxia risks.
- **Disease surveillance:** Monitoring of disease prevalence and pathology at the site.

Maerl pressure responses - priority research themes

- **Hydrocarbon impacts:** Investigation into the effects of hydrocarbon contamination on maerl structure and function.
- **Heavy metal contamination:** Evaluation of heavy metal concentrations and their biological impacts on maerl.
- **Synthetic compounds (Pesticides/biocides/antifoul):** evaluation of biological impacts on maerl.
- **Restoration potential:** Feasibility studies on temperate maerl bed restoration techniques, including habitat enhancement.

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Data Archive Appendix

Metadata for this project is publicly accessible through Natural Resources Wales' Data Discovery Service <https://metadata.naturalresources.wales/geonetwork/srv> (English version) and <https://metadata.cyfoethnaturiol.cymru/geonetwork/cym/> (Welsh Version).

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