NCEA Natural Capital and Ecosystem Assessment | UK PELAGIC HABITATS EXPERT GROUP

Detection of UK HAB hotspots from satellite ocean colour – interim report

Matthew M. Holland[1], Lawrence Sheppard[2], Tiago Silva[3], Michelle Devlin[3], Naomi Greenwood[3], Lenka Fronkova[3], Dimitry van der Zande[4], Eileen Bresnan[5], Mike Best[6], Abigail McQuatters-Gollop[1]

1. Marine Conservation Research Group, University of Plymouth, Drake Circus, Plymouth, PL4 8AA, UK
2. Marine Biological Association (MBA), The Laboratory, Citadel Hill, Plymouth PL1 2PB, UK
3. Centre for Environment, Fisheries and Aquaculture Science (Cefas), Pakefield Road, Lowestoft NR33 0HT, UK
4. Operational Directorate Natural Environment, Royal Belgian Institute of Natural Sciences, 1000 Brussels, Belgium
5. Marine Directorate of the Scottish Government, 375 Victoria Road, AB11 9DB, Aberdeen, Scotland, UK
6. Environment Agency, Quay House, Floor 6, 2 East Station Road, Fletton Quays, Peterborough, PE2 8YY, UK

Updated: February 2025

Executive summary

As an extension of the NC34 Pelagic Project (PEL-CAP) of Defra’s Marine Natural Capital and Ecosystem Assessment (mNCEA) programme, the UK Pelagic Habitats Expert Group (PHEG) has been tasked with using satellite data and statistical approaches to identify coastal areas in UK waters that experience the greatest risk of regular high biomass algae bloom events. These events occur frequently offshore and are an important part of the boom-and-bust seasonal dynamics which fuel the marine food web. However, particularly when they occur in coastal areas, these events can generate hypoxia, and unsightly “red tides” requiring the closure of bathing waters and the cessation of shellfish aquaculture harvest to protect human health, impacting ecosystem services.

As a preliminary study to test proof of concept, our objective was to map the geographic distribution of regularly occurring blooms around the southwest of England (as indicated by satellite ocean colour remote sensing data for UK waters; **Figure 1**). These repeatable, regular patches, have natural capital reporting potential, and can reveal areas where routine plankton monitoring should be prioritised. Once the algorithm for processing the satellite data has been developed, the analysis will be scaled up to cover the whole of UK waters and a Shiny web app will be developed, and hosted on the Plankton & People website, allowing users to explore seasonal maps of bloom risk across UK waters.

Please cite as:
Holland, M. M., L. Sheppard, T. Silva, M. Devlin, N. Greenwood, L. Fronkova, D. van der Zande, E. Bresnan, M. Best and A. McQuatters-Gollop (2025). Detection of UK HAB hotspots from satellite ocean colour – interim report. Defra mNCEA Programme - Pelagic Natural Capital.

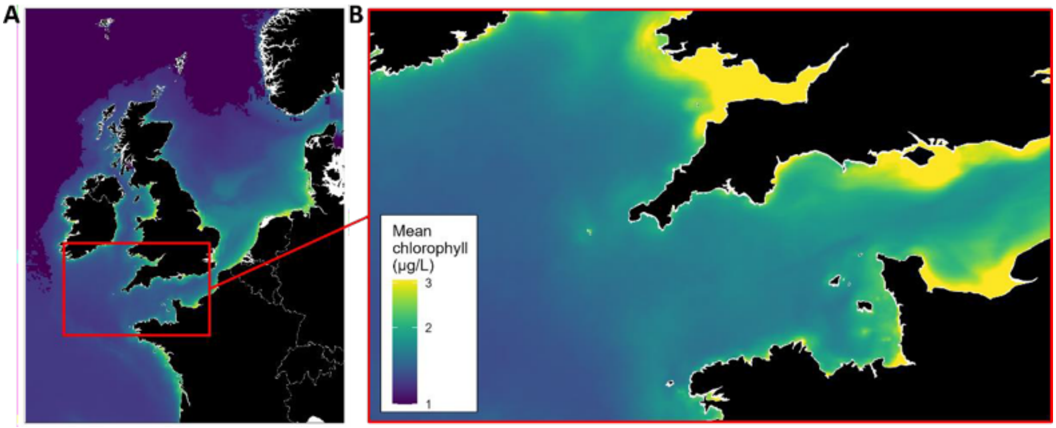

Figure 1. Mean chlorophyll concentration across North-east Atlantic waters from Copernicus CMEMS data (A) and mean chlorophyll concentration across southwest England from RBINS data (B).

Key messages

1. **Targeted monitoring and management:** Based on the refined HAB risk map and seasonal dynamics, we will be able to recommend specific locations and times of year to concentrate phytoplankton monitoring effort. This targeted approach is likely to be more efficient and cost-effective than broad-scale monitoring.
2. **Data-driven decision-making:** The web application will empower policymakers to use the project's findings to inform decisions related to marine spatial planning, coastal management, aquaculture, and public health.
3. **Integration with existing monitoring programs:** We will recommend how to integrate the project's findings with existing monitoring programs to enhance their effectiveness.
4. **Development of early warning systems:** Based on the improved understanding of HAB dynamics, we could explore the potential for developing early warning systems to provide timely alerts about potential HAB events.
5. **International collaboration:** Since this analysis is not strictly limited to UK waters, it provides the opportunity to examine transboundary HAB risks (i.e., for Ireland, France, Belgium, the Netherlands). We will explore collaborations with other OSPAR countries to address these shared challenges and how they impact their coastal regions.
6. **Public communication and education:** We will be able to recommend developing public communication strategies to educate coastal communities and other relevant stakeholders about HAB risk for their local communities, as well as the potential impacts HABs generate. The web app could be a valuable tool for communicating this information.

Methods

Data

To test these objectives, we initially used the satellite data product from the Royal Belgian Institute of Natural Sciences (RBINS; **Figure 1**). RBINS has developed and runs satellite data processing software on mass archives of satellite data from various missions.

We used weekly satellite chlorophyll concentration derived at 300m resolution for the period 1998 to 2024 for an area covering the southwest of England and the south coast of Wales. In terms of temporal resolution, weekly satellite data were used, rather than daily, to minimise missing values caused by cloud cover, particularly in winter. By focusing the initial analysis on the southwest of England we improve the efficiency of tool development, which will require much greater computing time and processing power when scaled up to cover the whole of UK waters. Once the algorithm for processing the satellite data has been developed, this will be scaled up to cover the whole of the UK for the finished product.

Statistics

To identify areas prone to experiencing regular high-biomass bloom events, we applied a set of thresholds based on the mean, standard deviation, skewness and kurtosis in the distribution of weekly chlorophyll measurements. These statistics were calculated across the time-series for each pixel, separately for winter, spring, summer and autumn data.

The distribution of mean values across the spatial domain identifies areas which typically exhibit greater chlorophyll concentration than their surrounding waters. Standard deviation identifies how widely chlorophyll concentration in a given season varies from sample to sample. Skewness identifies whether the variation in chlorophyll concentration is symmetrical, or whether it tends to produce high extreme or low extreme values. Finally, kurtosis identifies whether the distribution has fat tails and tends to produce more extreme values (i.e., spikes) than a normal distribution.

Thresholding and intersection

The distribution of values for each one of these four statistics was assessed, and thresholds for the 95th percentile were applied for each statistic. This means that for each statistic, only pixels exhibiting values in the top 5% were retained. This approach was modified from the one currently used for Water Framework Directive (WFD) phytoplankton assessment (the Coastal Water Phytoplankton Tool), which uses 90th percentile threshold applied to mean chlorophyll biomass across the growing season (Devlin et al., 2012). Our 95th percentile thresholds were created to be slightly more cautious than those used for WFD.

Binary masks for pixels exceeding this threshold for each of the four statistics were overlayed and the intersection of these pixels was retained. Therefore, remaining pixels identify areas which exceed the 95th percentile in each of the four statistics.

Results

The 95th percentile threshold in mean chlorophyll-a concentration values revealed that the greatest mean chlorophyll concentrations occur in coastal waters, particularly in the Bristol Channel and the South England coastline, particularly around the Isle of Wight (**Figure 2**). There was limited seasonal variability in the distribution of values exceeding the threshold, despite the seasonal variation in biomass typical of phytoplankton dynamics.

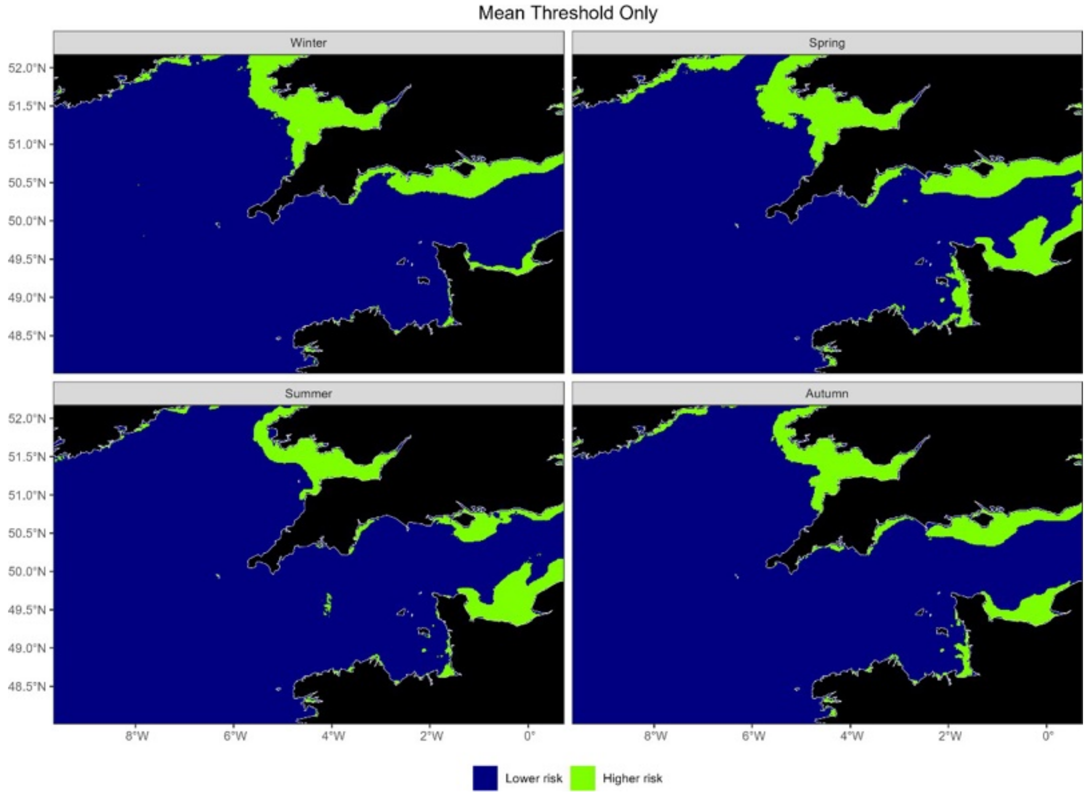

Figure 2. 95th percentile threshold for mean chlorophyll-a concentration (green).

The 95th percentile threshold in the standard deviation in chlorophyll-a concentration values (**Figure 3**) shared a substantial overlap with areas exceeding the threshold in mean values. The greatest areal coverage of pixels exceeding the threshold for standard deviation occurred in spring, for both coastal and offshore areas. Areas exceeding the standard deviation threshold, while mainly concentrated in coastal areas, were not limited to the coast, and there was evidence of high standard deviation in the western part of the English Channel in summer.

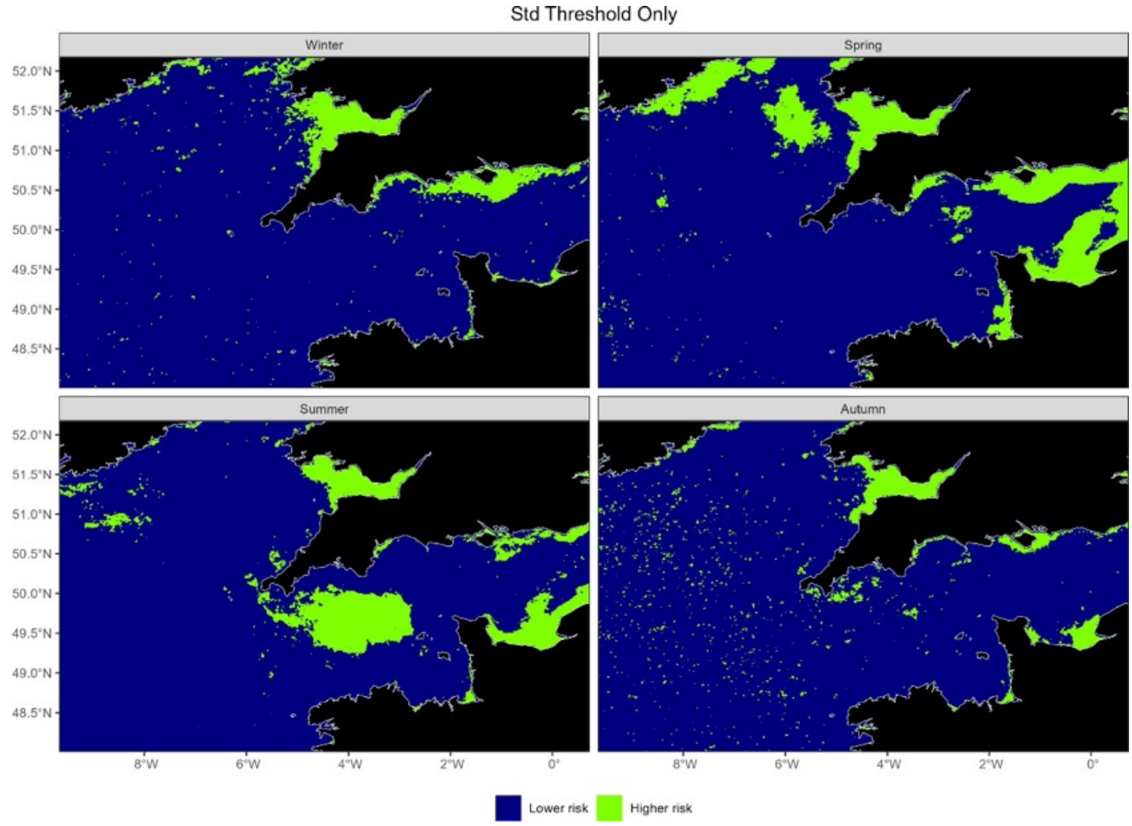

Figure 3. 95th percentile threshold for standard deviation in chlorophyll-a concentration (green).

The 95th percentile threshold in the skewness of chlorophyll concentration values (**Figure 4**), which identifies areas prone to high outlier values, showed a much noisier distribution, with a lot of high frequency noise, particularly in offshore areas in winter. There were also large offshore areas of high skewness in summer, particularly in waters south of Ireland and in the western English Channel.

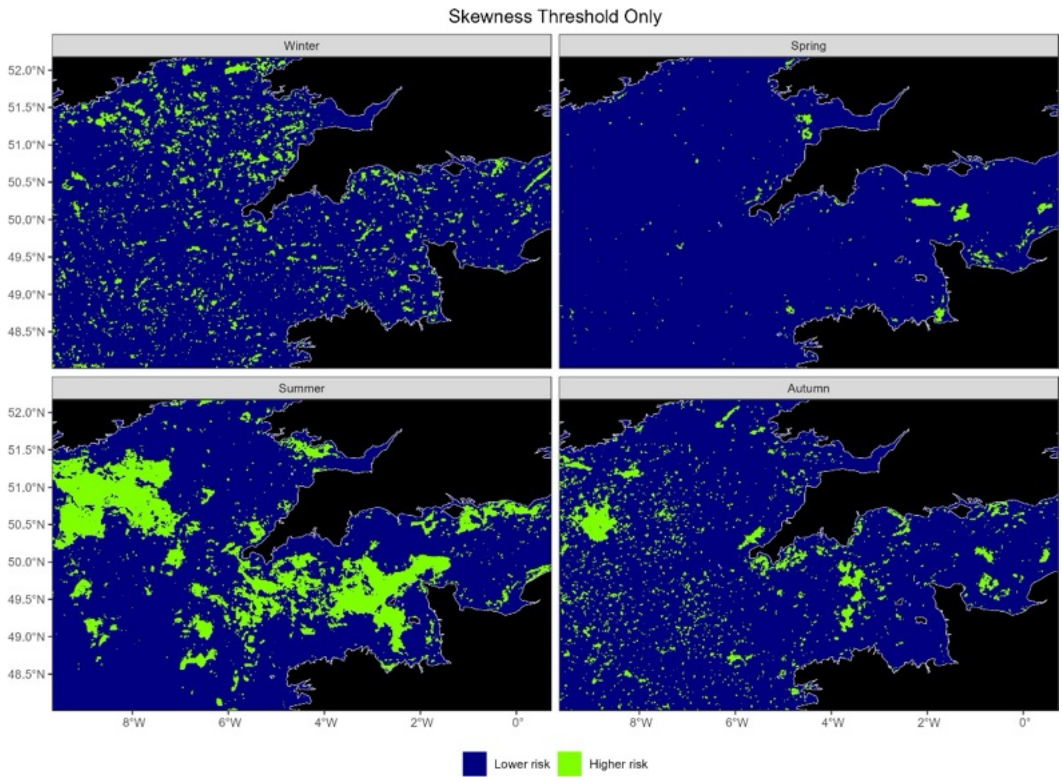

Figure 4. 95th percentile threshold for skewness in chlorophyll-a concentration (green).

The 95th percentile threshold in the kurtosis of chlorophyll concentration values (**Figure 5**) showed a very similar distribution to the results for skewness. There is a logical connection between the two statistics, since the presence of high outlier values would inevitably skew the overall distribution of values. Since both statistics roughly reveal the same thing, it may make sense to only examine either kurtosis or skewness, but not both.

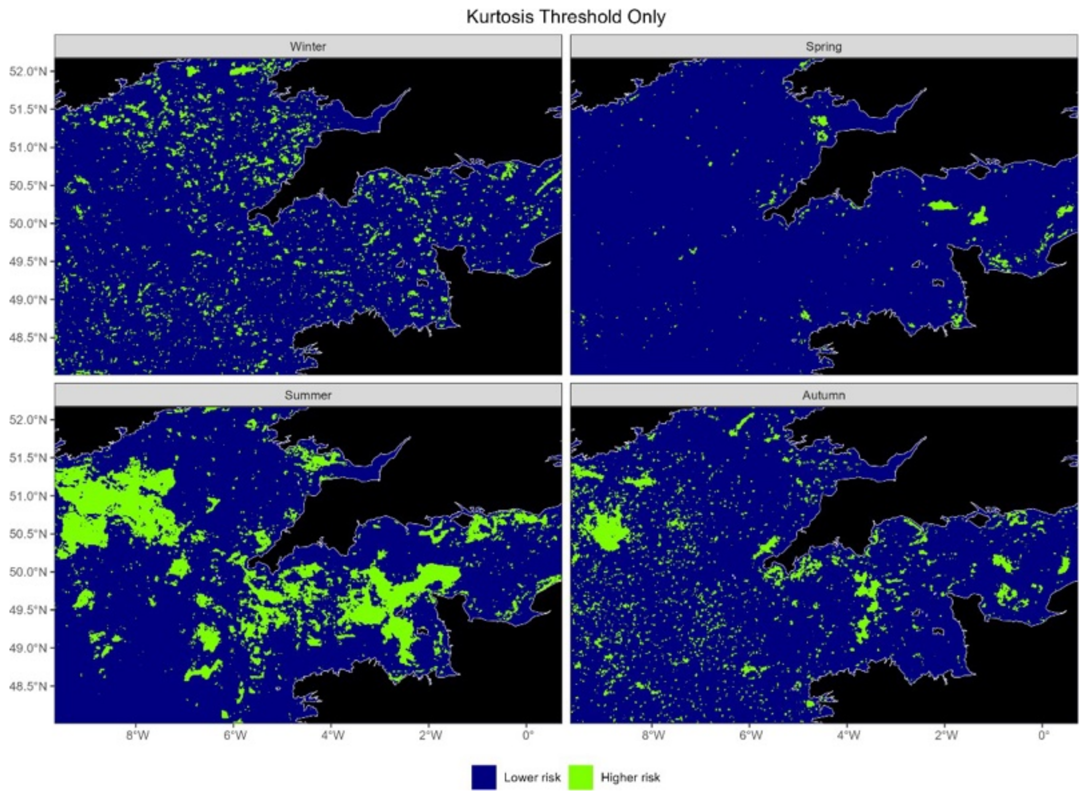

Figure 5. 95th percentile threshold for kurtosis in chlorophyll-a concentration (green).

Minor smoothing (erosion and dilation) was applied to the images to eliminate some of the high frequency noise. The smoothed distributions of mean, standard deviation and skewness were overlaid to better visualise how they compare to one another (**Figure 6**).

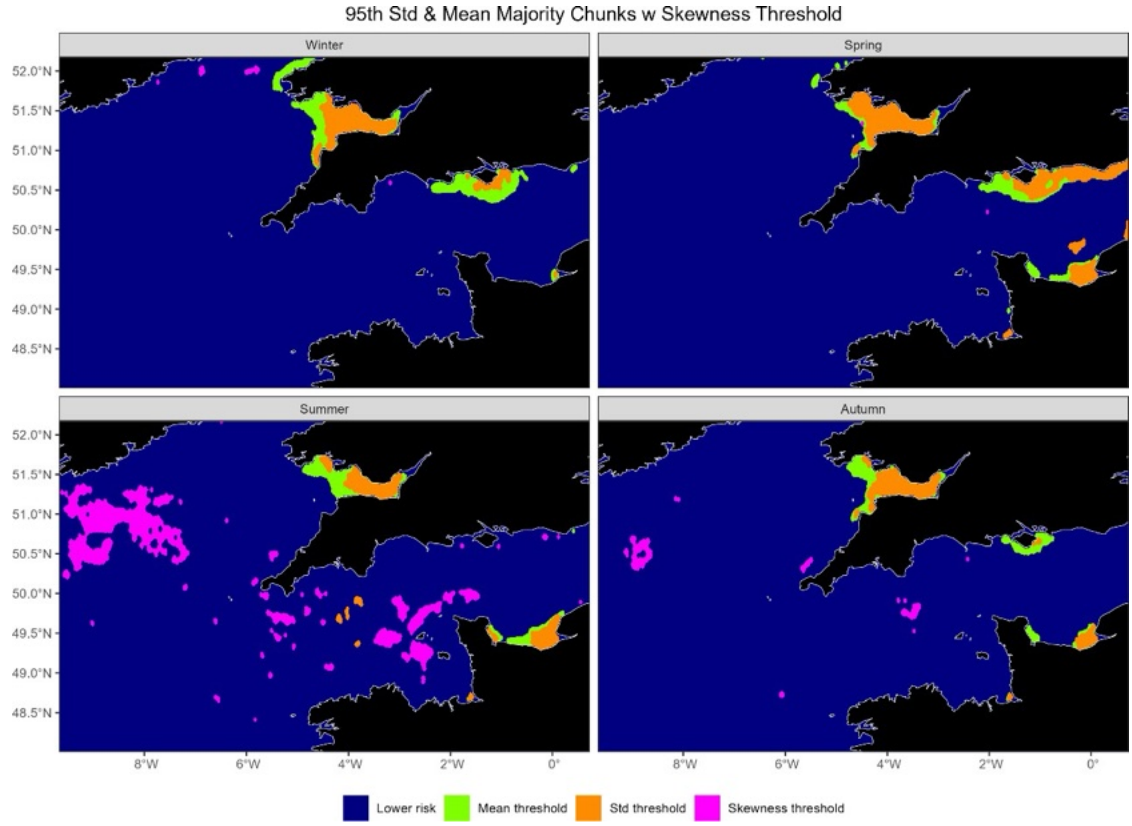

Figure 6. Composite figure generated from the union of smoothed masks for 95th percentile thresholds in mean (yellow), standard deviation (orange) and skewness (purple) in chlorophyll-a concentration.

Finally, binary maps for each of the four statistics were overlaid and intersected so that only pixels exceeding the 95th percentile threshold for all four statistics were retained (**Figure 7**). This step eliminated all offshore areas, since they did not exceed the threshold for mean and standard deviation which were more limited to coastal areas. Areas that were retained and identified as being prone to high biomass blooms include the Flat Holm and Steep Holm islands in the Bristol Channel in winter and spring, as well as the Isle of Wight and the south coast of Wales in summer

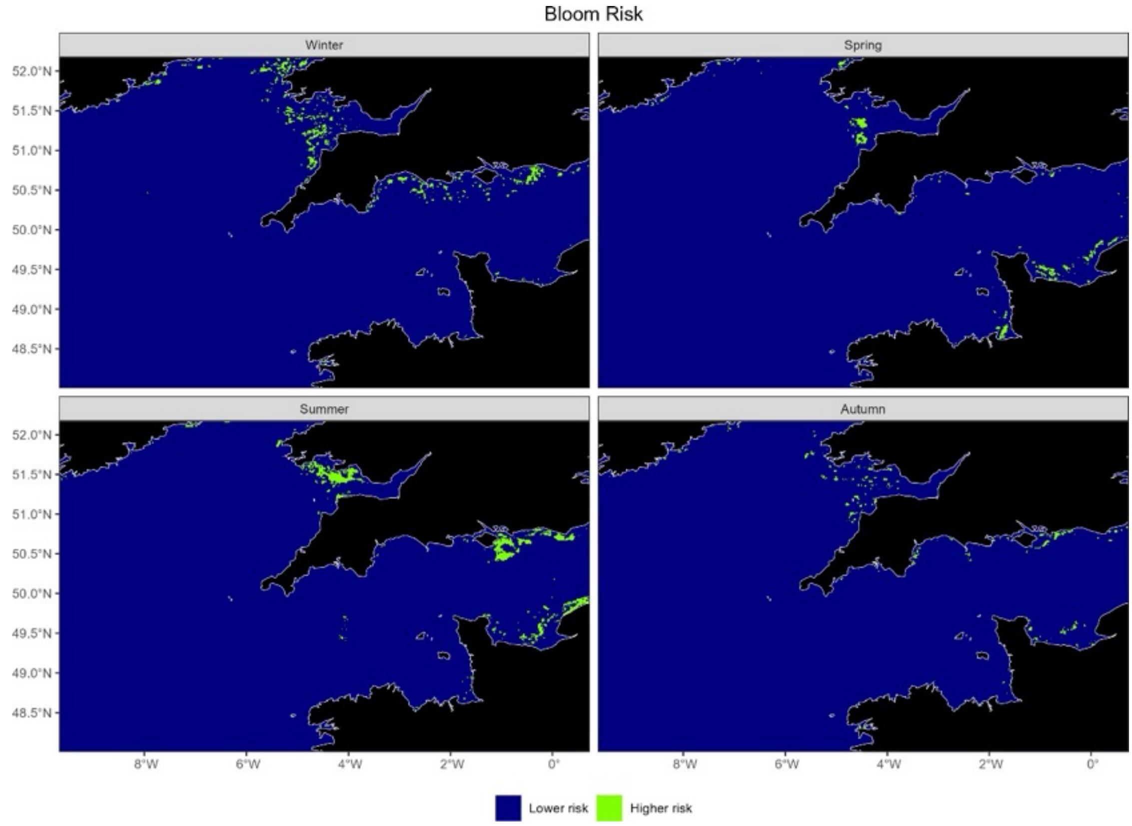

Figure 7. Composite figure generated from the intersection of masks for 95th percentile thresholds in mean, standard deviation, kurtosis and skewness in chlorophyll-a concentration.

The frequency distribution of values for each of the four statistics (**Figure 8**) were highly right skewed for mean, standard deviation and kurtosis values, indicating that most values for these statistics were on the lower end of their distributions. The exception was for skewness, which is not bounded by zero since there can be both low and high outliers. The distribution of skewness was mostly positive (>0) indicating that it was mostly high outlier values influencing the distribution.

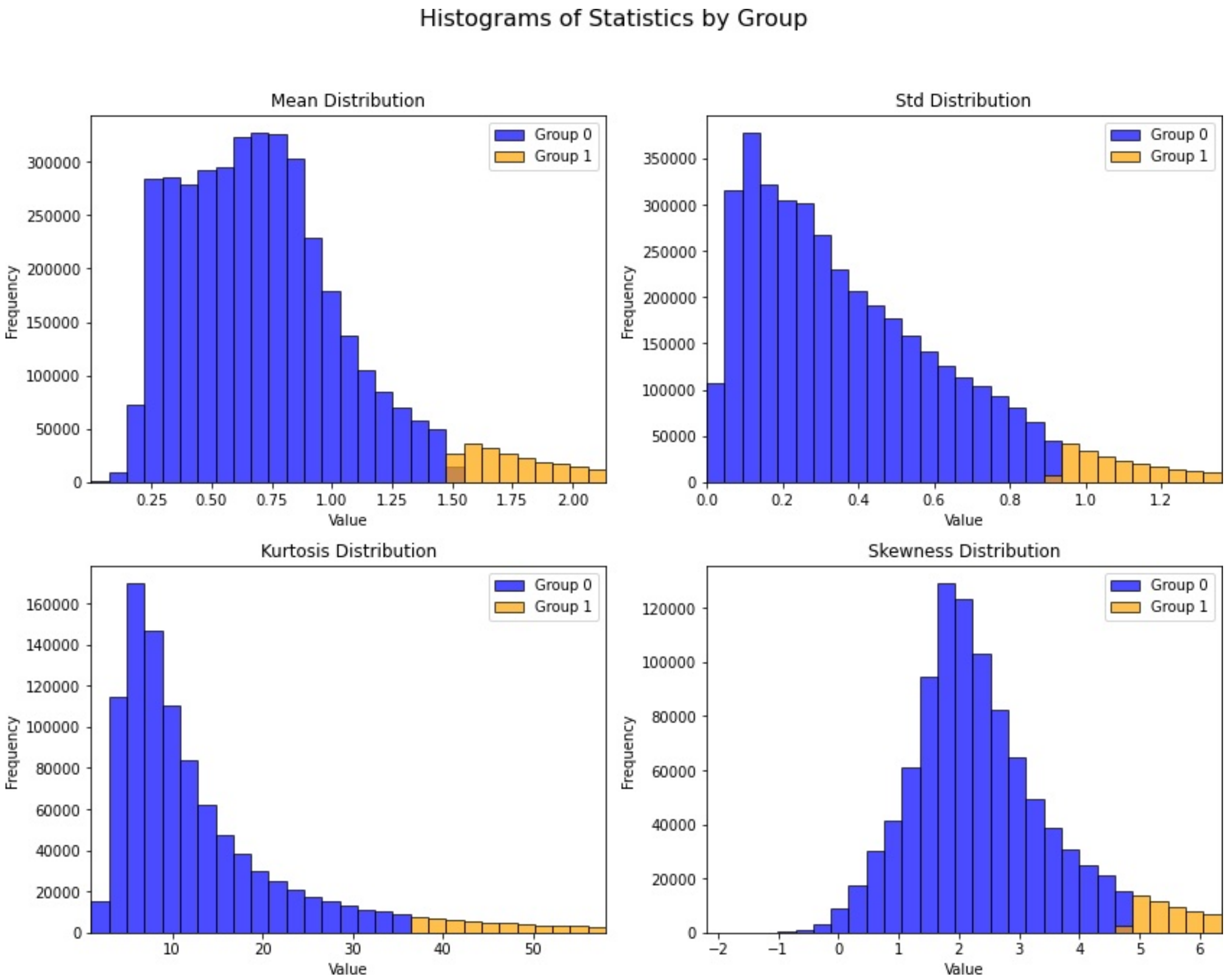

Figure 8. Histograms for the frequency distribution of values within the study domain across the four seasons for each of the four statistics. Colour indicates whether values are below (Group 0, blue) or above (Group 1, yellow) the 95th percentile threshold for that statistic.

Preliminary discussion

The preliminary analysis of satellite data has revealed some likely areas for HAB risk which warrant further investigation, but it has also highlighted a well-known problem with using satellite ocean colour to measure chlorophyll concentration in coastal waters. The detection of high mean chlorophyll values in coastal waters in winter is likely an error influenced by the high sediment load. High concentrations of suspended particulate matter (SPM) can generate erroneously high measurements for chlorophyll, simply because many sensors and algorithms cannot currently differentiate the two. This is a problem which becomes particularly apparent in winter, when the UK typically receives frequent stormy weather and high-volume rainfall events, which increase sediment load and river output. This problem is of course most apparent for river plume areas, which cover a large portion of the UK coast (**Figure 9**).

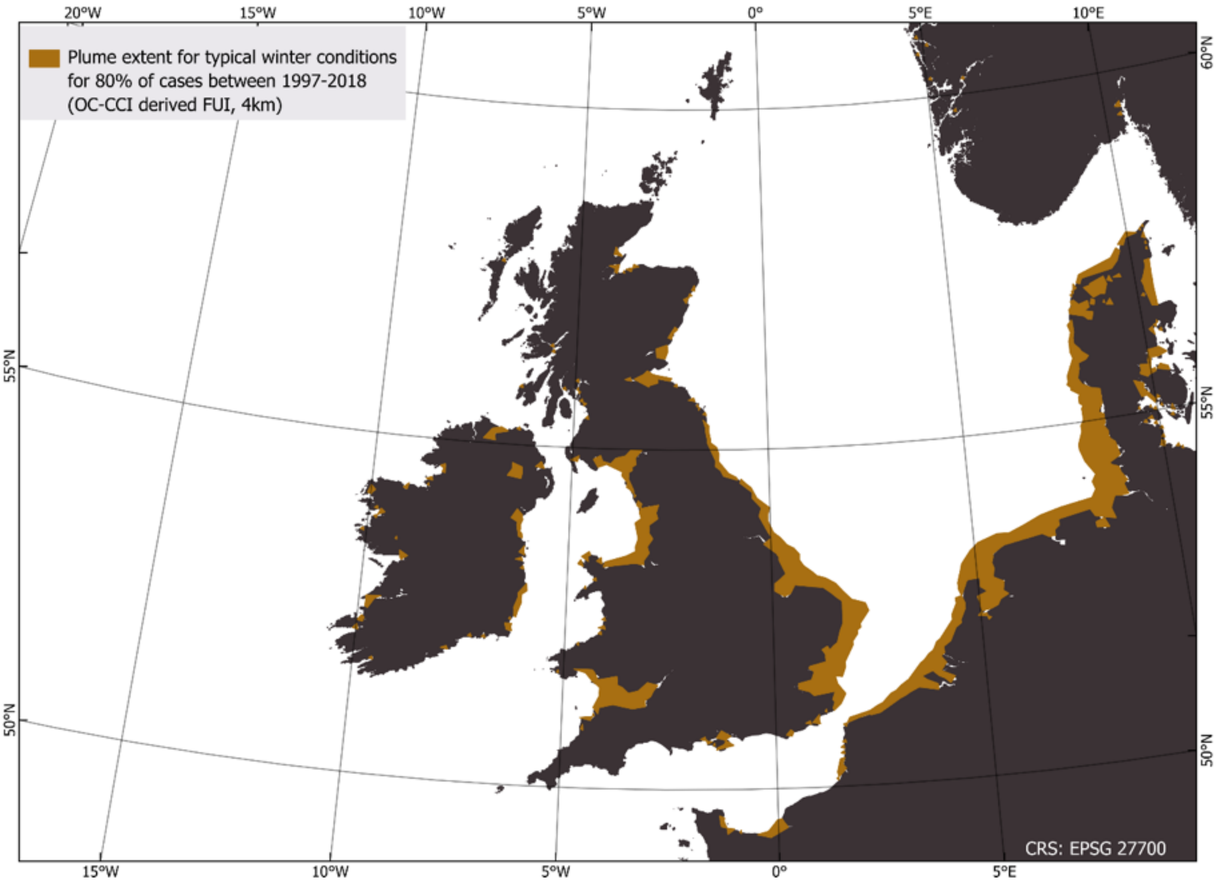

Figure 9. Winter plume extent derived from Secchi disk depth data, from Pitarch et al. (2019).

This problem becomes particularly apparent when examining the Bristol Channel, which is typified by very high sediment loads relative to surrounding waters (**Figure 10, Figure 11**).

Figure 10. Sentinel-2 image of the Bristol Channel from 20240119 which clearly shows the high turbidity zones in winter conditions.

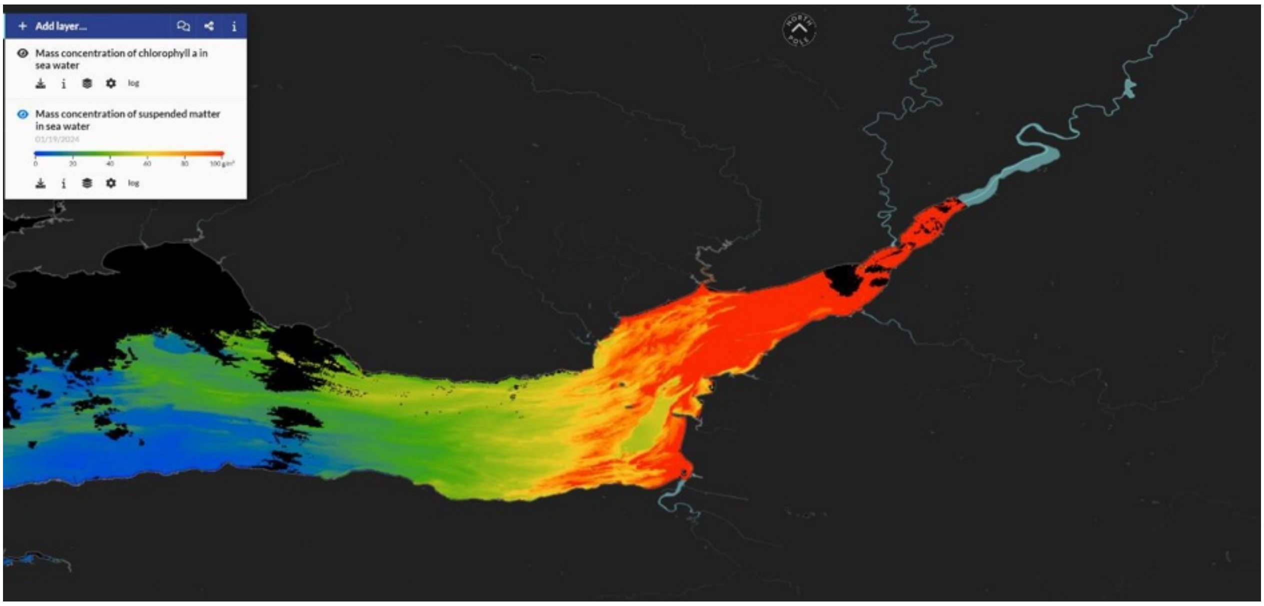

Figure 11. Chlorophyll-a concentration from the RBINS satellite product for the same date as **Figure 10**, displaying high values of chlorophyll in winter, likely erroneous due to the high SPM.

In light of this issue, several other satellite data products have been considered for this analysis, including alternatives to the RBINS algorithm, such as CCI (ESA Climate Change Initiative) and GlobColour. Each algorithm has its specific advantages and disadvantages. RBINS and CCI tend to overestimate chlorophyll values year-round. To assess the suitability of each algorithm, some follow-up analysis was performed by RBINS to compare chlorophyll measurements from these satellite products with *in situ* measurements.

The analysis revealed that *in situ* observations, which are biased to be closer to the coast, peak in June and July, while satellite estimates have a monthly minimum in July and August. RBINS had very high median values in Winter (>10 ug/l), CCI slighly less (7-8 ug/l) followed by GlobColour (4-6 ug/l). It is likely that neither CCI, GlobColour or RBINS algorithms are ideal for this analysis, which is confirmed by the fact that they actually show a turbidity signal (high winter values and low summer values) and not the typical chlorophyll signal (low winter values and high summer values). Of these algorithms, it appears that GlobColour comes closest to the true values, when only considering months between April and September, despite it still exhibiting elevated chlorophyll concentrations in December and January (**Figure 12**).

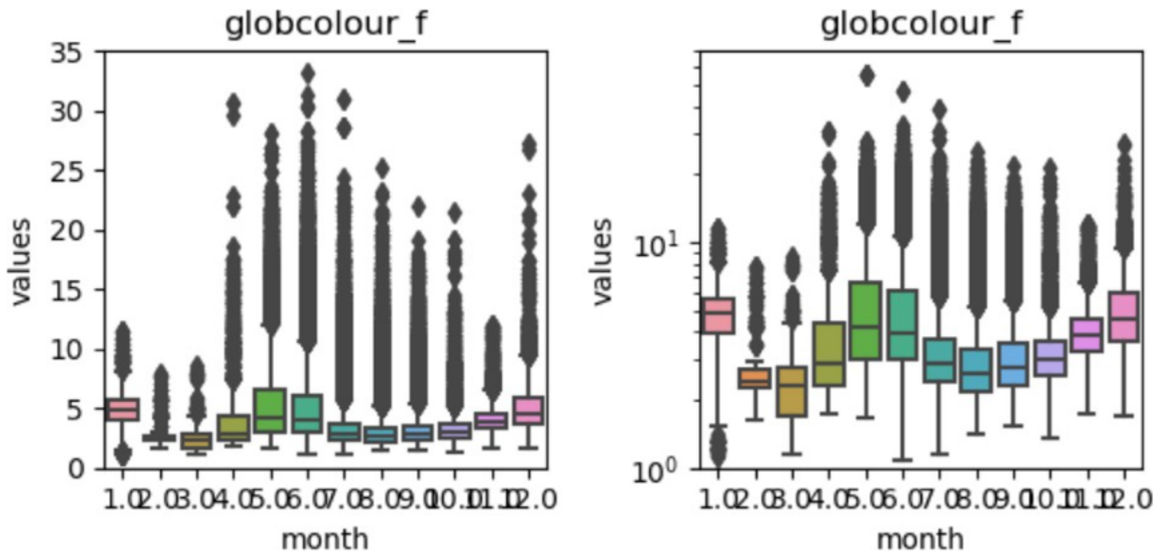

Figure 12. Distribution of chlorophyll concentration measurements for the Bristol Channel from GlobColour, revealing unlikely high values in January and December.

Next steps

To progress this work, we have decided to investigate using GlobColour instead of RBINS chlorophyll, which seem to suffer particularly from overestimation in turbid waters. We will use the satellite GlobColour dataset shared on Copernicus CMEMS as 009_113 (https://data.marine.copernicus.eu/product/OCEANCOLOUR_ATL_BGC_L3_MY_009_113/). This dataset includes chlorophyll and SPM at 1km resolution from multi-satellite daily images.

We have pre-processed the data to mask out chlorophyll measurements for pixels where SPM exceeds 7mg/l as these conditions are too turbid for the chlorophyll algorithm to be used accurately. The SPM measurement is determined from the same satellite images as chlorophyll. This filtering has improved considerably the seasonal description of chlorophyll when compared with *in situ* measurements.

We will re-run the statistical thresholding analysis on the filtered GlobColour data and once we are satisfied with its ability to identify blooms, we will scale the analysis up to cover all of UK waters.

This will likely require that we modify our code to support high performance computer (HPC) processing.

The results of this analysis will be written up into a peer-reviewed scientific paper, including a link to an interactive web application built using the R's Shiny package. Users will be able to explore seasonal maps of bloom risk across UK waters.

Conclusion

While satellite remote sensing is inherently challenging in coastal waters, we believe that our SPM filtering method applied to GlobColour data will allow us to overcome this. Although this work is not yet complete, we are confident that the outcome will allow us to deliver a set of key messages and recommendations to policymakers:

1. **Targeted monitoring and management:** Based on the refined HAB risk map and seasonal dynamics, we will be able to recommend specific locations and times of year to concentrate phytoplankton monitoring effort. This targeted approach is likely to be more efficient and cost-effective than broad-scale monitoring.
2. **Data-driven decision-making:** The web application will empower policymakers to use the project's findings to inform decisions related to marine spatial planning, coastal management, aquaculture, and public health.
3. **Integration with existing monitoring programs:** We will recommend how to integrate the project's findings with existing HAB monitoring programs to enhance their effectiveness.
4. **Development of early warning systems:** Based on the improved understanding of HAB dynamics, we could explore the potential for developing early warning systems to provide timely alerts about potential HAB events.
5. **International collaboration:** Since this analysis is not strictly limited to UK waters, it provides the opportunity to examine transboundary HAB risks (i.e., for Ireland, France, Belgium, the Netherlands). We will explore collaborations with other OSPAR countries to address these shared challenges and how they impact their coastal regions.
6. **Public communication and education:** We will be able to recommend developing public communication strategies to educate coastal communities and other relevant stakeholders about HAB risk for their local communities, as well as the potential impacts HABs generate. The web app could be a valuable tool for communicating this information.

References

Devlin, M., Best, M., Bresnan, E., Scanlan, C., & Baptie, M. (2012). Water Framework Directive: The development and status of phytoplankton tools for ecological assessment of coastal and transitional waters. *Water Framework Directive–United Kingdom Technical Advisory Group (WFD-UKTAG)*.

Pitarch, J., van der Woerd, H. J., Brewin, R. J. W., & Zielinski, O. (2019). *Twenty years of monthly global maps of Hue angle, Forel-Ule and Secchi disk depth, based on ESA- OC-CCI data* PANGAEA. https://doi.org/10.1594/PANGAEA.904266