Cyfoeth Naturiol Cymru
Natural Resources Wales

Intertidal SAC monitoring of egg wrack *Ascophyllum nodosum* Lawrenny Quay 2005-2022

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Aquatic Survey & Monitoring Ltd. and Natural Resources Wales

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Crynodeb Gweithredol

Mae Cyfoeth Naturiol Cymru yn cynnal gwaith monitro rhynglanwol blynyddol ledled Cymru mewn pum Ardal Cadwraeth Arbennig (ACA) forol. Mae rhan o'r gwaith o fonitro ACAau lle ceir Riffiau yn cynnwys cofnodi niferoedd y chwysigod ar wymon codog bras *Ascophyllum nodosum* yng Nghei Lawrenni, er mwyn asesu proffil oedran y gwymon.

Mae gwymon codog bras *Ascophyllum nodosum* (Linnaeus) Le Jolis 1863 yn wymon brown mawr cyffredin, sy'n dra chyffredin ar lannau creigiog cysgodol yn y DU a gogledd-orllewin Ewrop. Mae gan y rhywogaeth ffrondau hir sydd â chwysigod aer mawr siâp wy. Mae'r rhywogaeth yn byw am gyfnod hir iawn ac mae ganddi gyfradd recriwtio isel. Mae'r chwysigen aer gyntaf yn ffurfio ar ôl tua 5 mlynedd (Kurr, 2015) pan fydd y planhigion yn dechrau aeddfedu, ac ar ôl hynny maent yn cael eu cynhyrchu bob blwyddyn (MacFarlane, 1933). Mae'r chwysigod hyn yn ffurfio rhwng mis Mai a mis Awst bob blwyddyn.

Oherwydd y gyfradd recriwtio isel, mae *Ascophyllum nodosum* yn agored i aflonyddwch sy'n niweidio'r ffrond. Mae'r astudiaeth hon yng Nghei Lawrenni yn rhoi gwybodaeth am y lleoliad penodol, ond gellir ei chymhwyso hefyd i leoliadau eraill yng Nghymru lle mae naill ai gweithgareddau rhynglanwol yn peri pryder neu lle mae A. nodosum yn dirywio.

Dengys y canlyniadau mai tua 12 oed yw oedran cyfartalog y boblogaeth *Ascophyllum nodosum* yng Nghei Lawrenni ar hyn o bryd, yn seiliedig ar linell y cyfartaledd newidiol. Mae arsylwadau eraill yn dangos dirywiad ym maint yr ardal lle ceir y rhywogaeth mewn rhannau o'r ACA (Cei Lawrenni a Gorsaf Bŵer Penfro).

Executive Summary

Natural Resources Wales carries out annual intertidal monitoring across Wales in five marine Special Areas of Conservation (SACs). Part of the Reef SAC monitoring includes the recording of bladder numbers on egg wrack *Ascophyllum nodosum* at Lawrenny Quay, to assess the age profile of the wrack.

Egg wrack *Ascophyllum nodosum* (Linnaeus) Le Jolis 1863 is a common large brown seaweed, dominant on sheltered rocky shores in the UK and northwest Europe. The species has long strap like fronds bearing single large egg-shaped air bladders at intervals. The species is very long lived and has low recruitment. The first air bladder is formed after about 5 years (Kurr, 2015) when the plants begin to mature, after which they are produced annually (MacFarlane, 1933). The formation of these bladders occurring between May and August each year.

Due to low recruitment, *Ascophyllum nodosum* is vulnerable to disturbance that damages the frond. This study at Lawrenny Quay provides information about the specific location, but can also be applied to other locations in Wales where either intertidal activities are of concern or where *A. nodosum* is declining.

The results show that the average age of the *Ascophyllum nodosum* population at Lawrenny Quay is currently approximately 12 years old, based on the moving average line. Other observations indicate a decline in extent in parts of the SAC (Lawrenny Quay and Pembroke Power Station).

1 Introduction

The Habitats Directive establishes that the management of Special Areas of Conservation (SACs) should aim to achieve favourable conservation status of habitat and species (features) listed within its Annex I and Annex II. Article 17 of the Directive requires reporting of the conservation status of those habitats and species every 6 years. For SACs in Wales, Natural Resources Wales (NRW) is responsible for that reporting. To do this NRW has developed programmes of feature condition monitoring, which include intertidal features of marine SACs. Aquatic Survey & Monitoring Ltd. (ASML) have been contracted by NRW to develop and manage the monitoring programme for these intertidal features for the period 2007 to 2026; working as a team with NRW staff.

In Pembrokeshire Marine SAC intertidal reef covers much of the coastline within the site. One of the special and unusual characteristics of the Milford Haven waterway is that it includes large amounts of rocky reef far inland towards the upper reaches of the estuary.

Reefs are an important habitat for a huge variety of species. The species and communities found on and around the reefs depends on many things, geology, aspect, topography and wave and tide exposure.

Included in the huge variety of species associated with these reefs are populations that are rare, scarce, new to science, edge of range, particularly well-developed or exceptionally good examples of their type, slow-growing, long-lived, possibly infrequently recruiting and structurally fragile. *Ascophyllum nodosum* is a dominant large seaweed on the middle-shore of the wave-sheltered shores of the Milford Haven and is both structurally fragile and infrequently recruiting and as such is an ideal target for monitoring within the intertidal communities of the SAC.

1.1 Ecology of *Ascophyllum nodosum*

Ascophyllum nodosum (Linnaeus) Le Jolis 1863 is a common large brown seaweed, dominant on sheltered rocky shores in the UK and northwest Europe. The species has long strap like fronds bearing single large egg-shaped air bladders at intervals. The species is very long lived and has low recruitment. Growth rate is generally slow in germlings but increases as the plant ages. For example, in Norway during the first year growth takes place at 0.2 cm per year, rising to 1.5 cm per year in the second year (Sundene 1973). Growth is apical. 90% of the apical elongation takes place in the 0 to 5 mm zone behind the apex. In Strangford Lough in Northern Ireland, Stromgren & Nielsen (1986) found growth rate to be maximal in the morning, followed by a continuous decline throughout the day. Stengel & Dring (1997) observed growth to be highly seasonal with low growth rates during November and December, and highest growth rates in late spring and early summer. A decline in growth in mid-summer was observed at all shore levels. The first air bladder is formed after about 5 years (Kurr 2015) when the plants begin to mature, after which they are produced annually (MacFarlane 1933). The formation of these bladders occurring between May and August each year.

Individual fronds tend to break after about 15 years, if not before, but the holdfasts of *Ascophyllum nodosum* are thought to persist for several decades from which new fronds continually regenerate. They can also coalesce over time, making it difficult to differentiate individuals without destructive sampling (Åberg 1989). Sundene (1973) found that Norwegian *Ascophyllum nodosum* also needed five years to develop into fertile plants, with first gamete production occurring in March and April.

Ascophyllum nodosum is dioecious with receptacle growth initiated in April which may take one year to become fertile. Thus, receptacles are present on the plant for 12-14 months before ripening in April to June of the following year. Gametes are released from April onwards and the release of gametes is triggered by the exposure of ripe receptacles to air overnight. Fertilisation takes place externally and zygotes settle and form a rhizoid within ten days, after this the ability to settle and attach is lost. The receptacles are then shed during the late summer (Kurr 2015).

Recruitment in *Ascophyllum nodosum* is very poor with few germlings found on the shore. The reason for this poor recruitment is unclear, because the species invests the same high level of energy in reproduction as other fucoids and is extremely fertile every year (Printz 1959). However, the reproductive period lasts about two months, much shorter than for other fucoids. Printz (1959) suggests that it must be assumed that some special combination of climatic or environmental conditions is needed for an effective recolonisation of *Ascophyllum nodosum*. The slow growth rate of germlings, which increases the chance of their being covered by diatoms or grazed by gastropods such as *Littorina*, may also help to explain the scarcity of germlings (Baardseth 1970; Lazo et al 1994, Åberg & Pavia 1997; Cervin & Åberg 1997).

Ascophyllum nodosum repeatedly sloughs its entire outer epidermis, a phenomenon not exhibited by other related seaweeds (Filion-Myclebust & Norton 1981). Despite its longevity *Ascophyllum nodosum* is generally remarkably free of epiphytes, although some epiphytic growth occurs periodically (and this is something noticed at Lawrenny Quay). Filion-Myclebust & Norton (1981) frequently observed that when the outer layers are shed, potential epiphytes including spores and germlings of other algae that had settled on the surface were discarded with the epidermis. Only the epiphyte *Vertebrata lanosa*, with deeply penetrating rhizoids, is able to maintain a hold on the thallus.

The red alga *Vertebrata lanosa* is an obligate epiphyte that occurs primarily on *Ascophyllum nodosum*. The rhizoids of *Vertebrata lanosa* penetrate the host and obtain some nutrition from *Ascophyllum nodosum*. However, the quantity of carbon obtained is minimal (Levin & Mathieson 1991).

The thalli of *Ascophyllum nodosum* can also contain an endophytic fungus, an ascomycete, *Mycosphaerella ascophylli* Cotton 1909, that penetrates throughout the thallus (Fries 1988). Garbary & MacDonald (1995) provided experimental evidence for an obligate mutualistic symbiosis where infected thalli were longer, had greater apical diameters and more apical hairs than non-infected thalli. Garbary & London (1995) also suggest that the fungus may protect *Ascophyllum nodosum* from desiccation.

2 Methodology

2.1 Location

This method is completed at a single location at Lawrenny Quay, OS grid reference SN 00867 06268 (Figure 1). Here, the sandstone reef is level, west facing extensive and covered with *Ascophyllum nodosum* (Figure 2 and Figure 3). The site is sheltered from wave action, with a moderate tidal flow and is susceptible to silt deposits on the seaweeds and rock. The sampling location is on a level bedrock platform adjacent to a small escarpment of 1.5 m height.

Figure 1 Location of the *Ascophyllum nodosum* population at Lawrenny Quay (blue arrow). Contains public sector information licensed under the Open Government Licence v3.0

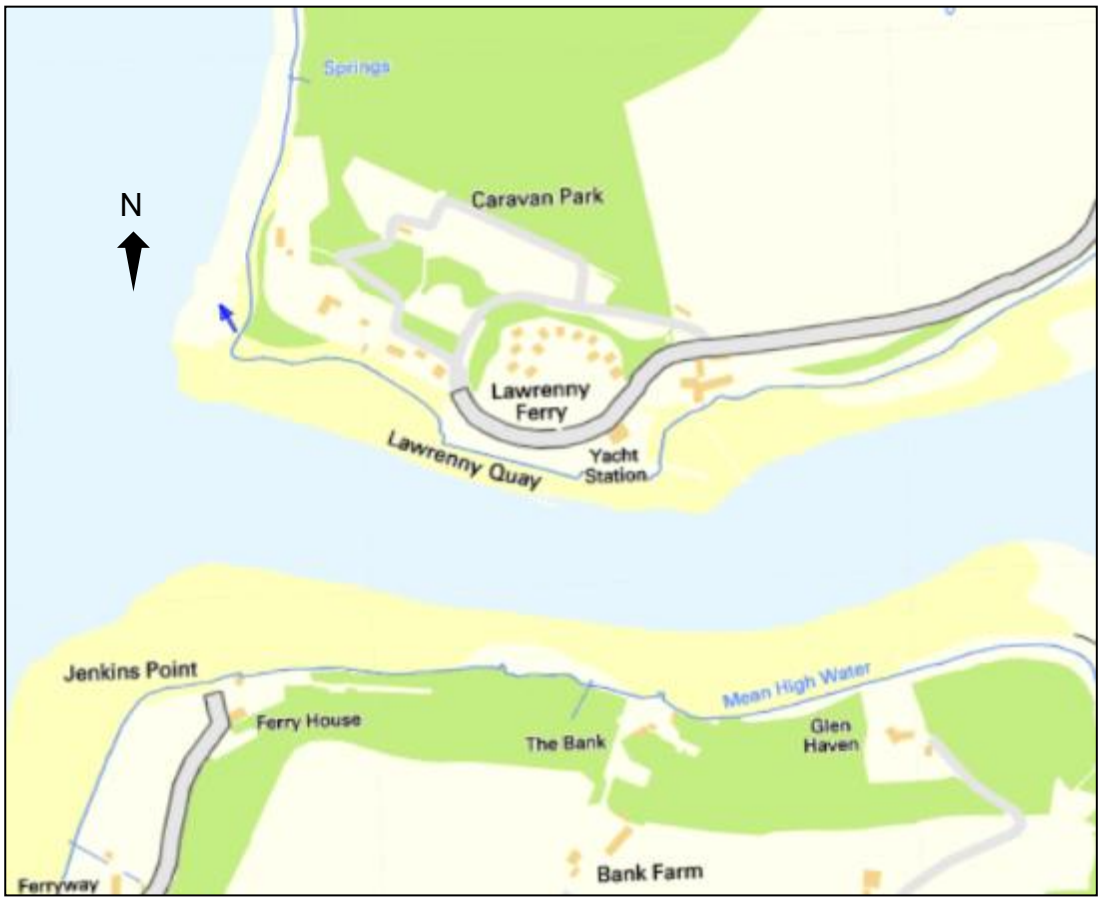


Figure 2 The bed of *Ascophyllum nodosum* viewed northwards to Castle Reach.

2.2 Survey technique

A random selection of 50+ knotted wrack, *Ascophyllum nodosum* plants have been examined annually (up until 2022). During each sampling occasion the longest intact frond of each 'clump' is carefully followed from the base to its growing tip and the bladders on the main axis of that frond are counted (= 'maximum bladder number') - Figure 4. Care must be taken not to damage the plant, since they are sometimes only loosely attached to the soft sandstone bedrock.

Figure 3 The bed of *Ascophyllum nodosum* viewed eastward to Lawrenny Quay.

Fronds can naturally be occasionally damaged and portions can be lost through grazing damage by winkles *Littorina* spp and amphipods *Idotea* spp. The position of these breakages stand out with obvious new growth occurring behind the break and these fronds are avoided during this exercise.

Figure 4 Close-up views of *Ascophyllum nodosum* at Lawrenny Quay.

2.3 Procedure

At the site, a 10m tape should be laid at random along the shore.

Starting at one end of the tape the surveyor should feel beneath the tape and beneath the mass of *Ascophyllum* lying on the shore in order to locate the first holdfast of a distinct plant.

Inspecting the holdfast, the surveyor then selects the longest intact frond emanating from it and counts all the bladders on its main axis (in newly established plants, this could be 0).

The data are recorded in the relevant box on the recording sheet.

The surveyor then progresses along the tape and selects the next distinct plant encountered beneath the tape and repeats the inspection and count.

In this way a random sample is recorded, by preventing the surveyor from choosing the plants and, minimising surveyor bias. 50+ records should be obtained.

2.4 Equipment

- 1 x 30m tape.
- 1 x Recording form on waterproof paper
- 1 x Weather writer
- PPE to protect from silty seaweed

3 Results

3.1 *Ascophyllum nodosum* bladder count data

Maximum bladder number data have been collected from Lawrenny Quay since 2005, with only a single gap in the data in 2006. Figure 5 shows the mean maximum number of bladders counted on a sample of 50+ undamaged thalli per year, with +/- standard error bars. The trend line shows a gradual increase in bladder number during this time period, although the year on year means can vary by up to 2 bladders. It is possible that this is the result of inconsistencies in the recording method. With no changes in levels of disturbance, the average number of bladders would be expected to be at a dynamic equilibrium within the population, as larger plants become detached and are replaced by younger, smaller plants.

Figure 5 Mean maximum number of bladders (+/- standard error) on the longest frond of an *Ascophyllum nodosum* plant in the middle shore at Lawrenny from 2005 to 2022.

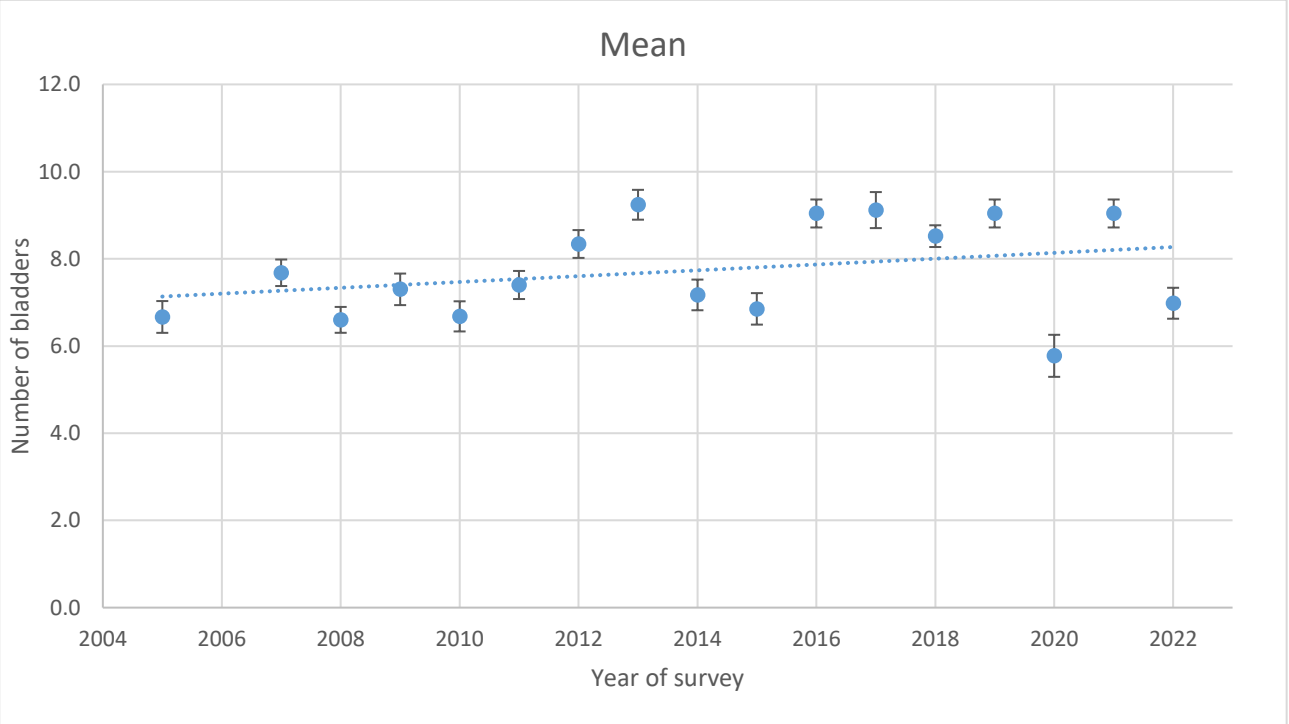
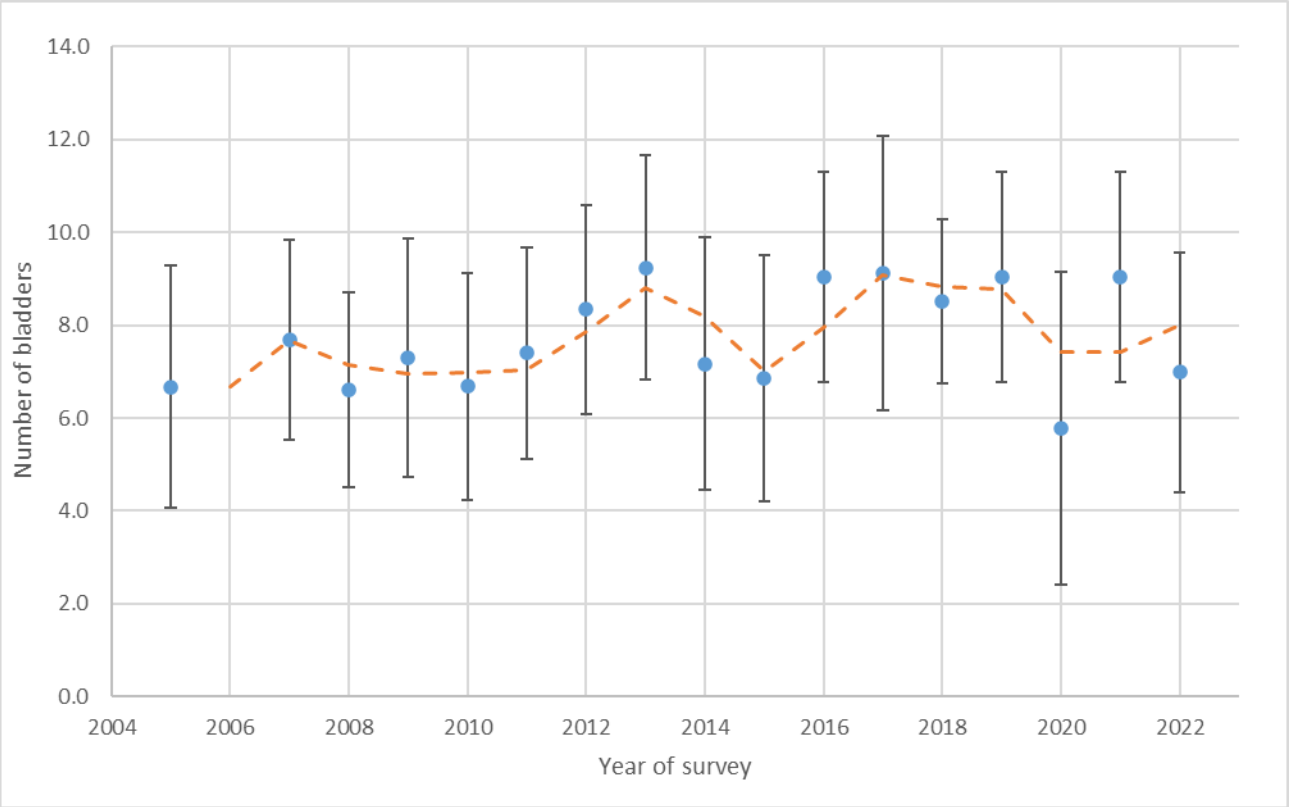


Figure 6 presents the same data along with +/- the standard deviation of each sample. The standard deviation measures the amount of variability, or dispersion, from the

individual data values to the mean value obtained on that survey, whilst the standard error of the mean measures how far the sample mean (average) of the data are likely to deviate from the true population mean. The Standard error is always smaller than the standard deviation.

Figure 6 Mean maximum number of bladders (+/- standard deviation) on the longest frond of an *Ascophyllum nodosum* plant in the middle shore at Lawrenny Quay from 2005 to 2022.



The results show that the average age of the *Ascophyllum nodosum* population at Lawrenny Quay is currently approximately 12 years old, based on the moving average line on Figure 5.

The standard recording form is presented in Appendix 1 and the raw data for the time period are presented in Appendix 2.

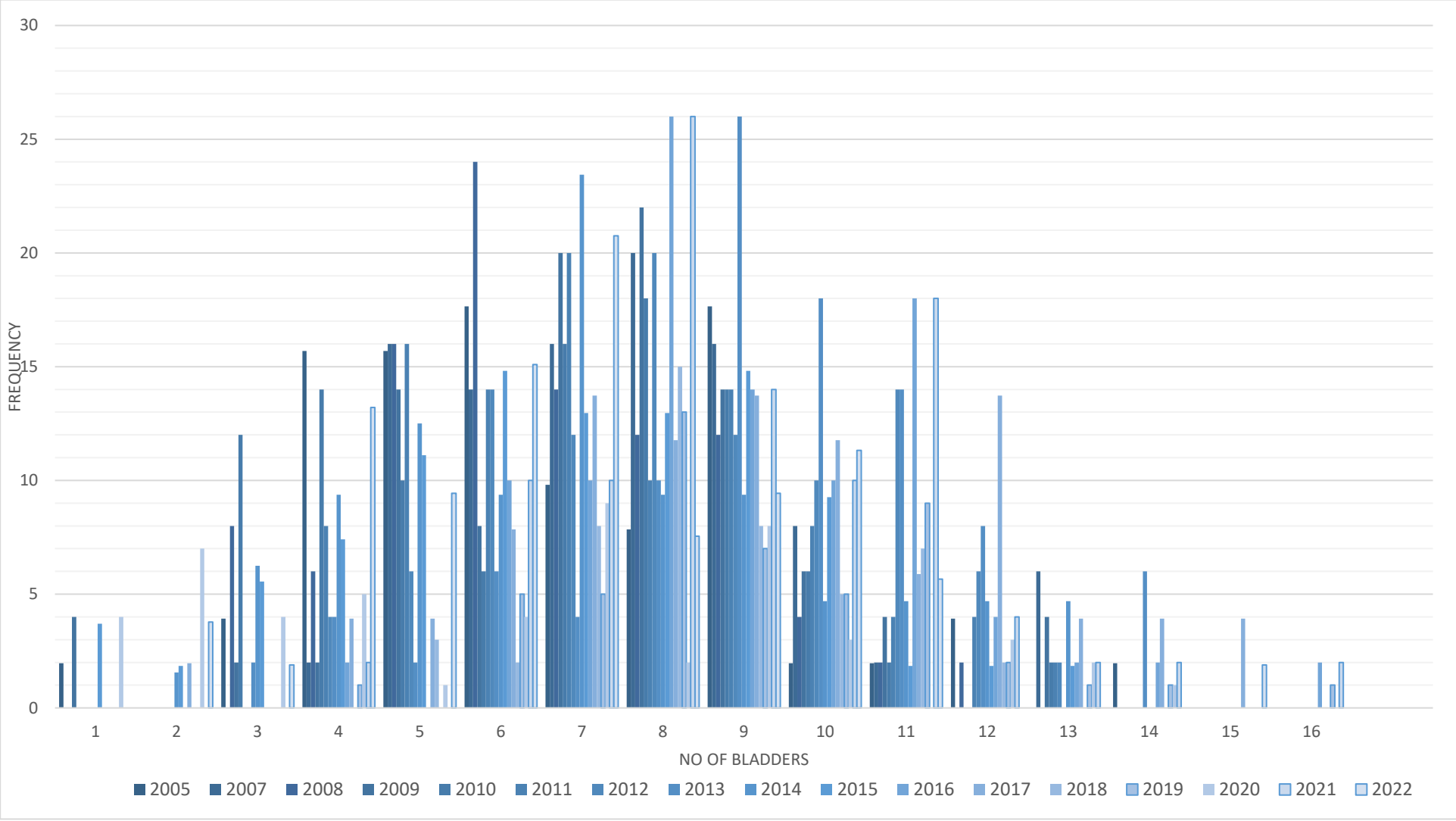
Figure *7* shows the distribution of number of bladders per plant for each year of survey.

Fronds with zero bladders were only recorded in 2020, raising concerns that this was not the protocol in other years. For this reason, the zeros have been removed from analyses. 2020 still remains lower than all other years, reflecting the lower maximum number of bladders recorded that year.

3.2 *Ascophyllum nodosum* density data

Additional data collected as part of a wider monitoring program of recording from fixed quadrats are presented here (Figure 8 and Figure 9). The measure is the average frequency (between 0 and 25 cells) across 4 quadrats at each shore height. Data are only shown for those locations where *A. nodosum* has been recorded in reasonable abundances.

Figure 7 The annual distribution of maximum bladder number within the *Ascophyllum nodosum* population at Lawrenny Quay – 2005 to 2022.



The overall trend of a decrease in average frequency of *A. nodosum* over time can be observed on the middle shore at Lawrenny Quay and the upper shore at Pembroke power station (Figure 8 and Figure 9). Images of the quadrat sites at both locations (Appendix 4, Appendix 6 respectively) as well as images of site overviews (Appendix 5, Appendix 7) visually support this trend of decreasing density of *A. nodosum* over time. Lower shore Lawrenny Quay had little difference in average frequency (Figure 8). The variability between replicates, evidenced by the large standard deviation error bars, as well as changes in frequency proving to be insignificant (Lawrenny Quay 1-way paired t-test testing whether 2005 and 2022 quadrat cell counts were the same p value = 0.20, Pembroke Power station 1-way paired t-test testing whether 2011 and 2022 quadrat cell counts were the same p value = 0.33) demonstrated further monitoring of both sites is required to explore this trend further.

Figure 8 The average frequency (+/- standard deviation) of *Ascophyllum nodosum* over 4 quadrats at Lawrenny Quay – 2005 to 2022.

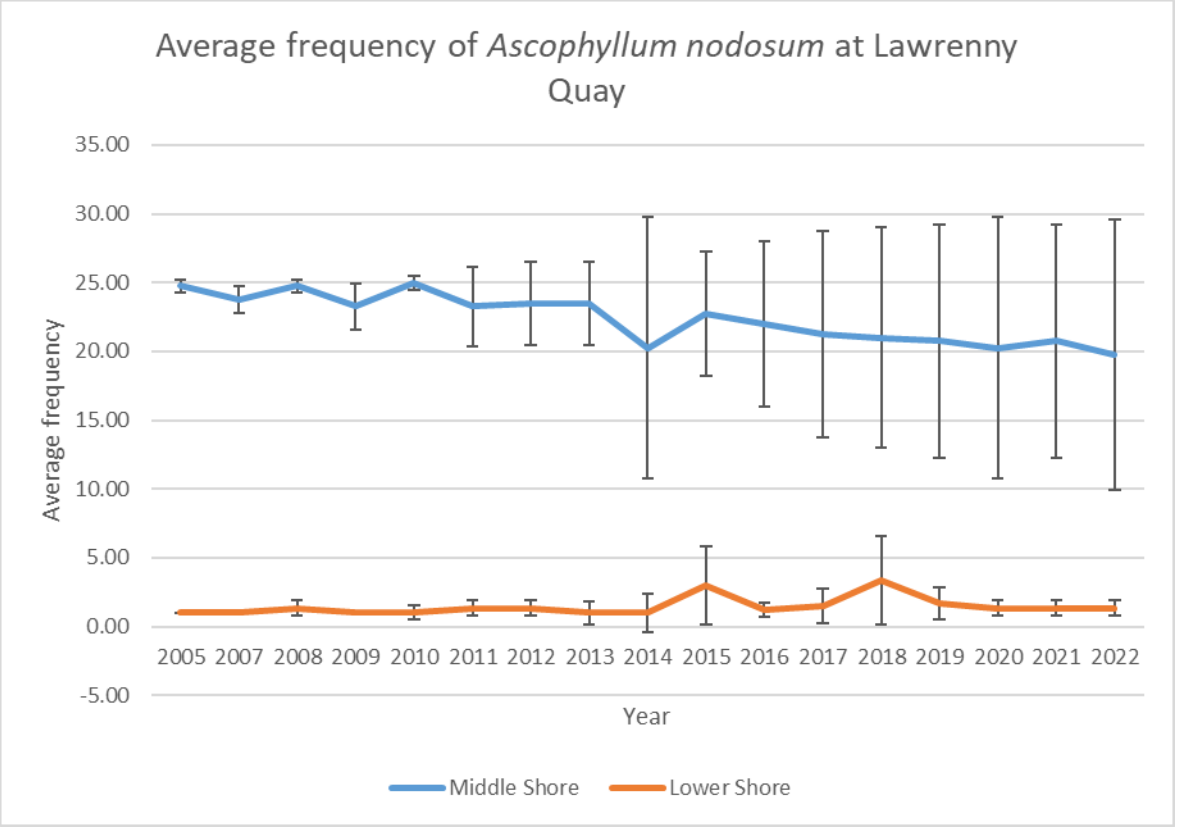
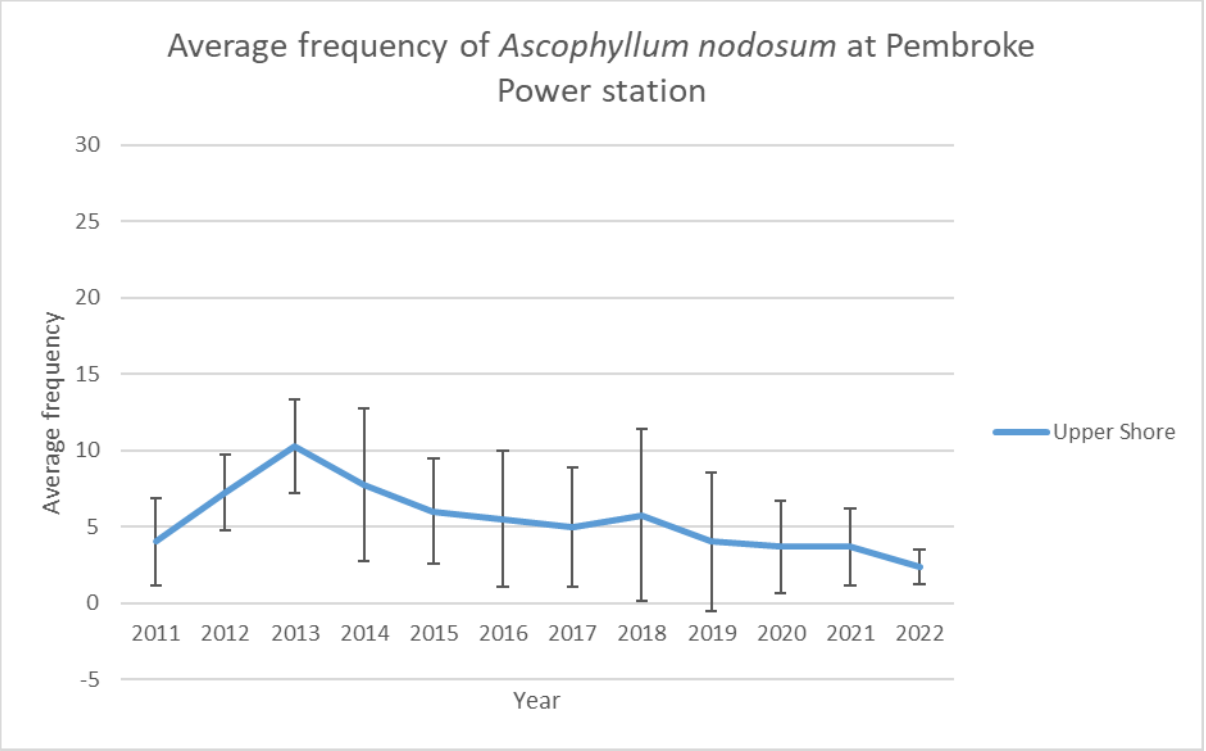


Figure 9 The average frequency (+/- standard deviation) of *Ascophyllum nodosum* over 4 quadrats at Pembroke Power station – 2011 to 2022.



4 Discussion

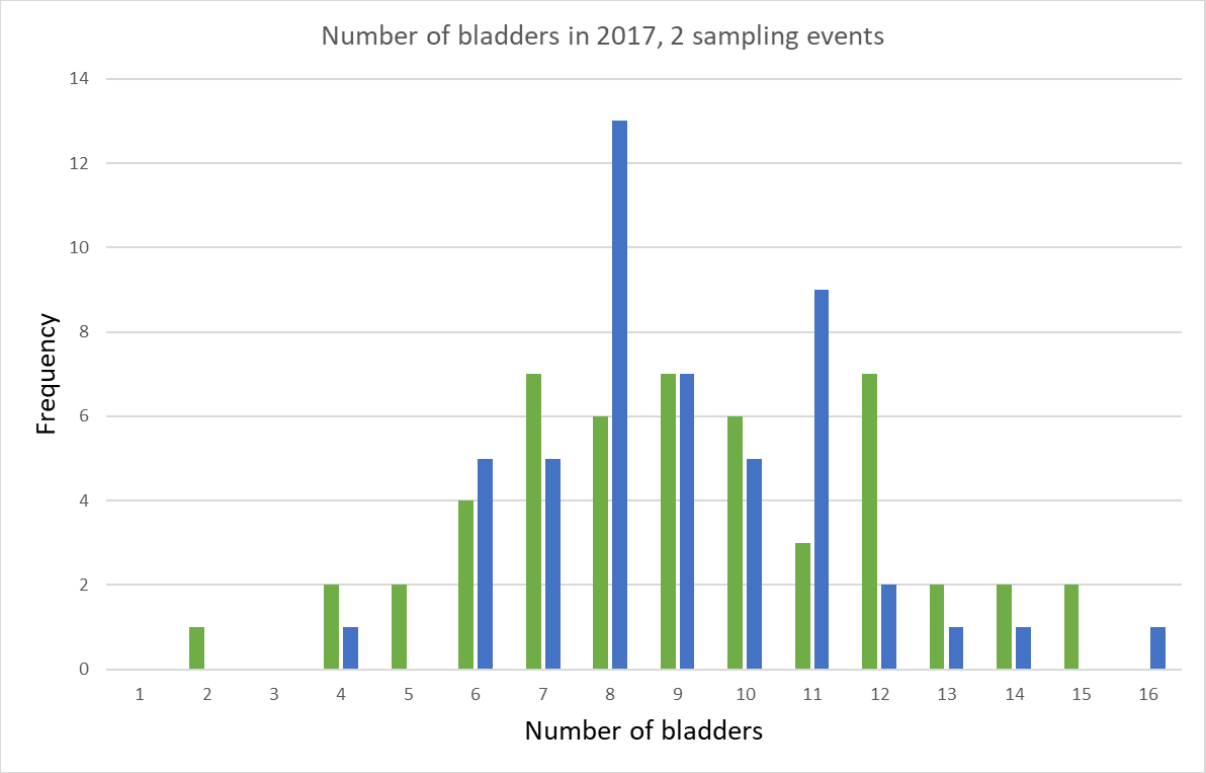
The average maximum bladder number of the *Ascophyllum nodosum* plants at Lawrenny Quay appears relatively consistent over the 17 year study time period. The trend shows a very slight increase in the number of bladders throughout the time span, but with some notable drops in maximum number of bladders recorded, on average, in 2015 and 2019. As *Ascophyllum nodosum* is known to recruit only sporadically, this pattern is not unexpected. The raw data for 2020 show considerably more 0 and 1 bladder records than the preceding years, hence a recent cohort of recruitment may account for that fact. There is some concern that in 2020, fronds with no bladders were recorded, when in other years, they were not, but the numbers with low numbers of maximum bladders in 2020 still make this an exceptionally lower year. The stability of the annual results also indicates that there are probably no new biological or anthropogenic influences acting on the population. Annual fixed point photography would also aid the monitoring assessment of this population.

The trend in decreasing density over time of *Ascophyllum nodosum* at both Lawrenny Quay and Pembroke Power Station can be seen visually (Appendix 4, 5, 6, 7). However large standard deviations amongst the frequency counts indicate that further monitoring is required to confirm if this trend is significant. *Ascophyllum nodosum* has low recruitment and is sensitive to climatic and invertebrate grazing pressures. Collecting dominant counts of *Ascophyllum nodosum* over time as well as comparing population sizes to known grazers would be useful measures for further investigation of this declining density trend.

The method used to survey *Ascophyllum nodosum* at Lawrenny Quay necessitates great care to prevent plant loss by trampling or by rough handling of tangled, matted fronds to count bladders. It necessitates being on hands and knees and is a dirty, painstaking job. It is essential that the method is carried out consistently and carefully in order to be able to compare the data collected year on year with confidence. For that reason, the detailed standard method is stated in Section 2.3.

In 2017, two sets of samples of numbers of bladders were recorded by separate surveyors to test the reproducibility of the method on the same bed of *Ascophyllum nodosum* (Figure 10). The hypothesis is that there is no effective difference between the two observed sample means. The probability of the samples reflecting the same population (mean and variance) using a Student's T-test is 0.88.

Figure 10 The number of bladders from 2 sampling events at the same bed of *Ascophyllum nodosum* conducted in 2017.



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6 Acknowledgments

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Appendix 1 PMSAC *Ascophyllum nodosum* recording form:

Ascophyllum nodosum	Surveyors:	Date:	Time start:
Weather:	Cloud: /8	Camera:	Location: SN 00867 06268

Longest intact frond bladder counts					.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.

Appendix 2 Raw data tables

Table 1 Raw data - *Ascophyllum* bladder counts: Number of bladders found on the longest frond of a 'thallus'

2005 raw data (mean= 6.67, St Dev= 2.61, St Err= 0.36)

5	5	4	6	4	6	8	6	8	6
4	7	5	14	9	12	9	12	9	9
6	4	6	4	7	9	9	4	9	4
10	5	11	5	4	3	9	5	5	7
7	8	9	6	6	6	5	3	8	7
.	.	.	.	.	.	.	.	.	1

2007 raw data (mean= 7.7, St Dev= 2.2, St Err= 0.3)

8	9	13	11	9	13	8	5	8	8
6	5	7	10	10	10	6	13	9	9
9	8	7	6	7	5	9	10	7	7
8	5	9	6	5	4	5	5	6	6
7	7	8	8	5	8	6	9	8	7

2009 raw data (mean= 7.3, St Dev= 2.6, St Err= 0.4)

7	6	6	8	11	9	10	0	3	8
9	7	8	5	8	7	5	5	5	10
7	4	7	9	13	5	11	6	9	8
8	7	13	7	9	8	5	7	7	8
5	6	7	8	9	8	8	0	9	10

2010 raw data (mean= 6.7, St Dev= 2.4, St Err= 0.3)

3	3	3	3	3	3	4	4	4	4
4	4	4	5	5	5	5	5	6	6
6	7	7	7	7	7	7	7	7	8
8	8	8	8	8	8	8	8	9	9
9	9	9	9	9	10	10	10	11	13

2011 raw data (mean= 7.4, St Dev= 2.3, St Err= 0.3)

9	12	10	8	4	7	5	9	10	10
7	11	7	9	5	6	7	5	11	9
8	9	5	4	6	8	6	7	5	9
6	4	5	7	12	8	4	6	6	7
7	8	5	10	9	5	7	6	13	7

2012 raw data (mean= 8.3, St Dev= 2.3, St Err= 0.3)

4	4	5	5	5	6	6	6	6	6
8	8	7	7	7	7	7	7	6	6
8	8	8	8	9	9	9	9	9	9
8	8	10	10	10	10	10	11	11	11
8	8	13	12	12	12	11	11	11	11

2013 raw data (mean= 9.2, St Dev= 2.4, St Err= 0.3)

3	4	4	5	6	6	6	7	7	8
9	9	9	9	9	9	8	8	8	8
9	9	9	9	9	9	9	10	10	10
10	10	10	10	10	10	11	11	11	11
11	11	11	12	12	12	12	14	14	14

2014 raw data (mean= 7.2, St Dev= 2.7, St Err= 0.3)

2	4	4	6	6	7	7	7	8	9
3	4	5	5	6	7	7	7	8	9
3	4	5	5	6	7	7	7	8	9
3	4	5	5	6	7	7	7	8	9
3	4	5	5	6	7	7	7	8	8
11	11	11	12	12	12	13	13	13	9
.	.	.	.	.	.	10	10	10	9

2015 raw data (mean= 6.9, St Dev= 2.7, St Err= 0.4)

1	1	2	3	3	3	4	4	4	4
5	5	5	5	5	5	6	6	6	6
7	7	7	7	7	7	6	6	6	6
7	8	8	8	8	8	8	8	9	9
10	10	10	10	9	9	9	9	9	9
.	.	.	.	.	.	10	11	12	13

2015 raw data (mean= 9.0, St Dev= 2.3, St Err= 0.3)

4	6	6	6	6	6	7	7	7	7
8	8	8	8	8	8	8	8	8	7
8	8	8	8	9	9	9	9	9	9
11	11	11	11	10	10	10	10	10	9
11	11	11	11	11	12	12	13	14	16

2017A raw data (mean= 9.1, St Dev= 3.0, St Err= 0.4)

2	4	4	5	5	6	6	6	6	7
8	8	8	8	7	7	7	7	7	7
8	8	9	9	9	9	9	9	9	10
12	12	11	11	11	10	10	10	10	10
12	12	12	12	12	13	13	14	14	15
.	.	.	.	.	.	.	.	.	15

2017B raw data (mean= 9.0, St Dev= 2.3, St Err= 0.3)

4	6	6	6	6	6	7	7	7	7
8	8	8	8	8	8	8	8	8	7
8	8	8	8	9	9	9	9	9	9
11	11	11	11	10	10	10	10	10	9
11	11	11	11	11	12	12	13	14	16

2018 raw data (mean= 8.5, St Dev= 1.8, St Err= 0.2)

5	5	5	6	6	7	7	7	7	7
8	8	8	8	8	8	8	7	7	7
8	8	8	8	8	8	8	8	9	9
10	10	10	10	9	9	9	9	9	9
10	11	11	11	11	11	11	11	12	12

2019 raw data (mean= 9.0, St Dev= 2.3, St Err= 0.3)

4	6	6	6	6	6	7	7	7	7
8	8	8	8	8	8	8	8	8	7
8	8	8	8	9	9	9	9	9	9
11	11	11	11	10	10	10	10	10	9
11	11	11	11	11	12	12	13	14	16

2020 raw data (mean= 5.3, St Dev= 3.6, St Err= 0.5)

0	0	0	0	1	1	1	1	1	1
3	3	3	3	2	2	2	2	1	13
3	4	5	5	5	5	6	6	6	6
8	8	8	7	7	6	6	6	6	6
8	8	8	8	8	9	9	9	11	11
.	.	.	.	.	.	.	12	12	11

2021 raw data (mean= 9.0, St Dev= 2.3, St Err= 0.3)

4	6	6	6	6	6	7	7	7	7
8	8	8	8	8	8	8	8	8	7
8	8	8	8	9	9	9	9	9	9
11	11	11	11	10	10	10	10	10	9
11	11	11	11	11	12	12	13	14	16

2021 raw data (mean= 7.0, St Dev= 2.6, St Err= 0.4)

2	2	3	4	4	4	4	4	4	4
6	6	6	6	6	5	5	5	5	5
6	6	6	7	7	7	7	7	7	7
9	9	8	8	8	8	7	7	7	7
9	9	9	10	10	10	10	10	10	11
.	.	.	.	.	.	.	15	11	11

Table 2 Raw data - Frequency of *Ascophyllum nodosum* (between 0 and 25 cells) across 4 quadrats at each shore height at Lawrenny Quay

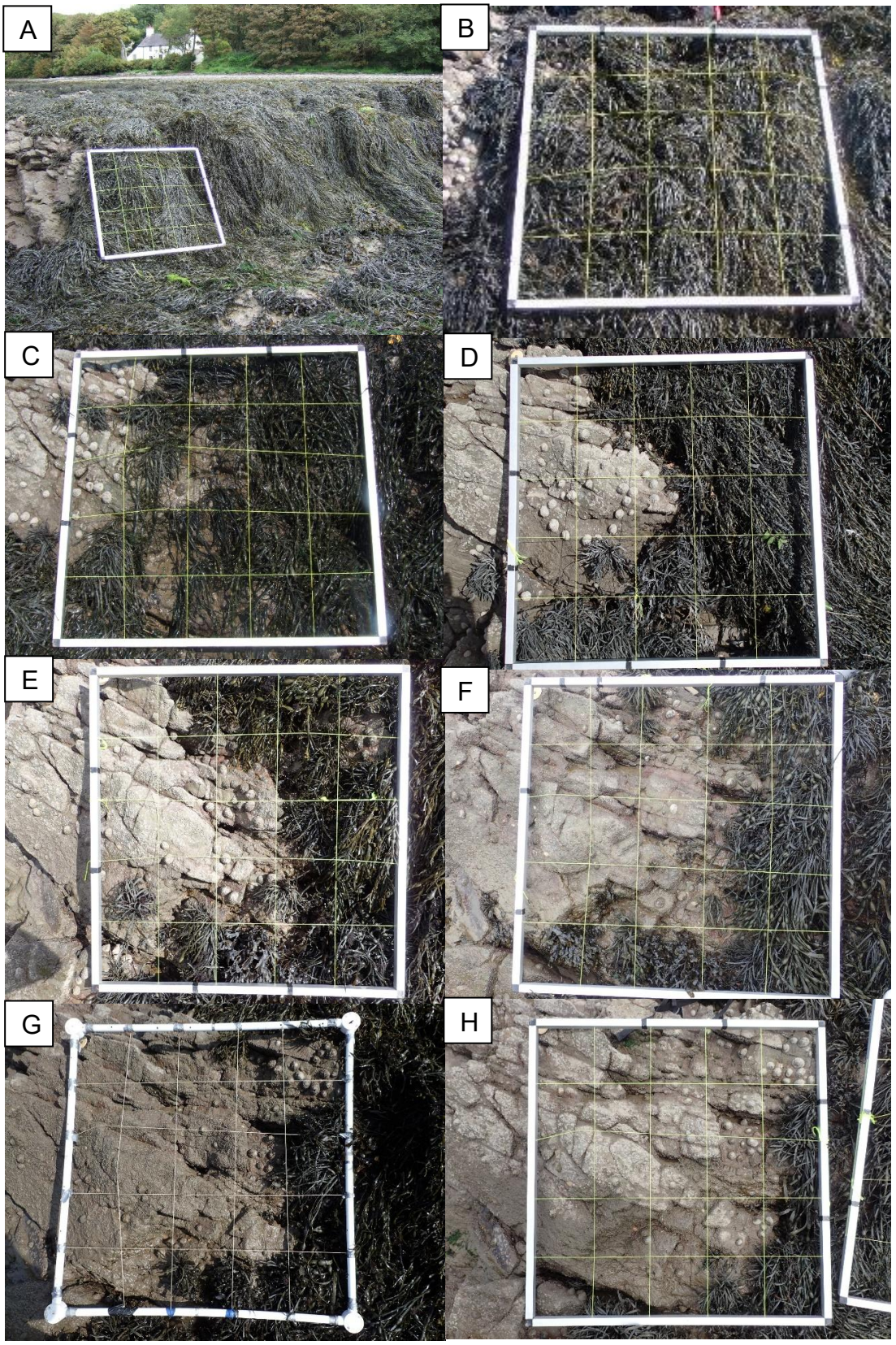
Year	Mid Shore 1	Mid Shore 2	Mid Shore 3	Mid Shore 4	Low Shore 1	Low Shore 2	Low Shore 3	Low Shore 4
2005	25	24	25	25	0	1	1	0
2007	23	23	24	25	1	1	1	1
2008	25	24	25	25	0	2	1	1
2009	23	21	24	25	1	1	1	0
2010	24	25	25	25	0	1	1	1
2011	19	25	24	25	0	1	1	2
2012	19	25	25	25	0	1	2	1
2013	19	25	25	25	0	1	2	1
2014	6	25	25	25	0	0	3	1
2015	16	25	25	25	0	5	1	0
2016	13	25	25	25	1	1	1	2
2017	10	25	25	25	0	3	1	2
2018	9	25	25	25	0	1	2	7
2019	8	25	25	25	0	1	3	1
2020	6	25	25	25	0	1	1	2
2021	8	25	25	25	0	1	1	2
2022	5	24	25	25	0	1	1	2

Table 3 Raw data - Frequency of *Ascophyllum nodosum* (between 0 and 25 cells) across 4 quadrats at upper shore of Pembrokeshire Power station site.

Year	1	2	3	4
2011	6	4	0	6
2012	8	4	10	7
2013	10	6	13	12
2014	3	4	11	13
2015	3	3	9	9
2016	0	4	10	8
2017	1	3	10	6
2018	1	1	12	9
2019	0	1	10	5
2020	0	1	7	3
2021	0	1	6	4
2022	0	1	3	3

Appendix 4 Lawrenny Quay Midshore Quadrats

Figure 11 Images of Midshore quadrat at Lawrenny Quay over time (A: 2009, B: 2011, C: 2013, D: 2015, E: 2017, F: 2019, G: 2020, H: 2022)

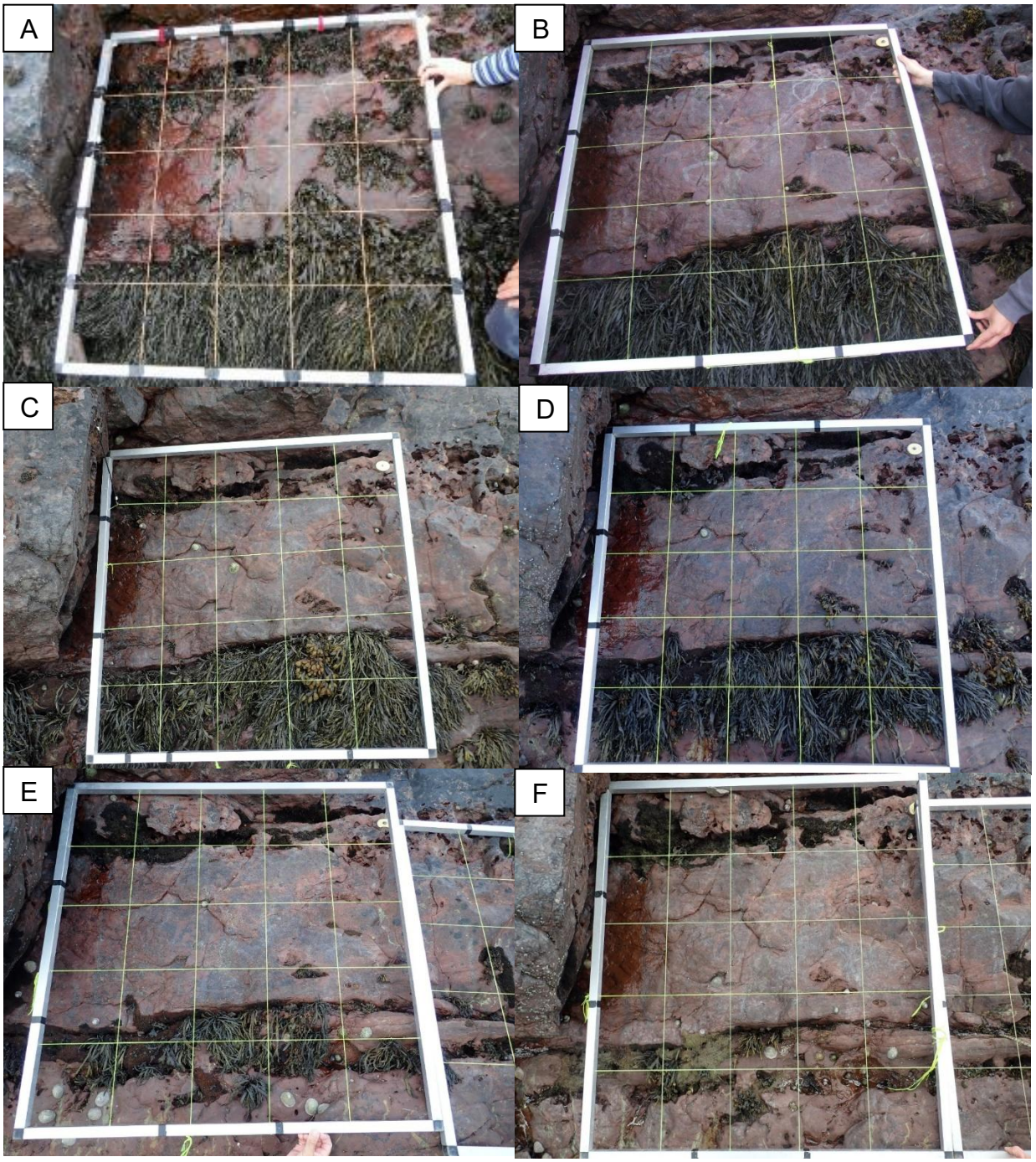


Appendix 5 Images of Lawrenny Quay Site

Figure 12 Images of Midshore Lawrenny Quay Site (Upper image: 2005, Lower image: 2022)

Appendix 6 Images of Pembroke Power Station Upper Shore Quadrats

Figure 13 Images of Upper shore quadrat at Pembroke Power Station over time (A: 2011, B: 2013, C: 2015, D: 2017, E: 2019, F: 2021)



Appendix 7 Images of upper shore Pembroke Power Station Site

Figure 14 Images of Upper Shore Pembroke Power Station Site (Upper image: 2014, Lower image: 2021)

Appendix 3 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] A set of images from the surveys, in jpg format.

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