<u>**Analysis of likely sea state at seaweed farm site**</u>

I have been asked by the SPIBG to evaluate the likely sea state at the licenced seaweed farm site in Port Isaac Bay. I have over a decade of experience evaluating climate and weather related datasets, including a PhD, and have written or co-authored over 20 peer-reviewed papers.

The context of this analysis is the MMO's guidance relating to the suitability of areas within coastal waters for suspended aquaculture schemes of this nature. This area is not within a '*strategic area of sustainable aquaculture production'*, as per the MMO Marine Plan Explorer mapping. Further, as detailed in the MMO1184 document, at page 65 (emphasis added):

> *In this study, <u>**peak wave height**</u>, for all seaweed species was considered optimal between 0-4m, suboptimal between 4-6m, and <u>**unsuitable >6m**</u>*

The text then goes on to state (emphasis added):

> *<u>**The possibility of a catastrophic loss of the farm during storm events must also be factored into the site placement, so a detailed study of the local wave climate should be considered**</u> (Capuzzo et al., 2014). In this context, the WaveNet network (https://www.cefas.co.uk/cefas-data-hub/wavenet/) provides continuous data of wave height (as well as water temperature) along the English coast.*

The Capuzzo et al. (2014) study cited in MMO1184 actually states "*The probability of catastrophic loss of the farm during winter storm events must also be factored into the site placement, and for this reason it would be necessary to study the local wave climate in more details for extremely rare maximum wave height events e.g. using WaveNet continuous data*", such that it is <u>singular maximum wave heights</u> that are the concern when considering the possibility of failure of farm infrastructure.

<u>**Scope of this analysis**</u>

This analysis, based on available evidence, seeks to assess (1) the possibility of peak wave heights exceeding 6m at the licence site, (2) the likely frequency of such an exceedance, (3) an estimate of likely singular maximum wave height and (4) comments on the implications of climate change on the sea state at the site.

Note that this analysis is reliant on the evidence discussed below. A preferable approach to assessing the likely conditions would be to model the local conditions in detail, or to install a wave buoy to provide observations. Either approach could be considered consistent with the desire to utilise a '*detailed study of the local wave climate'*, as described in MMO1184. The below analysis is therefore caveated as being informed by best available evidence. It is noted that the MyOcean data is from the application site and uses the latest available Met Office forecast/analysis model, so might be reasonably considered the best possible source of data available 'off the shelf' for such a study and here it is used in a manner consistent with Cefas' analysis as part of the Seaweed East Anglia project (2024).

<u>**Wave data in the application**</u>

The Navigational Risk Assessment (NRA) provided in the application documents includes wave data from Port Isaac (Appendix 3). There is no detailed analysis of the interpretation of this data in the NRA. The Water Framework Directive & Ecology Assessment discusses the Site Suitability. It references the Perranporth Buoy, but does not provide data from that source. The WFD states:

Data from 2009 to 2019 indicates storm frequency, wave (swell) heights and other parameters are lowest in April, May and June (harvesting). From January to March and October to December, swell and wave heights are associated with winds and storms. The average is 5 m swell, with maximums of up to 7 m swell during major storm activity. However, the location of the proposed farm is within a relatively sheltered area (protected from south westerlies due to the bay formation and location).

It not clear what the source of this data is and the application site is not sheltered from the principal swell direction. At Perranporth, the largest significant (not peak) wave heights are observed in March and exceed 8.5m. Maximum/peak wave heights substantially exceed the significant wave height. In Cefas' recent report on Seaweed in East Anglia they assumed that peak wave heights would be 1.8 times the significant wave height. Using this approximation, an 8.5m significant wave height would equate to a 15.3m peak wave height.

It is of note that Port Isaac harbour, and the wave gauge used in the application documents, are sheltered from westerly swells due to the coastline. Figure 1 shows the location of the wave gauge, which is on the western side of the harbour, and is sheltered from westerly swells by the coastline and the headland immediately to the west of the harbour.

Figure 1: Location of Port Isaac wave gauge (Source: Cefas)

<u>Wave data in this analysis</u>

The data discussed below comes from three sources – the Environment Agency's State of the Nation (SoN) dataset, Cefas' Coastal Monitoring (CM) dataset and from the Copernicus MyOcean analysis dataset. **It is requested that the MMO consults the EA and Cefas in relation to this licence and the data which (1) was provided with the application documents and (2) this analysis, in order to obtain independent comment from those data holders, given their technical expertise, on the likely sea conditions at the site of the seaweed farm**. It is noted that a recent Cefas Seaweed in East Anglia report[1], evaluating that area for sites suitable to culture seaweed, used the Copernicus MyOcean data.

The EA's SoN dataset is modelled, rather than observed, and the limitations of the data are described in the State of the Nation Phase 2 report (MCR5676-RT003-R02-00, August 2018). It is noted that Figure 4.1 of that document benchmarks offshore data against observations, demonstrating that the model may underestimate wave heights for larger waves when

[1] https://hethelinnovation.com/wp-content/uploads/2024/02/SEA_Project_Seaweed_Suitability_AnnualLR.pdf

compared to observations. The primary dataset provides ‘significant wave height’, this being the average of a highest third of waves during non-extreme periods of wave activity, and a second dataset which uses a further model to derive significant wave heights for extreme events. Both are shown here for completeness, and due to the greater uncertainty in the latter dataset.

A wave transformation model is then employed to derive nearshore wave heights. The local uncertainties relating to modelled inshore wave heights will be far greater, though Figure 4.2 in the SoN report demonstrates the adequacy of the model at a test site. The offshore data modelling employs observations from the Met Office WaveWatch III data point at site 340, which is to the west of the application site. The nearshore data discussed in this report is from site 520, in 7.97m of water, directly inshore of the application site. Again, this is for significant wave height, which is the average of the highest third of waves.

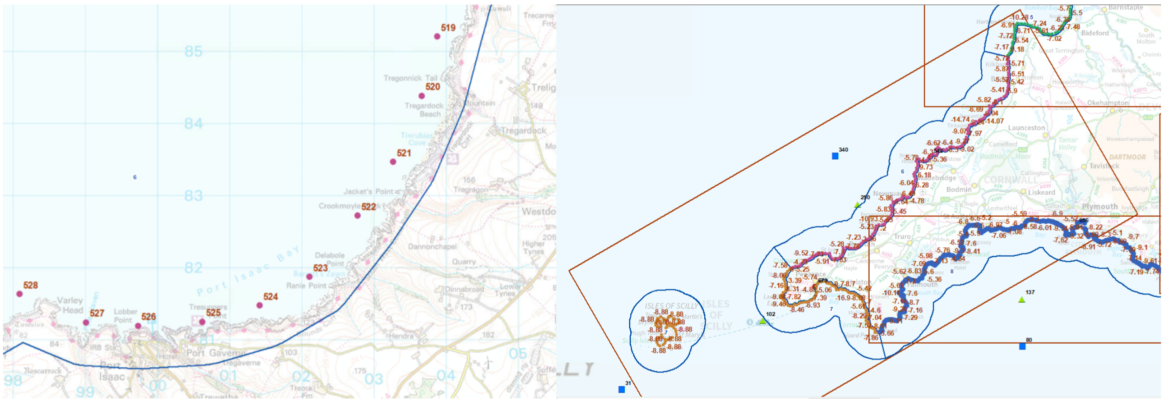

Figure 2: Left, location of site 520. Right, location of site 340.

The Cefas Coastal Monitoring station data discussed below is from the Perranporth WaveRider MkIII buoy, a site approximately 30km to the south-west of the application site, but with a similar direct exposure to westerly swell. The buoy is situated in approximately 14m of water. Data is evaluated from 2006 to the present day. For comparison, data from Port Isaac harbour wall is also provided below, from 2012 to the present day. The Coastal Monitoring data includes Maximum Wave Height, and that is what is shown here. The Port Isaac wave gauge does not have wave direction data due to the nature of the site.

The Copernicus MyOcean data is taken from Atlantic-European North West Shelf - Ocean Physics Reanalysis dataset (NORTHWESTSHELF_ANALYSIS_FORECAST_PHYS_004_013) and is at a 3-hourly interval at a 0.03 x 0.01 resolution. In the Cefas SEA analysis, the significant wave heights provided in the MyOcean data were transformed into peak wave height by multiplying the significant wave height by 1.8[2]. Data is shown from January 1980 to December 2023. The grid-point analysed here is from the application site (Figure 3). The data here is reanalysis, with necessary caveats associated with the nature of the data being modelled. It is again noted that Cefas has recently used this dataset to evaluate sea state in East Anglia, justifying its propriety for present purposes.

[2] Wave heights typically follow a Raleigh distribution, such that peak wave heights are likely 1.8-2 times the significant wave height. The Australian Bureau of Meteorology have suggested that twice the significant wave height is a reasonable estimate for likely maximum wave height.

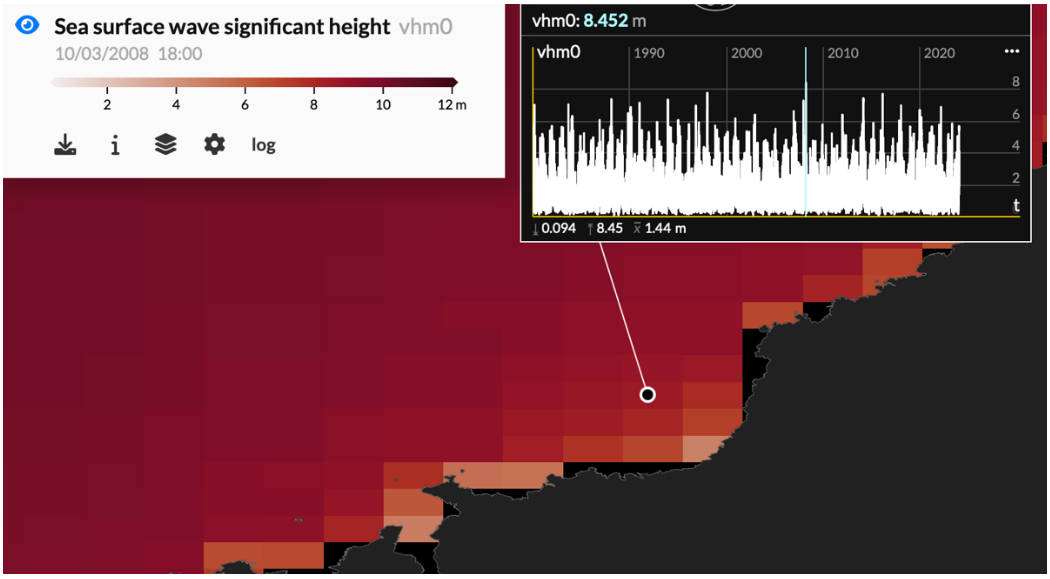

Figure 3: Location of MyOcean data used in this analysis. The image shows significant wave height from 10th March 2008 at 1800 with a timeseries of the data inset. Significant wave height was 8.45m at the analysis gridpoint, such that peak wave height (using Cefas' approach) would be 15.21m.

Evaluation of data

In Figure 4, Coastal Monitoring data from Perranporth (2006-2024) is shown. Maximum wave heights of greater than 6m are observed 2.2% of the time (a total time equivalent to 8 days per year), with the largest swells typically from the west. Average wave heights also exceed 6m.

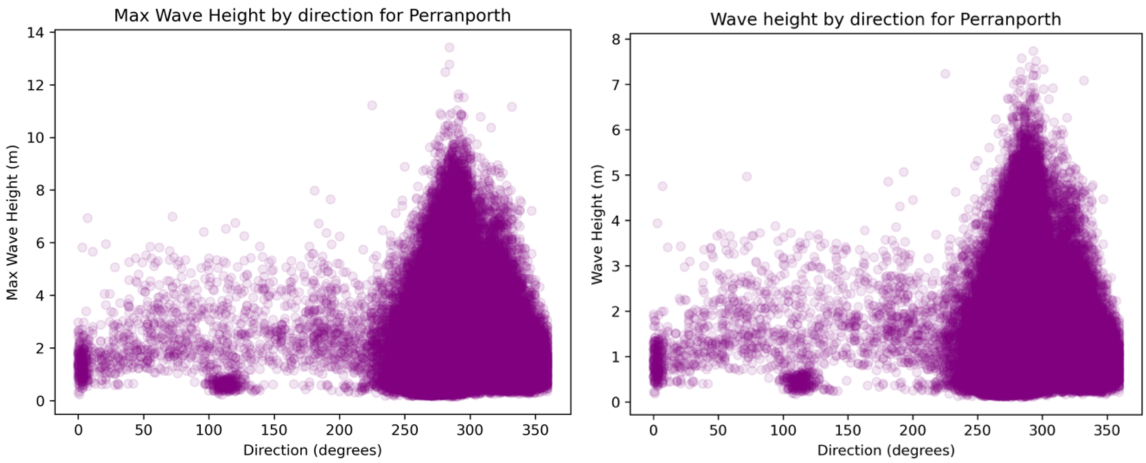

Figure 4: Left, Maximum wave height (m) vs Wave Direction (degrees) for Perranporth. Right, Mean Wave Height vs Wave Direction for Perranporth.

In Figure 5, wave data for Perranporth and Port Isaac is shown (without direction). It is evident that both maximum and mean wave heights at Perranporth are over twice the height of those at Port Isaac. Given the largest wave heights at Perranporth are typically westerly (Figure 4), the fact Port Isaac is sheltered from westerly swells likely explains a large part of this difference (Figure 1). In addition, the buoy is in deeper water rather than attached to a harbour wall, where the local bathymetry will have attenuated wave energy on approach to the shore.

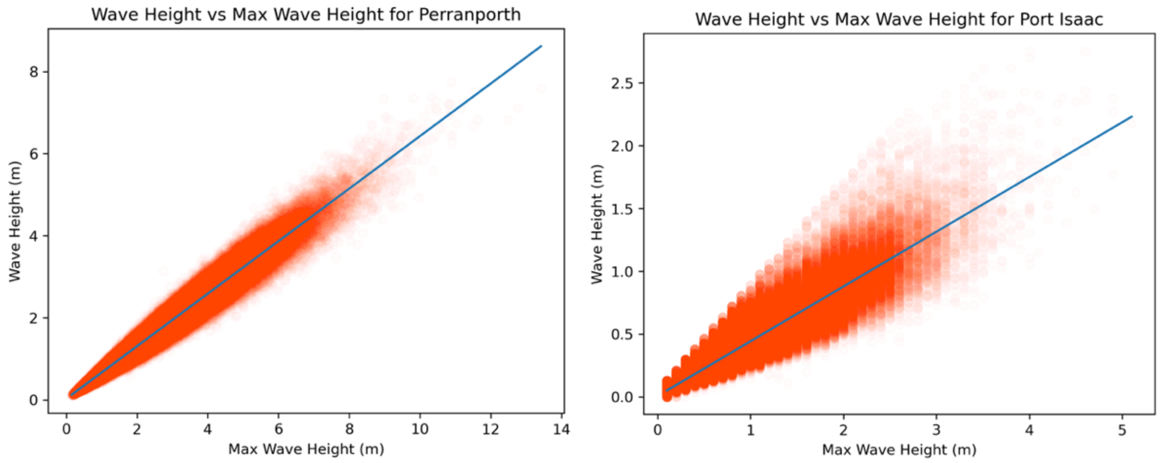

Figure 5: Maximum wave height vs wave height (m) for (left) Perranporth and (right) Port Isaac.

Figure 6 shows data from the EA SoN dataset. Figure 5 shows the modelled significant wave heights for extreme events ('samples') and significant wave heights for non-extreme events ('lower peaks'). The significant wave heights during extreme events reach up to 12m (note the maximum wave heights, using the assumption of a transformation by 1.8, would exceed 21m). Combining the two datasets, as the EA suggest for analysis, shows that significant wave heights exceed 6m in 5.7% of the total number of samples (equivalent to 21.5 days per year). Using the Cefas approach of multiplying significant wave heights by 1.8 would yield maximum wave heights exceeding 6m for over 23% of the total number of samples (equivalent to over 86 days per year).

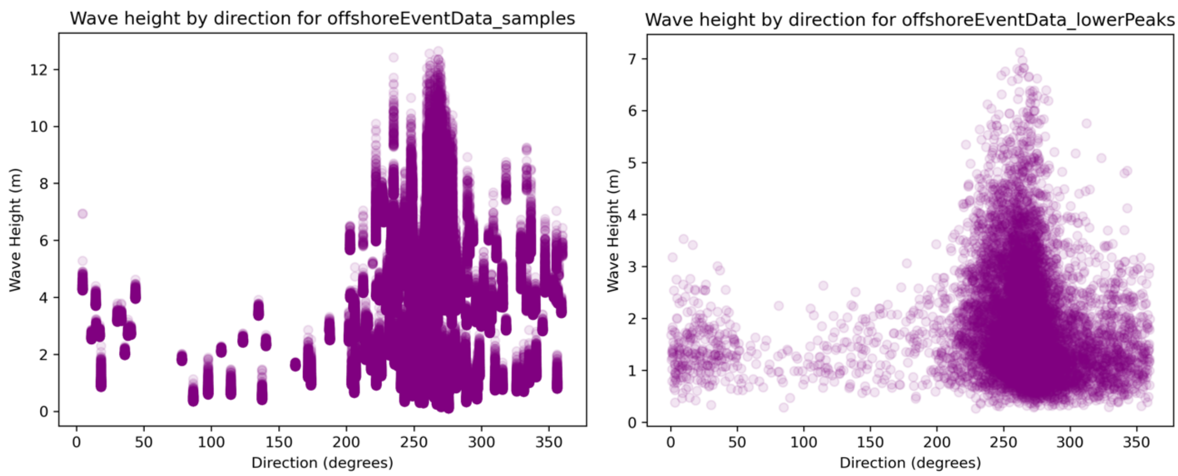

Figure 6: Offshore data showing (left) modelled significant wave height for extreme events (m) vs direction (degrees) and (right) significant wave height vs direction for non-extreme events.

Figure 7 shows data from location 520, inshore of the seaweed farm site at Tregardock, in 7.97m of water. This data is for significant wave height only, and the significant wave height exceeds 6m 0.7% of the time (equivalent to 2.5 days per year). The frequency with which peak wave height would exceed 6m would be greater, but again cannot be accurately quantified with the available data. Using a transformation of multiplying the data by 1.8, as Cefas have recently done in the SEA project, would give a maximum wave height exceeding 6m over 13% of the time (equivalent to 49 days per year). Figure 7 also shows wave period against direction, since the energy in a wave is proportional to both height and period. The longest period swells are typically westerly, as expected given the westerly direction of the largest waves. This suggests the highest energy, and potentially most damaging waves, would be westerly, but to quantify and evaluate this for the seaweed farm site would require a more detailed and site-specific analysis. It further exemplifies that the Port Isaac wave gauge is not a representative site to assess the seaweed farm site conditions, since Port Isaac is sheltered from the large and high-energy swells.

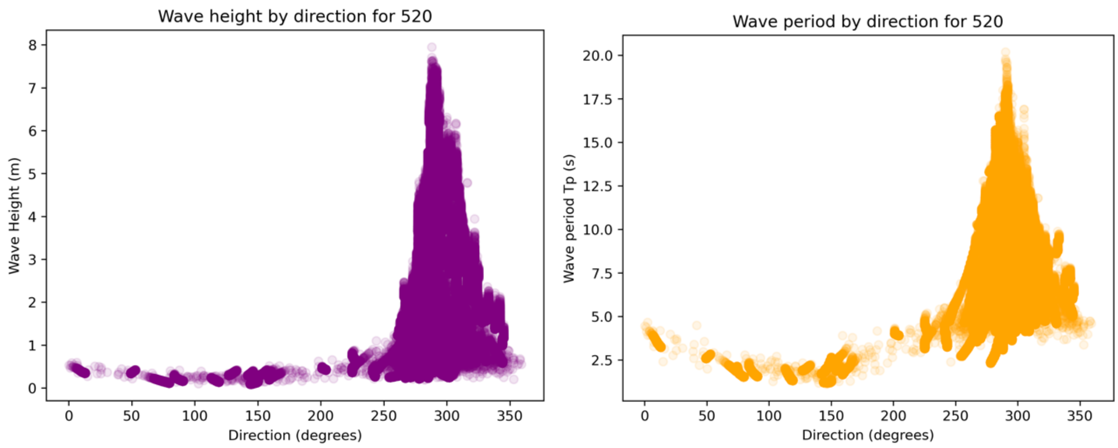

Figure 7: Left: Significant wave height (m) vs direction (degrees) for site 520 and (right) period (seconds) vs direction.

Figure 8 shows the Copernicus MyOcean data from the application site. Following the approach used by Cefas for Copernicus data in East Anglia, the significant wave height has been transformed into peak wave height yy multiplying the data by 1.8. The farm site experiences maximum wave heights in excess of 6m for 4.3% of all data points since 1980. Maximum wave heights in excess of 10m are experienced most years.

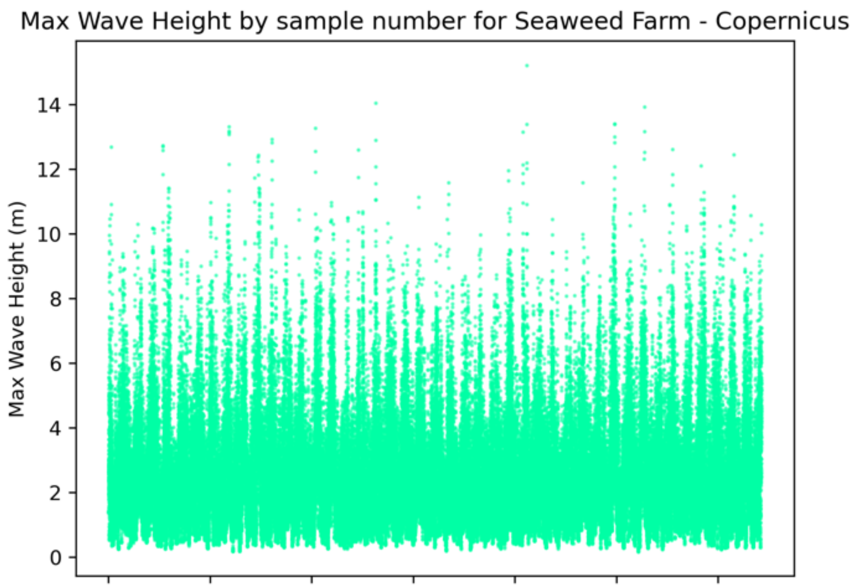

Figure 8: Timeseries of maximum wave heights (m, 1980-2023) at the seaweed farm site from Copernicus MyOcean dataset.

<u>Implications for wave height at the seaweed farm site</u>

Having already noted the caveats of this analysis, and the need for proper site-specific analysis in order to fully assess the wave heights and sea state, the following statements represent a summary position based on the best available data, which is discussed above. It is of note that the UK Marine Policy Statement requires that a precautionary approach is required to the assessment of evidence. The evidence evaluated here provides considerable a considerable base upon which to premise the below conclusions. If these conclusions are to be rebutted, then should rebuttal should be premised on accurate, quantified and site-specific evidence.

What is the possibility of peak wave heights exceeding 6m at the licence site?

It is indisputable that the available evidence indicates that peak wave heights will exceed 6m at the application site. Exceedance of this threshold occurs in the observed data at Perranporth 2.2% of the time. The two EA modelled datasets both exceed this threshold, including the inshore data which is significant wave height rather than peak wave height, which would be far greater. The Port Isaac dataset is not representative of the application site due to the fact it is both sheltered from westerly swells and attached to a harbour wall. Whilst Perranporth is further away from the seaweed farm site, it has more comparable characteristics and is therefore a preferable baseline dataset for analysis. The Copernicus modelled data further supports these conclusions, with a 6m max wave height exceedance over 4% of the time series, and has been utilised by Cefas in other studies, indicating it is an appropriate dataset to rely on for this analysis.

What is the likely frequency of such an exceedance?

This is a far more difficult question to answer given the nature of the available data. It is reasonable to assume that waves exceeding 6m would pass through the seaweed farm on multiple occasions each year, associated with the passage of storms. Such a conclusion is consistent with the Copernicus data from the seaweed farm site, where 10m maximum wave heights are indicated most years.

Many of these storms, and the largest observed wave heights, occur in winter and spring, with the largest significant wave heights recorded at Perranporth in March. It is of note that on 9th April this year, maximum wave heights at Perranporth reached 9.5m during Storm Kathleen, with significant wave heights exceeding 6.5m, and the seaweed farm site would likely have experienced similar conditions during that event.

What is the likely peak wave height at the seaweed farm site?

This is a difficult question to answer with the available data, but it would be reasonable to assume that waves in excess of 10m pass through the seaweed farm site, particularly given the evidence from the Copernicus reanalysis data. It is noted that the energy per square metre of water associated with waves scales approximately as the square of wave height, so waves of 10m have around 3 times the energy of waves of 6m and 15m waves have around 6 times the energy. In addition, the lateral forcing from depth limited (or breaking) waves considerably enhances the forcings on any infrastructure situated where such waves are present.

The upper limit of the sort of "*extremely rare maximum wave height events*" referenced in Capuzzo et al. (2014) are impossible to estimate, particularly given the 25-year lifetime of the licence, but the available evidence in this analysis includes maximum wave heights in excess of 15m at both Perranporth and the seaweed farm site, with waves up to 21m offshore. The possibility of waves in the range of 15m+ cannot be excluded at the seaweed farm site.

What are the implications of climate change for the sea state at the site?

In a warming climate, available data from climate models does not provide consistent evidence in relation to potential changes in mean wave heights. Peak wave heights are associated with storm events. The implications for extreme wave heights at any given location depend on the response of the storm track and jet stream to climate change. In a warming climate, extreme storm events, in the UK and North Atlantic, are expected to become more intense and frequent[3] and it is these storms that drive extreme peak wave heights. It is therefore likely that peak wave heights will increase in the future at this site. It is not possible to quantify the magnitude of these increases the data available in this analysis, but using a risk-based precautionary approach, any proposal should, at minimum, demonstrate is it robust to present conditions, and establish the likelihood of those conditions changing during the lifetime of the project. No such analysis was undertaken prior to this licence being granted.

It is requested that Cefas and the Environment Agency are consulted in relation to this licence, the data provided in the application, and the analysis undertaken here to ask whether they support these conclusions.

Dr. Matt Hawcroft

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[3] e.g. Catto et al. (2019) https://link.springer.com/article/10.1007/s40641-019-00149-4; Little et al. (2023), https://www.nature.com/articles/s41467-023-40102-6; Manning et al. (2024) https://www.sciencedirect.com/science/article/pii/S2212094724000343