Cyfoeth Naturiol Cymru
Natural Resources Wales

Intertidal SAC monitoring of the non-native alga *Agarophyton vermiculophyllum* 2017-2022

Report No: 666

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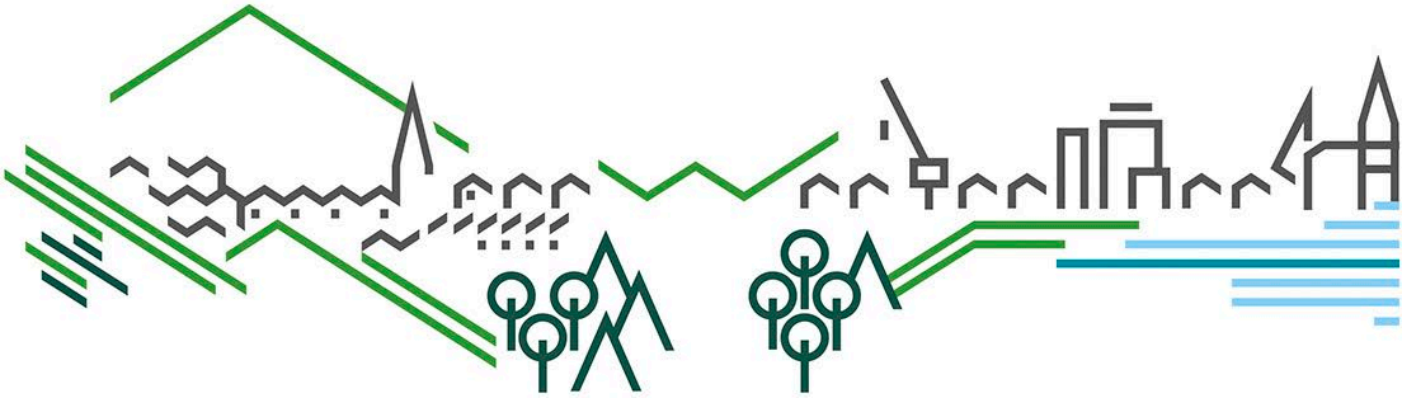
Tom Mercer and Paul Brazier

Aquatic Survey & Monitoring Ltd. and Natural Resources Wales



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Our purpose is to ensure that the natural resources of Wales are sustainably maintained, used and enhanced, now and in the future.

We work for the communities of Wales to protect people and their homes as much as possible from environmental incidents like flooding and pollution. We provide opportunities for people to learn, use and benefit from Wales' natural resources.

We work to support Wales' economy by enabling the sustainable use of natural resources to support jobs and enterprise. We help businesses and developers to understand and consider environmental limits when they make important decisions.

We work to maintain and improve the quality of the environment for everyone and we work towards making the environment and our natural resources more resilient to climate change and other pressures.

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- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
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Mae Cyfoeth Naturiol Cymru yn cynnal arolygon monitro rhynglanwol bob blwyddyn ledled Cymru mewn pum Ardal Cadwraeth Arbennig (ACA) forol. Yn 2017, yn ystod arolwg samplu gwaddodion ar wastadeddau llaid aberoedd Dwyryd a Glaslyn, canfuwyd rhai darnau bach o'r gwymon estron *Agarophyton* (*Gracilaria*) *vermiculophyllum* yng nghyffiniau Porthmadog yn ACA Pen Llŷn a'r Sarnau.

Ers 2017, mae'r rhywogaeth anfrodorol hon o facro-algâu wedi'i chanfod mewn nifer o leoliadau ledled Cymru, gan fynd yn fwyfwy toreithiog o flwyddyn i flwyddyn. Mae'r adroddiad hwn yn crynhoi'r arsylwadau a wnaed ledled Cymru ac yn ystyried ecoleg ac effaith debygol y gwymon hwn ar y gymuned fiolegol waddodol. Mae'r rhywogaeth bellach wedi'i chofnodi yn aber Malltraeth, Traeth Lafan ger Bangor, aberoedd Glaslyn/Dwyryd, Mawddach, Dyfi a Llwchwr yng Nghymru a gwelwyd ei bod yn ffurfio clystyrau trwchus hyd at 0.8 ha o faint yn aber afon Llwchwr (Cilfach Tywyn).

Argymhellir ein bod yn parhau i gasglu cymaint o wybodaeth â phosib am ledaeniad A. vermiculophyllum yng Nghymru ac yn ceisio dod i ddeall yr effeithiau'n well. Mae ganddo'r potensial i drawsnewid y cynefin Atodiad I 'Gwastadeddau llaid a gwastadeddau tywod nad ydynt o dan ddŵr môr adeg llanw isel' a'r cynefin Adran 7 'Gwastadeddau llaid rhynglanwol' yn gynefinoedd eraill, a gallai achosi niwed i'r pysgodfeydd cocos a chregyn gleision.

Executive Summary

Natural Resources Wales carries out annual intertidal monitoring across Wales in five marine Special Areas of Conservation (SACs). In 2017, during a sediment sampling survey of the sediment flats of the Dwyryd and Glaslyn estuaries, some small patches of worm wart weed *Agarophyton* (*Gracilaria*) *vermiculophyllum* were found in the vicinity of Porthmadog in the Pen Llyn a'r Sarnau SAC.

Since 2017, this non-native species of macro-alga has been found in numerous locations across Wales, with increasing density year on year. This report summarises the observations made across Wales and considers the ecology and likely impact of this seaweed on the sediment biological community. The worm wart weed is now known from the Malltraeth estuary, Traeth Lafan near Bangor, Glaslyn/Dwyryd, Mawddach, Dyfi and Loughor estuaries in Wales and has been found to form dense stands of up to 0.8 ha in the Loughor estuary (Burry Inlet).

Recommendations are to continue to gather as much information as possible on the spread of *A. vermiculophyllum* in Wales and to better understand the impacts. It has the potential to transform the Annex I habitat 'Mudflats and sandflats not covered by the sea at low tide' and Section 7 habitat Intertidal mudflat into other habitats, and can potentially compromise the intertidal cockle and mussel fisheries.

1 Introduction

1.1 Description of *Agarophyton vermiculophyllum*

Worm wart weed *Agarophyton vermiculophyllum* (*Gracilaria vermiculophylla* (Ohmi) Papenfuss) also known as rough wart or rough agar weed, is a marine non-native macroalga originally from Vietnam and west Pacific coast. Plants are dark-red to almost black (when dry), elongated with slender branched fronds growing to a length of 2 m. Attachment is by a small discoid holdfast. Branches are circular to slightly compressed in cross-section. Branching is irregular and dense with fronds tending to be widest in their central region, tapering towards the apices. Branches tend to be wrinkled and can show longitudinal grooves. The plants are cartilaginous but branches can feel elastic due to the lower parts being hollow. The growth form can vary from bushy to long and straggly. Female plants are long, poorly branched, strongly wrinkled and very thick towards the base; small hemispherical warts (conceptacles) adorn the frond surface. Male and tetrasporophyte plants are densely branched; male plants appear pale due to microscopic conceptacles on the surface. DNA analysis is required to confirm this species' identity due to physical similarities shared with a number of closely related species (GBNN 2019), however, the habitat in which they live differs and there are marked differences in appearance, compared to the native species of the genera *Gracilariopsis* and *Gracilaria*.

Figure 1 Images of *Agarophyton vermiculophyllum* in the field in the Dwyryd estuary.

Figure 2 Images of *Agarophyton vermiculophyllum* in the hand and pressed.

Large established populations were confirmed in Dorset from Brownsea Island in Poole Harbour (first record 2009) and from Christchurch Harbour (2015), a single plant was discovered in Devon in the Salcombe-Kingsbridge estuary (2015) and apparently since then it has spread throughout the south-west of England. Using satellite imagery, the start of an invasion in the Clonakilty estuary, Ireland can be dated to summer 2014 (Bermejo et al. 2020). In 2017 it was first found in the Glaslyn/Dwyryd estuaries during a Natural Resources Wales annual intertidal sediment monitoring survey of the Pen Lyn a'r Sarnau SAC at Porthmadog. The very sparse nature of the records in 2017 suggests that this was discovered early in the invasion.

The following details are taken, in part from the NNSS Information portal factsheet, last updated in October 2019: Worm wart weed Fact sheet

1.2 Invasion pathway

Aquaculture is the most likely vector for its arrival in Britain, as known locations also host Pacific oyster *Magallana gigas* aquaculture sites. Further introductions may take place by this route or through transport of fragments via shipping or leisure craft. Secondary spread around GB is likely via dispersal of vegetative fragments by currents, via fishing and leisure craft, human leisure activities, entanglement in fishing gear, migrating birds, or shellfish movements. In Sweden, spread was very rapid (150 km in 2 years) (Nyberg *et al*. 2009; Maggs & Magill 2014; Krueger-Hadfield *et al*. 2017b).

1.3 Species Status

A. vermiculophyllum is a widespread macroalgal invader in temperate estuaries of the northern hemisphere including western and eastern North America, NW Africa and Europe. The first record from the NE Atlantic was from western Germany (the Wadden Sea) in 2002 (Thomsen *et al*. 2007), and it has been present in NE Ireland since 2008 (Carlingford Lough (2008), Dundrum Bay (2012) and Strangford Lough (2013)). Large populations have been confirmed (using molecular analysis) in Dorset from Brownsea Island in Poole Harbour (2009) and Christchurch Harbour (2015).

1.4 Ecology

1.4.1 Dispersal Mechanisms

The spores and spermatia are non-motile and can only survive for up to a few days, so natural dispersal is limited. However, this species has the capacity to undergo extensive vegetative fragmentation, and these unattached fragments can grow and reproduce. As they are negatively buoyant, dispersal distance is again limited, unless facilitated by strong currents or anthropogenic means e.g. on nets and other marine equipment or shellfish movements (Weinberger *et al*. 2008; Krueger-Hadfield *et al*. 2017b).

1.4.2 Reproduction

A. vermiculophyllum can reproduce both sexually and asexually. In its native range, where it is predominantly found on rocky shores, sexual reproduction is the norm. In GB (and over most of its non-native range) vegetative propagation of tetrasporophyte (diploid) plants dominates at the sites of introduction, possibly due to the lack of hard substratum necessary for spore recruitment (Krueger-Hadfield *et al*. 2017b, Bunker *et al*. 2017). However, in Ireland all reproductive phases have been observed (Maggs & Magill 2014).

1.4.3 Known predators/herbivores

A. vermiculophyllum does not support a wide range of grazers, although some fauna may be associated with grazing the epibiota on the thallus, including periwinkles, isopods and amphipods (Thomsen *et al*. 2007; Fofonoff *et al*. 2018). More recent work has demonstrated that the plant produces chemical feeding deterrents, which can enhance the survival of fragments in the sediments (Stiger-Pouvreua *et al*. 2022).

1.4.4 Resistant stages

A. vermiculophyllum can survive several weeks of burial in sediment (Thomsen & McGlathery 2007), ice cover (Nyberg *et al*. 2009) and absence of light and immersion in water for at least five months (Nyberg 2007; Nyberg & Wallentinus 2009). Nyberg and Wallentinus (2009) found that *A. vermiculophyllum* from the west coast of Sweden could survive more than five months at 8 °C under total darkness, even with a dehydration of up to 19 %. Stiger-Pouvreau *et al*. (2022) demonstrated that fragments of the thallus that are buried up to 12 cm below the level of silty sediment remained viable and provides a reserve biomass suitable for subsequent localised blooms.

1.5 Habitat summary

In its native range, plants are predominantly attached to hard substrata such as rocks, whereas in its non-native range, including GB, this species is often found as loose-lying or entangled plants and favours sheltered estuaries and bays with mud and muddy sand sediments. Plants may attach to small shells or pebbles, but

established populations are often found in association with habitat-building benthic invertebrates, for example using the byssal threads of mussels *Mytilus edulis*, or polychaete tubes for attachment (Thomsen *et al*. 2007; Nyberg *et al*. 2009). *A. vermiculophyllum* can grow up to bloom proportions when in the presence of high nutrient levels, this has been well documented by Bermejo *et al*. (2020).

It has broad environmental tolerances, surviving at salinities from 2-45 ppt and temperatures from below 5 to 35 C (Maggs & Magill 2014; GISD 2018). It has been recorded from both cold and warm temperate waters.

1.6 Environmental impact

This species forms algal mats which can outcompete and even smother native seagrasses and modify intertidal saltmarshes (Thomsen *et al*. 2009). Once established *A. vermiculophyllum* can attain very high biomass, and these large populations may displace native species of seaweeds such as fucoids, retard settlement of native species by making substratum unavailable, and cause mortality in larval stages by reducing light and oxygen availability. This species can dominate algal assemblages. However, it may also increase biodiversity by introducing structural complexity to soft-bottomed shores, supporting grazers such as gastropods and epibiota such as red algae, and providing new refugia for mobile invertebrates (Maggs & Magill 2014; GISD 2018). Additionally, the movement, accumulation and decomposition of *A. vermiculophyllum* is likely to have important implications for nutrient cycling and trophic dynamics in areas it invades (Thomsen *et al*. 2009; Bermejo *te al*. 2020). A full review can be written by Hu & Lopez-Bautista (2014). Some of the impacts seen in Wales are described in the results section.

1.7 Economic impact

Plants can damage nets and foul propellers. In the USA power plant cooling intakes have been blocked by drift *Agarophyton* (Maggs & Magill 2014). There are likely to be influences on the cockle (*Cerastoderma edule*) beds, as a result of the changes in sediment type and smothering. Cockle gathering is likely to be compromised by the presence of excessive amounts of plant material, as well as the deleterious effects of smothering on the cockles.

2 Methodology

2.1 Monitoring survey method

Most observations of *A. vermiculophyllum* have been *ad-hoc*, during completion of regular sediment sampling surveys by the NRW monitoring team, across SACs in Wales. Soon after the initial discovery, a dedicated survey was carried out on 25th June 2018 on the south side of the Dwyryd/Glaslyn estuary to attempt to ascertain the full extent within the Morfa Harlech NNR. Numerous National Nature Reserve staff dispersed across the suitable habitats to record evidence of attached or drift plants. A standard recording form has been used, see Appendix 1

A Garmin GPSMAP 64S GPS was used to mark single locations of records of *A. vermiculophyllum* and also to track around beds of denser plants on the sediments. See Table 1 for a list of sources of records.

2.2 Search requirements

The thallus of *A. vermiculophyllum* is a long, branching cartilaginous brown-red filament up to 50 cm long. The filaments hold their own weight (cartilaginous) when held up and are particularly stretchy. It is the only alga of this form that grows in sandy and muddy sandy habitats in estuaries in Britain. This species is similar to the native species *Gracilaria gracilis* and *Gracilariopsis longissima*, although both of these will usually have small carpospores (nodules) along their length and are attached to rocks. These similar species can often be buried by sediments, since they live in sand scoured locations, but ultimately, will be attached to hard substrata. Bunker *et al* (2017) provides further details on identification.

The location, on mud and sand habitats in sheltered bays and estuaries, and the nature of the thallus, make *A. vermiculophyllum* quite distinct in the field. The thallus is softer, more compressed and with many fine branches. *Gracilariopsis longissima* and *Gracilaria gracilis* by contrast are more turgid, with a circular cross section and almost always have many cystocarps along the thallus. The branching in *A. vermiculophyllum* appears more acute (less than 45°), whilst the branching in the native species is less acute (>45°) to perpendicular.

3 Results

3.1 Distribution in Wales

Since 2017, there have been confirmed records from the Glaslyn/ Dwyryd, Mawddach, Dyfi, Loughor and Malltraeth estuaries and from Traeth Lafan, although it is almost certainly under recorded.

All locations where *A. vermiculophyllum* has been recorded are muddy sand or sand in sheltered conditions. All of the estuaries in which it has been found are macro-tidal, with typically an almost fully marine salinity, although there are many records in saltmarsh pools, particularly in the Glaslyn/Dwyryd system, where salinity and temperature will be highly variable. Such plants were probably drift, but were able to continue to survive in this habitat.

On the south side of the Mawddach estuary, *A. vermiculophyllum* has been recorded wherever surveyors have been (along a number of transects), which suggests that the alga is likely to be much more widely spread than the map indicates. The full extent of all of these sites would be required to fully quantify the spread of this alga.

Figure 3 A map of Wales showing the locations where *A. vermiculophyllum* has been recorded 2017 - 2022. Contains public sector information licensed under the Open Government Licence v3.0.

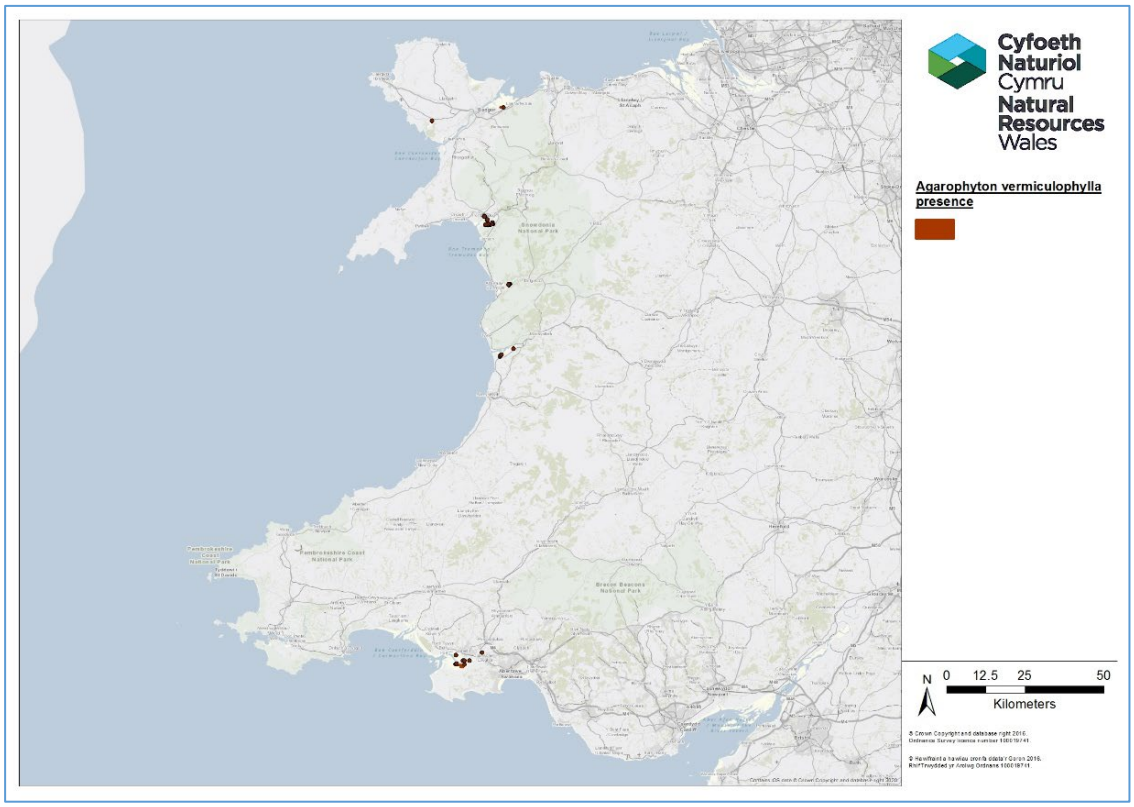


Table 1 List of surveys from which records of *A. vermiculophyllum* have been collated

Date	Survey	Locations	No of stations recorded
23/07/2017	Pen Llyn a'r Sarnau (PLAS) intertidal SAC monitoring 2017	Glaslyn/Dwyryd	3
22/05/2018	Ynys recording survey (PLAS)	Llechollwyn	11
25/06/2018	NNR staff dedicated *Agarophyton* survey	Llechollwyn	40
01-02/07/2019	PLAS intertidal SAC monitoring 2019	Glaslyn/Dwyryd, Mawddach	25
04/05/2020	Ad-hoc records (irecord)	Malltraeth	1
21/07/2020	PLAS intertidal SAC monitoring 2020	Glaslyn/Dwyryd	5
30-31/08/2020	Ad-hoc records (irecord)	Loughor estuary	2
03/09/2020	Ad-hoc records (irecord)	Loughor estuary	1
13/07/2021	PLAS intertidal SAC monitoring 2021	Dyfi	7
08-09/10/2021	Carmarthen Bay and Estuaries intertidal SAC monitoring 2021	Loughor estuary	13
13/07/2022	PLAS intertidal SAC monitoring 2022	Mawddach	9
22/07/2022	Cockle fishery Traeth Lafan seagrass survey	Traeth Lafan, Bangor	2
13/10/2022	Carmarthen Bay and Estuaries intertidal SAC monitoring 2022	Loughor estuary	8

The following maps show the locations of the current records of *Agarophyton vermiculophyllum* in Wales.

Figure 4 A map showing the locations where *A. vermiculophyllum* has been recorded in the Malltraeth Estuary, Anglesey. Contains public sector information licensed under the Open Government Licence v3.0.

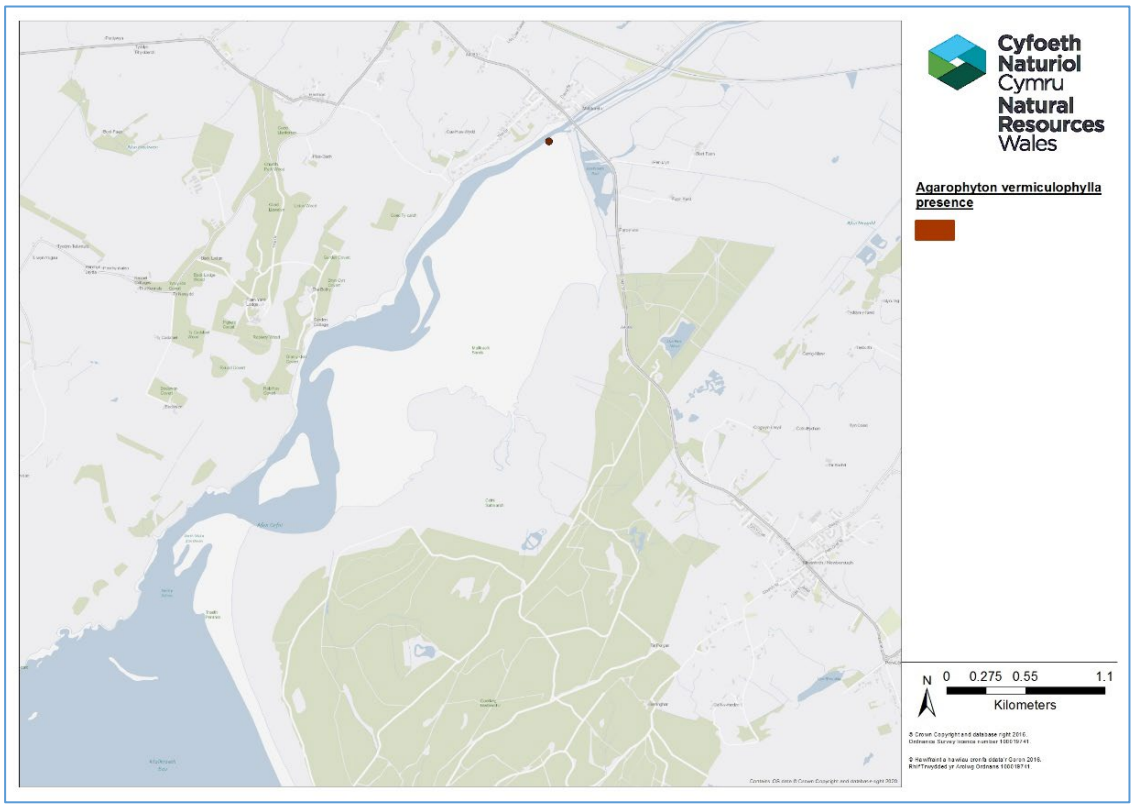


Figure 5 A map showing the locations where *A. vermiculophyllum* has been recorded on Traeth Lafan sandflats, near Bangor.

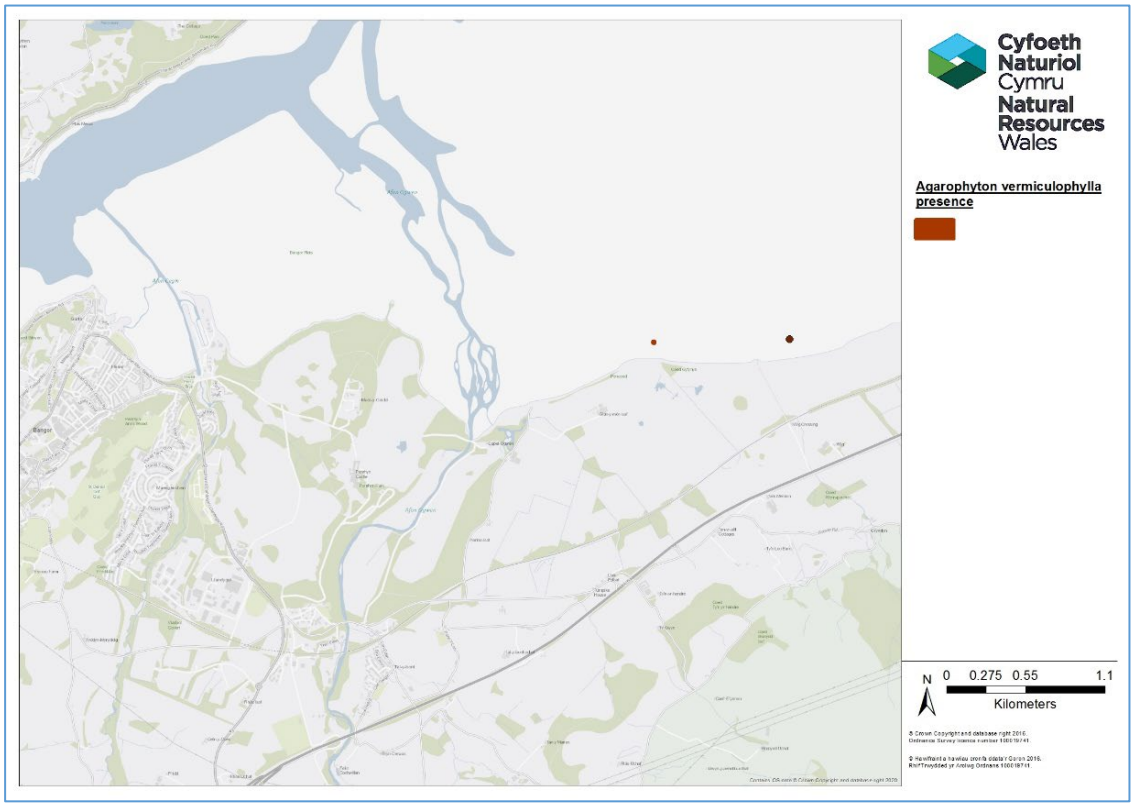


Figure 6 A map showing the locations where *A. vermiculophyllum* has been recorded in the Glaslyn/Dwyryd Estuaries.

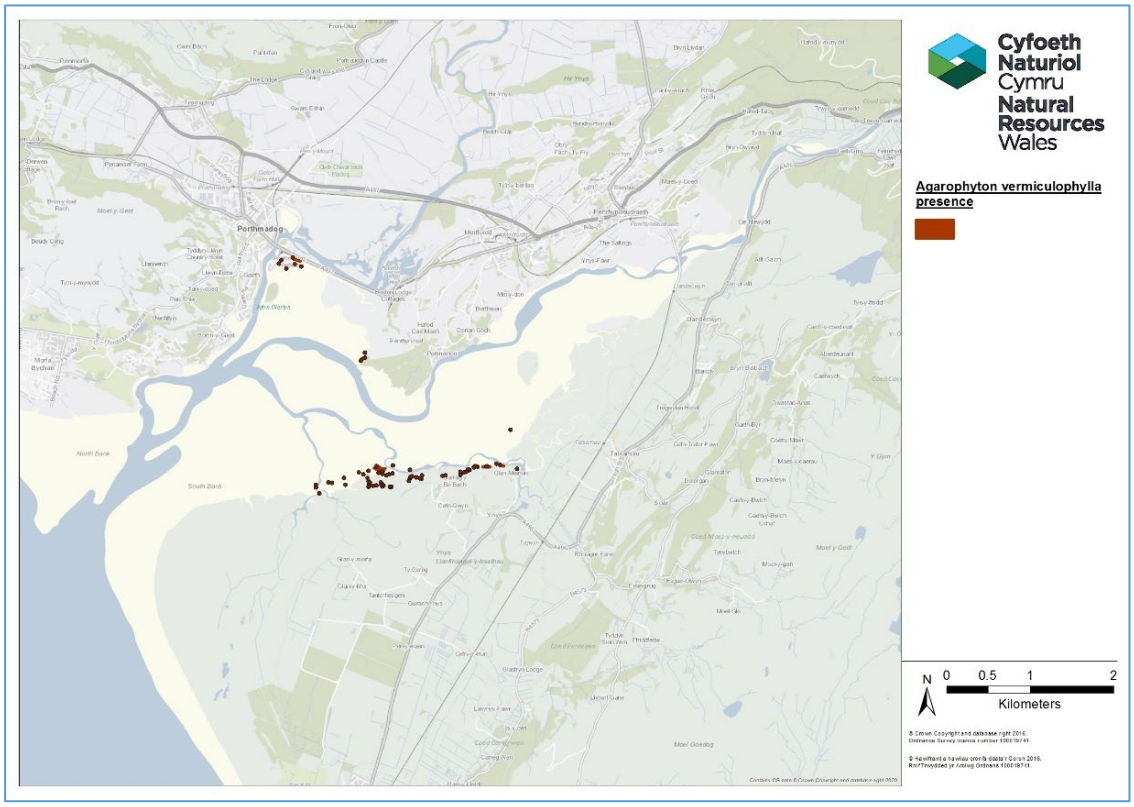


Figure 7 A map showing the locations where *A. vermiculophyllum* has been recorded in the Mawddach Estuary.

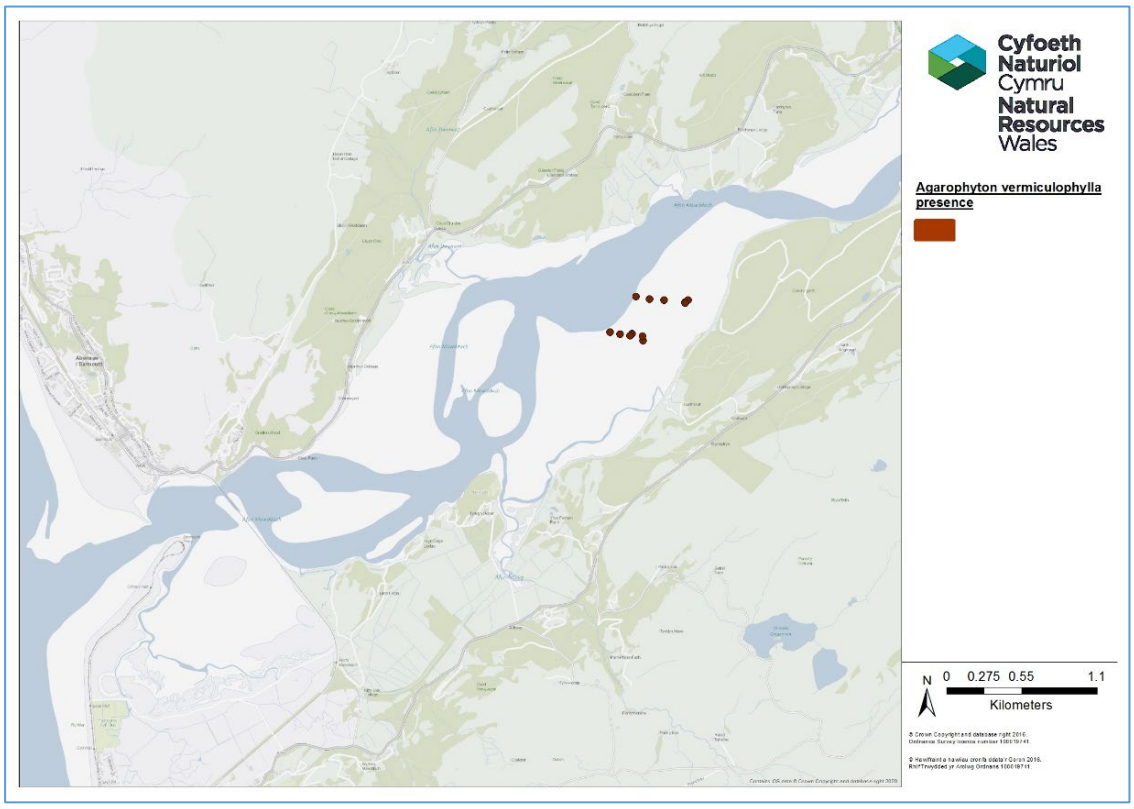


Figure 8 A map showing the locations where *A. vermiculophyllum* has been recorded in the Dyfi Estuary.

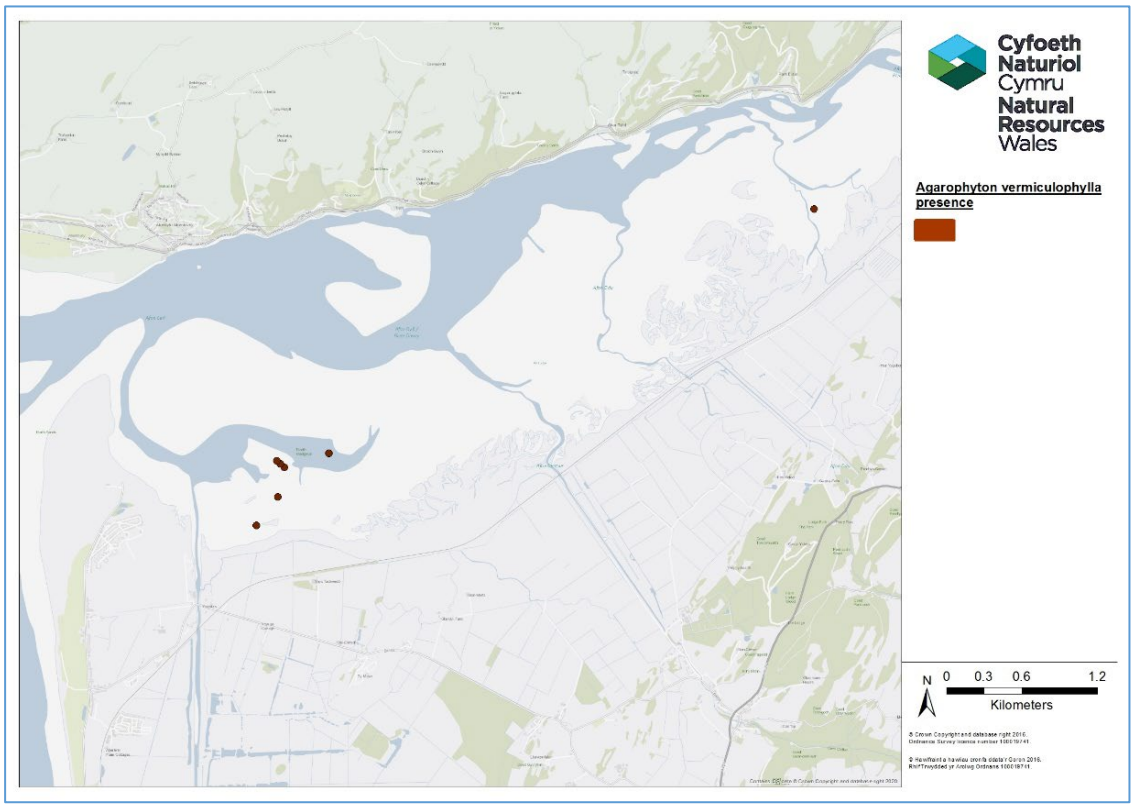
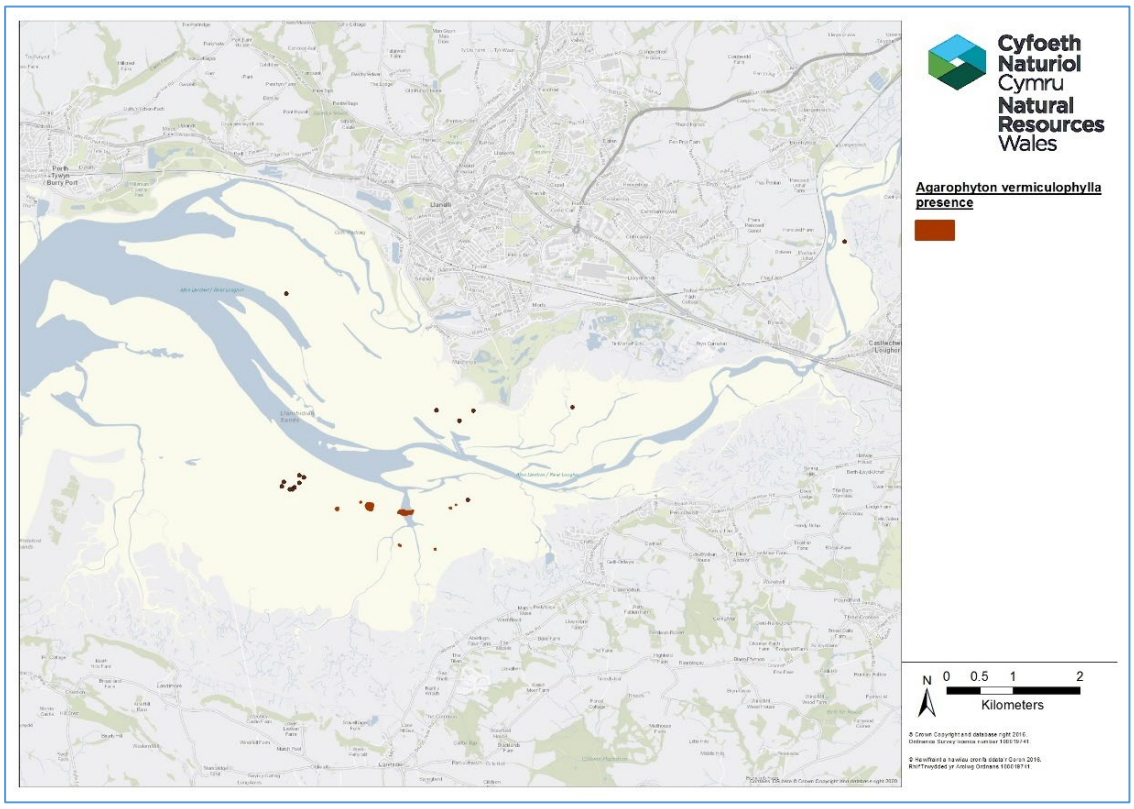


Figure 9 A map showing the locations where *A. vermiculophyllum* has been recorded in the Loughor Estuary.



In 2022, in the Loughor estuary, the extent and density of *A. vermiculophyllum* was notably much greater in places, where previously there were only a few scattered plants. The density of plants has resulted in the build-up of mud in the vicinity, as well as a settlement of *Mytilus edulis* spat and *Cerastoderma edule* spat onto the thalli. This is likely to transform the habitat into a mussel *Mytilus edulis* bed in the immediate future.

Figure 10 Images of sediment habitat typical for colonisation by *A. vermiculophyllum*.

Figure 11 *A. vermiculophyllum* at Crofty, Loughor estuary, extent and close up 2022.

4 Discussion

The establishment of *A. vermiculophyllum* in a number of estuarine systems in Wales was very rapid, with synchronised appearance in a number of locations at the same time. This suggests that there was likely a substantial and widespread cloud of propagules present around 2016/2017. The establishment, in particular, in the Loughor estuary has been notably rapid, from 2 single plants spotted in 2020, to 22 records, including 2 extensive areas (in the region of 0.88 ha each) in 2022. It is quite likely that this expansion is through localised spread of fragmented plants within the estuary system. The dramatic increase has changed the habitat to a muddier sediment and, through spat settling on the plants, potentially a future mussel bed. The capacity for *A. vermiculophyllum* to survive as buried fragments is likely to see the continued presence and probable increase in cover in the Loughor estuary. These areas have become unfishable for cockles *Cerastoderma edule*, due to the muddy nature of the habitat, the potential smothering effect on cockles and the difficulty in raking and riddling cockles when mixed in with plant material. Where high density of *A vermiculophyllum* is present, there may be a long term change from the Annex I mudflats and sandflats habitat to another habitat.

It is unclear whether the distribution, extent and biomass of *A. vermiculophyllum* elsewhere is likely to increase to a level that causes environmental and economic impact in Wales. For this reason, it is going to be important to maintain observations of the alga in the currently known locations and in other locations where it is as yet unrecorded. Due to the widespread nature of the habitat that can potentially be colonised, a number of avenues to capture records of the alga are considered, including:

- Encourage public/citizen science survey throughout Wales to report occurrences of *A. vermiculophyllum* and collate records. Shoresearch is a well-placed volunteer program that could add this species to their list of non-native species to look for.
- Collate *ad-hoc* records gained by current planned NRW and contracted surveys.
- Survey, using NRW staff or through contract, locations where *A. vermiculophyllum* would be expected to occur in the intertidal SACs of Wales.

- Ensure that *A. vermiculophyllum* is searched for on seagrass and other Section 7 habitats, and to further identify any risks to those habitats.
- Monitor sites already colonised to gain a better understanding of *A. vermiculophyllum* population dynamics in certain habitats or locations.

All of the surveyors are confident that they can differentiate this species from others, although none of the records have been confirmed by DNA testing (Maggs & Magill 2014; Krueger-Hadfield *et al*. 2017a).

Other recommendations for future work are:

- If *A. vermiculophyllum* becomes established in habitats where the native Gracilariales are also present, DNA analysis would be useful to confirm the presence of the different species.
- Unusually for an invasive species, *A. vermiculophyllum* is not concentrated on man-made structures such as ports, harbours or marinas. There is a risk therefore that standard non-native monitoring protocols do not fully consider its range and extent.
- *NRW marine and coastal evidence priorities*, which are published on the NRW website, has the evidence need "*What is the likely impact of Agarophyton (Gracilaria) on Welsh habitats and what is its likely spread in Wales?*", demonstrating the threat that this species may pose on marine protected features in Wales.

There are no management options for eradicating or controlling *A. vermiculophyllum*. Should the difficult task of removal be attempted, it is clear that the remaining biomass in fragments will result in a renewed growth the following season. The seaweed can be moved around on the tide, which also results in re-inoculation of sites within an embayment or estuary.

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Appendix 1 Proposed standard recording form

***Agarophyton vermiculophyllum* survey : Site Name: ..... Location: .....**
Surveyors:.....Date:..... Time start: ..... Weather:.....
Cloud cover: .... /8 Camera: ..... GPS: ..... Downloaded post survey Y/N

Way pt. no.	Time	Patch description (include sediment/location description,) other dominant species. Notes negatives as well as positives?	Area size L x Wm (m^2 if small)	Photo no.

Appendix 2 Data archive

Data outputs associated with this project are archived in the NRW Document Management System on server–based storage at Natural Resources Wales.

The data archive contains:

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

[B] Excel spreadsheets of data

[C] An ArcGIS layer with all records collated.

[E] A set of images from the surveys, in jpg format.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue by searching 'Dataset Titles'.