University of Southampton

CHASM Project Report 2024

Crustacean, Habitat and Sediments Version 2.0

CHASM
Crustaceans Habitat and Sediment Movement

Version	Description	Author	Approved by
1.0	Draft Report	D. Townsend	C.Thompson
2.0	Report revised following feedback from J. Cunningham.	D. Townsend	C.Thompson

CHASM
Crustaceans Habitat and Sediment Movement

Contents

Acknowledgements 2
1. Introduction 3
1.1 Project background 4
2. Literature review 5
2.1 Species decline 5
2.2 Habitat decline 6
3. Sediment mapping 10
4. Water quality monitoring 14
4.1 Sonde analysis 14
Site locations & record overview 14
Temperature 17
Turbidity 20
4.2 Satellite analysis 24
5. Sediment source identification 28
5.1 Dredging 28
5.2 Medmerry re-alignment scheme 31
5.3 Further inputs 33
6. Discussion 35
7. Summary and conclusion 38
8. References 39
Appendix A – Sonde Records 42
Appendix B – Bed Orbital Velocity Calculation 76
Appendix C – Difference model methodology 77
Appendix D – Marine Licence Application numbers for dredge extractions (2009 – 2022) .. 79

Acknowledgements

Funding gratefully received from:

- This written report and data analysis has been funded by the Woodger Trust.
- Two of the sonde units placed outside Pagham Harbour and Medmerry were funded by East Wittering & Bracklesham Parish Council and West Wittering Parish Council.

Specialist input gratefully received from:

- Chichester District Council
- Chichester Harbour Conservancy
- Environment Agency National Water Quality Instrumentation Service (NWQIS)
- Manhood Peninsula Partnership
- Mulberry ME
- Selsey Fishermen
- Southsea Sub Aqua Club
- University of Brighton

1. Introduction

This report provides an update of analysis conducted as part of the CHASM (Crustacean, Habitats and Sediment Movement) project carried out by the University of Southampton in summer 2024. The CHASM project was set up with an aim to identify causes behind the decline in crab and lobster catch, changes in sea water and habitat quality, and the increased quantity of marine sediment on the UK south coast initially observed by the fishermen of Selsey Bill. This report seeks to understand environmental change from a sediments perspective, and sets out to answer a series of questions using various data sources and analysis. The questions are:

1. What sediments make up the seabed and has this changed overtime?

2. What is the water quality (temperature, turbidity *etc.*) like within the study site and has it changed overtime?

3. What are the sources of (fine) sediment in the system and has their magnitude changed over time?

4. How might what we have learnt about the sediment system have influenced the decline in crab and lobster populations?

To address the questions the following analyses are performed:

Table 1 – Data and analysis included within this report.

Question	Data collection	Analysis	Report section
1	• Diver samples • Bathymetry survey	Mapping exercise	3
2	• Sonde data • Satellite imagery	Link water quality parameters to local drivers Determine trends over time	4
3	• Topographic data • Dredging records • Scoping exercise for other sediment sources	Quantify sub-aerial sediment sources Look at changes overtime for dredging records Identify other sediment sources and consider the proximity and pathway of each source to Selsey site.	5
4	All	Discussion of findings	6

1.1 Project background

The fishing grounds near Selsey Bill, West Sussex (Figure 1), have traditionally been well managed and productive. Fishing in the area has been shown to date back to the Bronze Age, while individual fishing families can trace their roots back centuries. The Selsey fishery was first recorded by Bede in 730AD and, typical of most small inshore UK fisheries, is of huge cultural significance locally. Many local fishermen are traditionally potters whose main catch is comprised of edible crab (*Cancer pagurus*) and European lobster (*Hommarus gammarus*), while other species includes fin fish, common or edible whelks (*Buccinum undatum*), and cuttlefish (*Sepia officinalis*) according to season.

The sea surrounding the Manhood Peninsula and within local harbours should be healthy. The Selsey fishery should thrive here alongside the marine plant and animal inhabitants. These are key components in the marine ecosystem and food web, and alongside tourism, contribute heavily to the blue carbon economy whose significance is increasingly being recognised. Instead, the Selsey fishery together with many UK inshore fisheries is in a state of sharp decline.

Initial investigations into the seabed and water column, the factors most likely to impact crustaceans, appear to show that reduced crab and lobster catch is an indicator of many changes currently taking place in coastal seas (crabs and lobsters are the canaries in the coal mine in this respect). Similar observations have also been made elsewhere in the world. Previous overfishing cannot be discounted but reasons such as contaminants in sediment, water quality, and changes in other environmental parameters also need to be considered.

Something has affected the marine environment, but it isn't clear what that is. Observations indicate a huge range of potential environmental stressors making the issues extremely complex. Some are likely to be seen globally, others will be local. A key feature is that environmental stressors are normally examined on an individual rather than a holistic basis. However, this approach fails to consider the combined effects, a potentially damaging omission. CHASM hopes to address this.

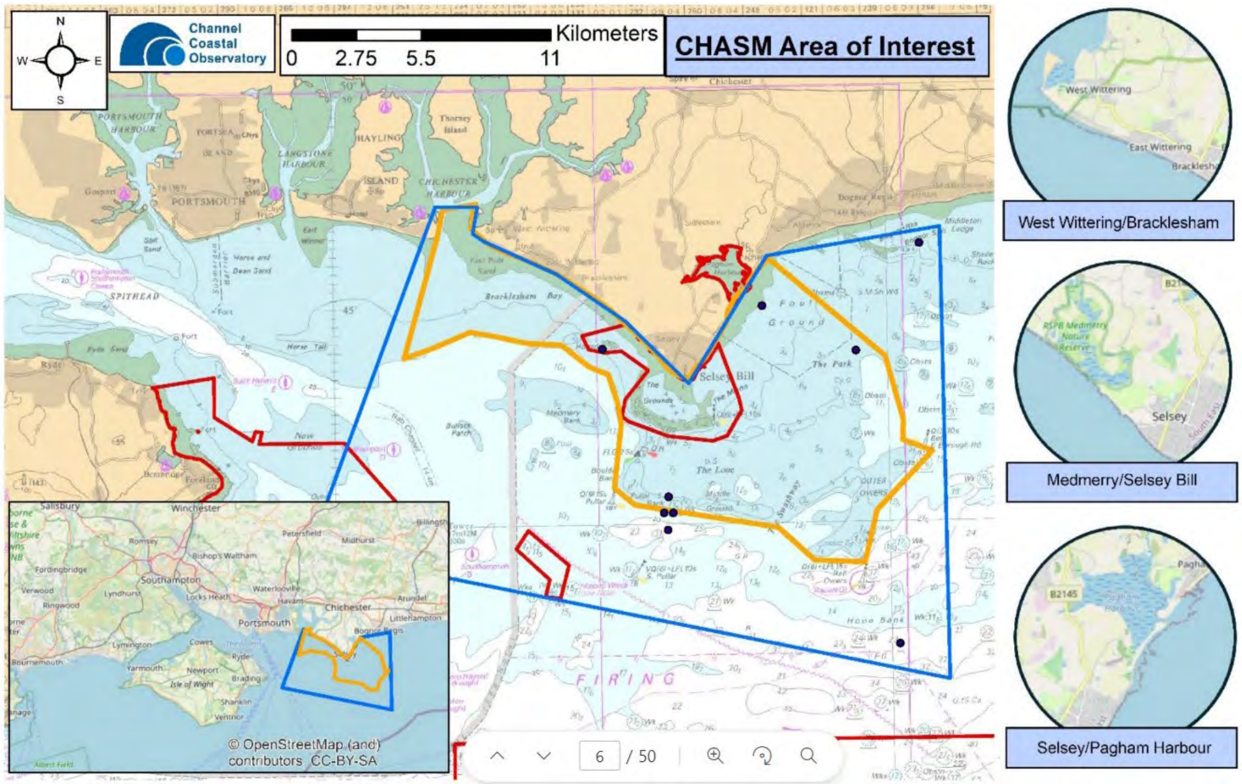


Figure 1 - Study area and fishing grounds examined within this report. Red = marine protected areas, yellow = fishing grounds and blue = wider CHASM area of interest

2. Literature review

This literature review provides an overview of species and habitat decline in the area. The species decline is informed and guided by the stakeholder interviews conducted between May 2020 and January 2021. The habitats decline is informed by the wider academic literature within the Solent area and current restoration projects, including the Medmerry managed realignment project which was completed in 2013.

We refer the reader to the 'CHASM Project Report (2020-2021)' for extensive background information on the sedimentology of the area, including the geology, historic and current coastal change.

2.1 Species decline

As part of the initial CHASM meeting seven fishermen, two coastal officers from Chichester District Council, two marine education specialists (Mulberry ME) and the Southsea Sub Aqua Club were interviewed about the changes in sediment and species distribution over time.

Historic changes

Understood that the grounds historically (1800s) supported Herring, Skate and Whiting populations however these were not caught by the fishermen within living memory. Additionally, the site was also known to support Cod, and these were caught up into the 1960s. Kelp forests were lost in the 1980s, gradually at some sites but overnight at Mixon rock following a severe storm. Dog whelk catch also declined in the 1980s.

Recent change (2000 – 2020)

There has been an increase in some species, which may be related to the decline in other species through predation/outcompeting other species, including spider crab (first observed 2005), five fingered starfish (2018) and smooth hounds (2014-2018).

The species which have experienced declines in the last 20 years are as follows: **crustaceans:** lobsters, inshore crab populations; **sea snails**: whelks, winkles; **sea weeds**: kelp, weed, lace weed, seaweed, bootlace weed, black weed, Japanese weed; **star fish**: brittle star; **cephalopods**; cuttlefish; **fish**: mackerel. In particular, declines were observed in:

- 2005 – 2010: Japanese, laceweed and kelp decline across the study site
- 2013: Bootlace weed was disappearing from Medmerry
- 2014: Boulder bank lobster reduction
- 2017 – present: decline in lobster catch
- 2018: Bognor rocks and Pullar (sudden) loss of marine life

Whilst edible crab numbers on the whole are not reported to have declined, the number of sleepy and dead crabs has been observed to increase. An investigation by Cefas found an infestation by the opportunistic pathogen *Janickina feisti*. The pathogen had not been found in crab species before, and the detection of the pathogen in the local crab population at Selsey was the first time it had been detected (Bateman *et al*., 2022). This is thought to be a factor in inshore crab decline however a definitive link has yet to be established. The pathogen leads to what is now termed 'amoebic crab disease' (ACD) whereby the only external symptom is lethargy although the eventual outcome of the disease is death. There are no reported ill effects on human-health.

2.2 Habitat decline

Oyster reef decline

Over 30 years ago, the Solent estuary was the largest native oyster fishery in Europe; however, in 2007 the fishery collapsed and was temporarily closed in 2013 (IFCA, 2019).

Although there are strict regulations on the oyster catch, the broodstock becomes less and less every year, which is related to numerous factors (Figure 2). The collapse of the oyster fishery may have wider impacts on the environment as oysters and other filter feeders play an important role in not only water quality, but also clarity, as fine sediments which are ingested whilst in suspension, are clumped together as pseudo-faeces, and ejected settling on the seabed. The degree to which this may affect the wider area is unknown.

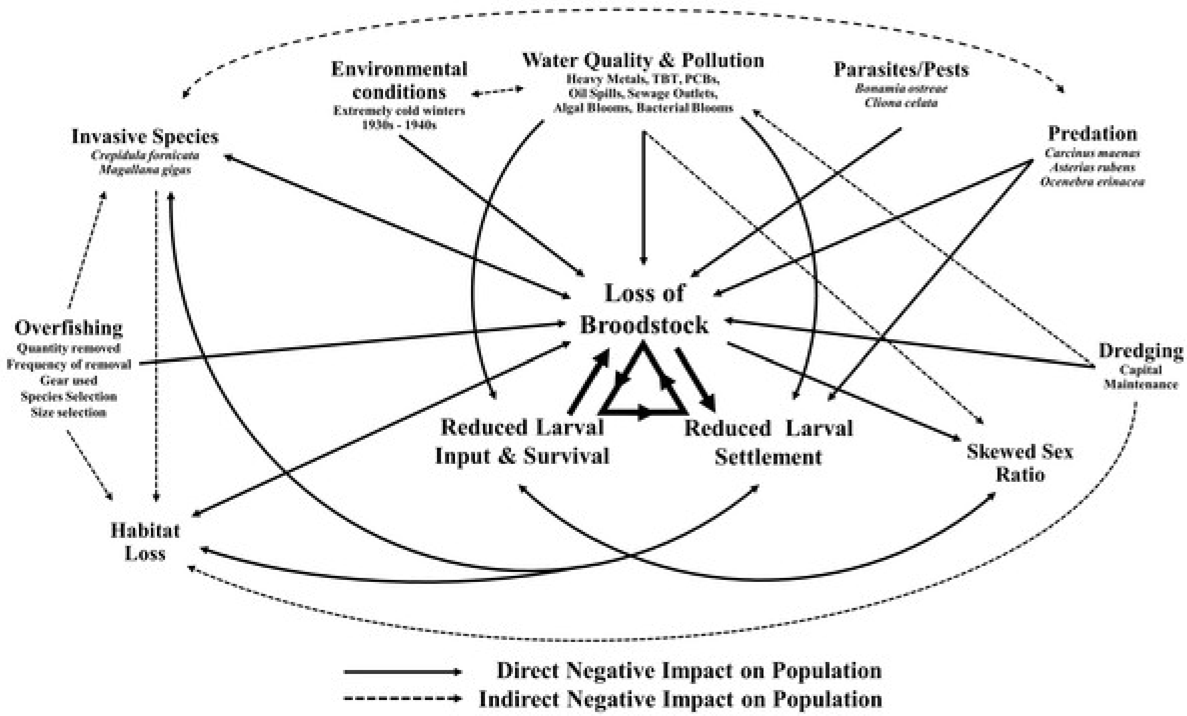


Figure 2 - 'Interactive effects adversely affecting Ostrea edulis. The factors that are known to be adversely affecting Ostrea edulis populations within the Solent and their interconnecting relationships. Examples of the factors are shown where necessary.' From Helmers et al. (2019).

Kelp forest decline

Kelp forests once covered an area of approximately 177 km^2 to the east of Selsey Bill in the late 1970s, yet only 6.3 km^2 occupies the same area today (HR Wallingford, 2019). There are a number of reasons for the decline in kelp, including: over-harvesting and overfishing by people, changes in water quality (pollution, sedimentation, eutrophication), impacts of other species (overgrazing by urchins) and climatic effects (heatwaves, storms and warming water) (Figure 3; Williams et al., 2020). In the case of the Sussex beds, it is thought that a combination of trawling activities and the 'Great Storm' of 1987 were responsible for the population decline (Sussex Kelp Restoration Project, 2019). In order to prevent further loss of habitat, a local byelaw was passed 'The Sussex Nearshore Trawling Byelaw' prohibiting trawling activities within 302km^2 of the nearshore zone.

Figure 3 - No trawl zone. Sussex Kelp Recovery Project 2019.

Saltmarsh decline

Saltmarsh habitat provides vital nursery habitats for a vast number of marine species, as well as numerous other benefits, such as carbon sequestration and coastal defence. In the Solent historic saltmarsh decline is well documented both through processes of coastal squeeze, ongoing coastal erosion and land reclamation (Figure 4; Cope *et al*. 2008). Some of the largest historic losses in the region occurred within Chichester Harbour, which declined by half from over 700ha of saltmarsh in the 1940s to approximately 350 in the late 1990s. More recent estimates suggest that Chichester and Langstone Harbours are still experiencing saltmarsh losses with declines of 26 and 10.6 ha, respectively, between 2008 and 2016. In contrast Portsmouth Harbour gained (small) levels of saltmarsh 3.3 ha between 2008 and 2016 and a further 2.1 ha between 2019 and 2016 (Natural England, 2022). However, the quality of the saltmarsh habitat across the Solent is poor, with 90 % in unfavourable conditions, 5 % extinct and 0 % in good condition (Natural England, 2022).

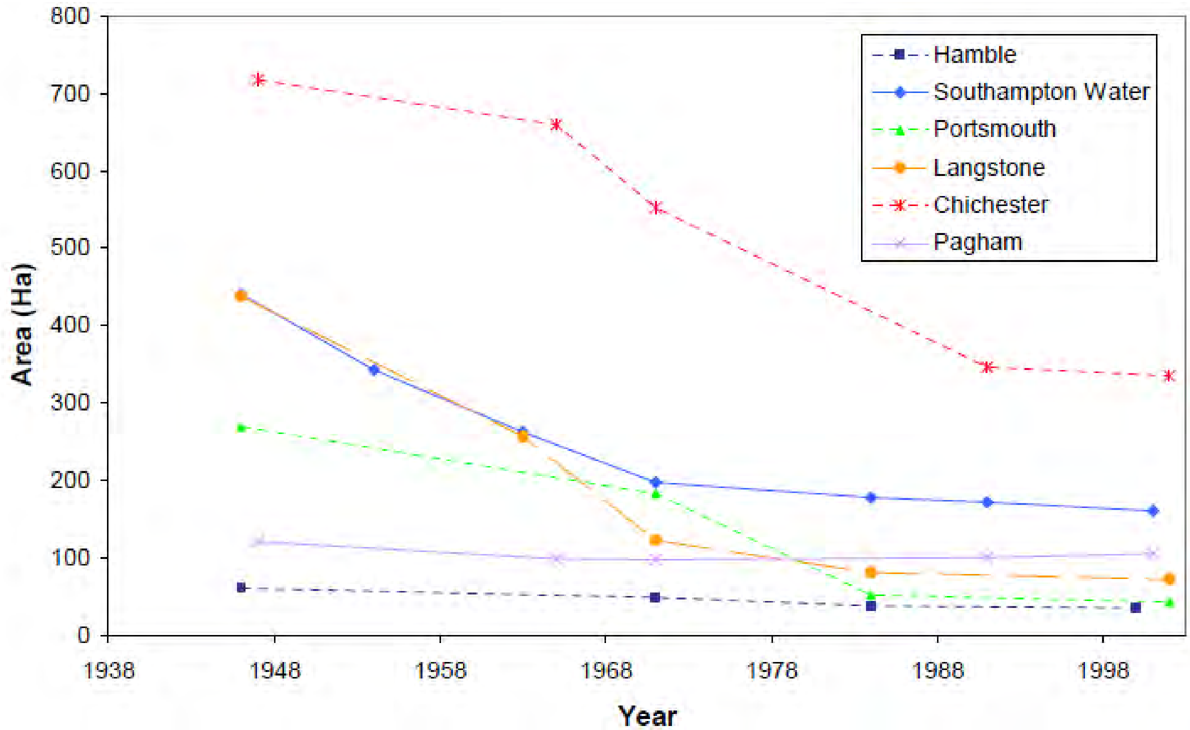


Figure 4 - Historic change in saltmarsh extent; East Solent (Cope et al. 2008)

Medmerry managed realignment

The Medmerry managed realignment scheme was completed in 2013, whereby approximately 183ha of intertidal habitat and 80 ha of transitional grassland were created (Figure 5). This was done through the construction of earth embankments around the site and a managed breach of the shingle beach which had consistently been losing sediment over the past decades. The project set out to initially create 130ha coastal saltmarsh, amongst many other habitats, including mudflats and saline lagoons (Environment Agency, 2013).

Figure 5 - Medmerry managed realignment scheme (ICE, 2015)

3. Sediment mapping

Sediment samples were collected from the seabed surface either by hand, collected by divers, or by van Veen grab when sampling in deeper water. Target volumes of 100 grams were collected and stored in glass jars. Divers sampled the top 5 cm of the sediment surface, using a non-biased, randomised sampling strategy to collect representative samples from each site.

Sediment sampling locations were planned based on conversations with maritime users, informed by noticeable changes in species mortality and population or sediment composition. In total 31 samples were collected through joint efforts of the Southsea SAC, Mulberry Divers and Southern IFCA. The samples were analysed by both the University of Southampton and the University of Brighton. The samples per location are shown in Table 2 and a map showing the relative distributions of gravel, sand and mud is shown in Figure 6. These results are also shown alongside each other in graphical form in Figure 7.

Table 2 – Map reference (see Figure 6), location and number of grab samples.

Map ref	Location	No. of samples
A	A1 Submarine	8
B	Landing Craft Bracklesham Bay	3
C	Medmerry intertidal (landward)	2
D	Medmerry Breach	2
E	Nr Hounds Reef	1
F	Medmerry Bank	2
G	Mixon Rocks (A + B)	3
H	Inner West Mulberry	1
I	Far (Outer) Mulberry East (Bognor) End	1
J	Nab Tower	3
K	Pullar Bank	2
L	Hooe Bank	3

Each sample of 100 grams maximum was wet-sieved to remove salts and fine material, then dried at 60 (degrees Celsius) for at least 24 hours.

For grain sizes greater than 0.063mm, the samples were analysed using dry-sieving. The samples were vibrated for 10 minutes on a mechanical shaker, using a 17-tier sieve stack ranging from 0.063 mm to 8 mm at half phi (ϕ) intervals. The operation was undertaken in two stages due to equipment restrictions. For grain sizes smaller than 0.063 mm, the sample was dried and weighed to assess the proportion of fines in the sample. All grain size statistics were calculated using GRADISTAT (Blott & Pye, 2001).

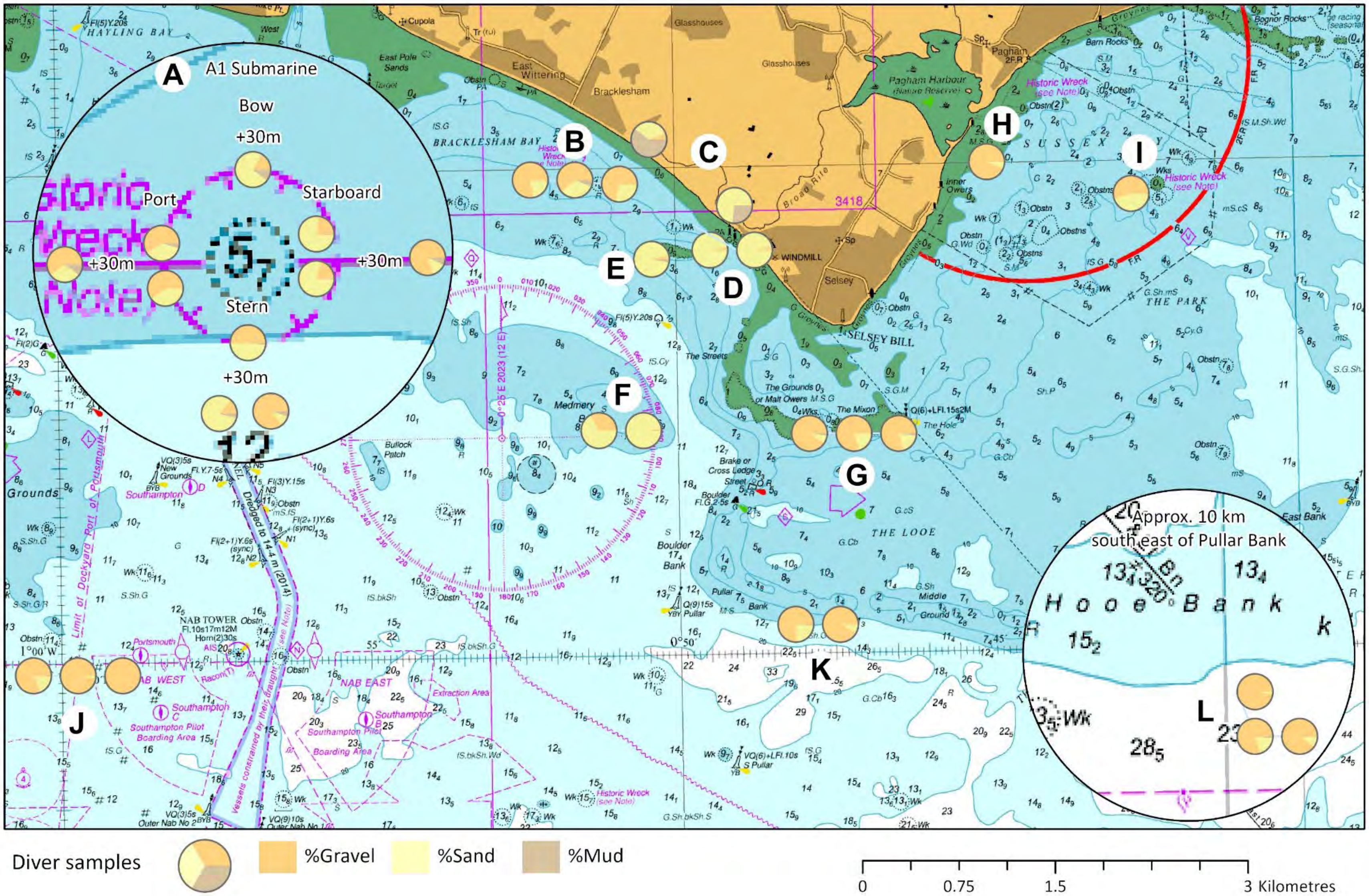


Figure 6 – Map showing locations of grab samples analysed and their proportions of gravel, sand and mud. Location name given in Table 2.

CHASM
Crustaceans Habitat and Sediment Movement

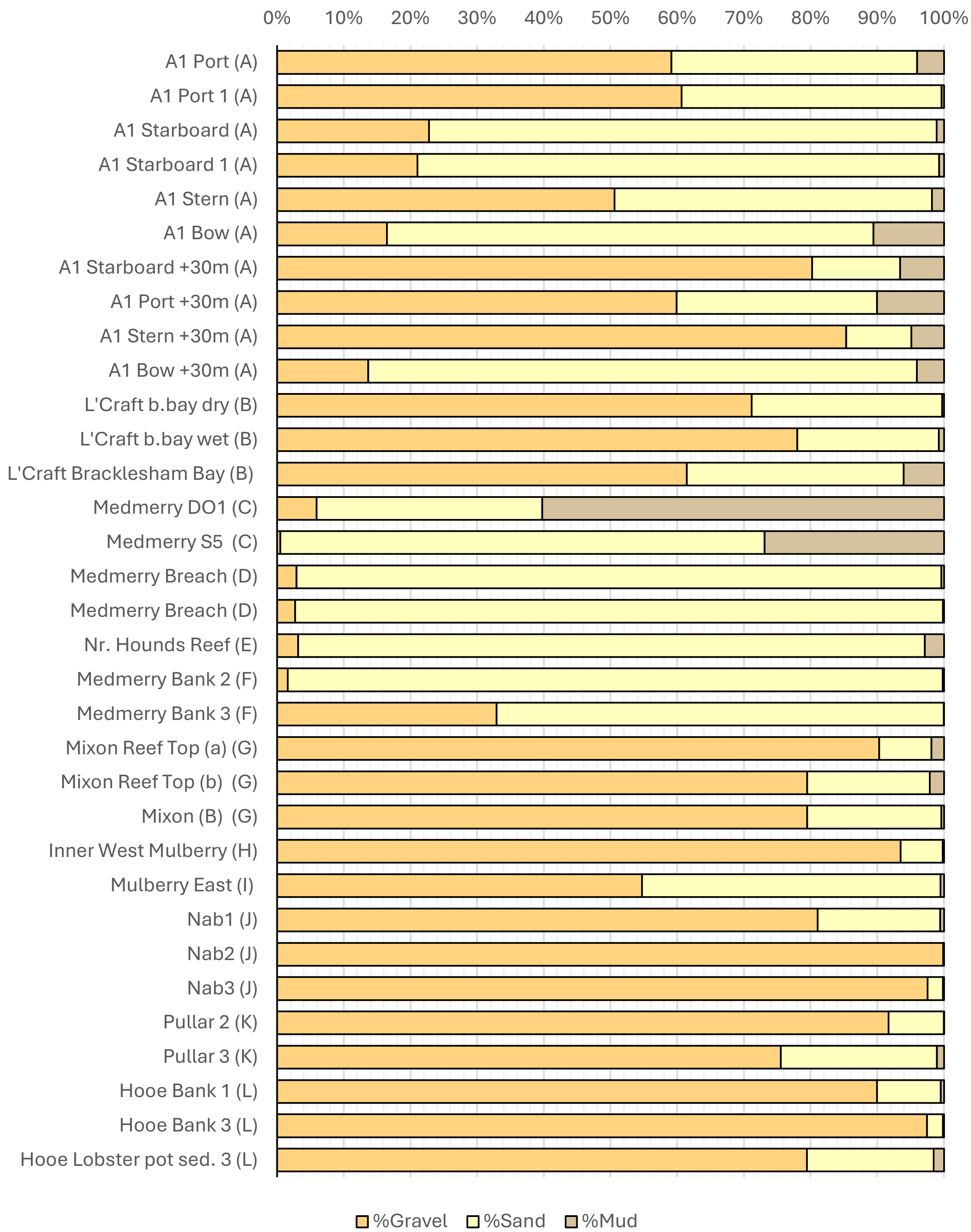


Figure 7 – Proportion of different gravel, sand and mud distribution per sample.

4. Water quality monitoring

To understand short and longer-term changes in fine suspended particles in the water column over time, two analyses were undertaken:

1) Near bed (sonde) measurement of turbidity and other factors at a number of sites across the study area between 2020 and present day (Section 4.1); and
2) Analysis of trends in ocean colour, including (inorganic) Suspended Particle Matter (SPM), derived from satellite imagery between 1997 and present day (Section 4.2).

Both methods have their pro's and con's, and so using a joint approach enables us to widen our outlook on the matter. Both datasets show a distinct seasonal pattern: *i.e.* higher turbidity in the winter, due to resuspended sediment from waves, and lower turbidity over the summer whilst conditions are calmer.

4.1 Sonde analysis

Site locations & record overview

Sonde monitoring as part of the CHASM project began in 2021 (Table 3) over 6 sites (Figure 8). The Landing craft, A1 Submarine and Inner Mulberry sites covered the time epoch between May 2021 and October 2021 and are referred to as Set 1 from here on. The West Pole and Chichester Marina sites cover the time period June 2022 to August 2024, with a shorter additional coverage at Fishbourne Dell Quay which ran between Feb 2023 to August 2023. Note that the Chichester Marina site is actually located within Fishbourne Channel, however, to avoid confusion with the Fishbourne Dell Quay site we refer to it as Chichester Marina here. Collectively this group is referred to as Set 2.

Additionally, sonde data was also recorded at the Pagham and Medmerry sites as part of a PhD project (Dale *et al.* 2017). This work aimed to observe any changes at the site following the breach in the shingle barrier at Medmerry as part of a managed realignment scheme (Dale 2018). We do not further analyse this dataset here, but refer the reader to the thesis for further information.

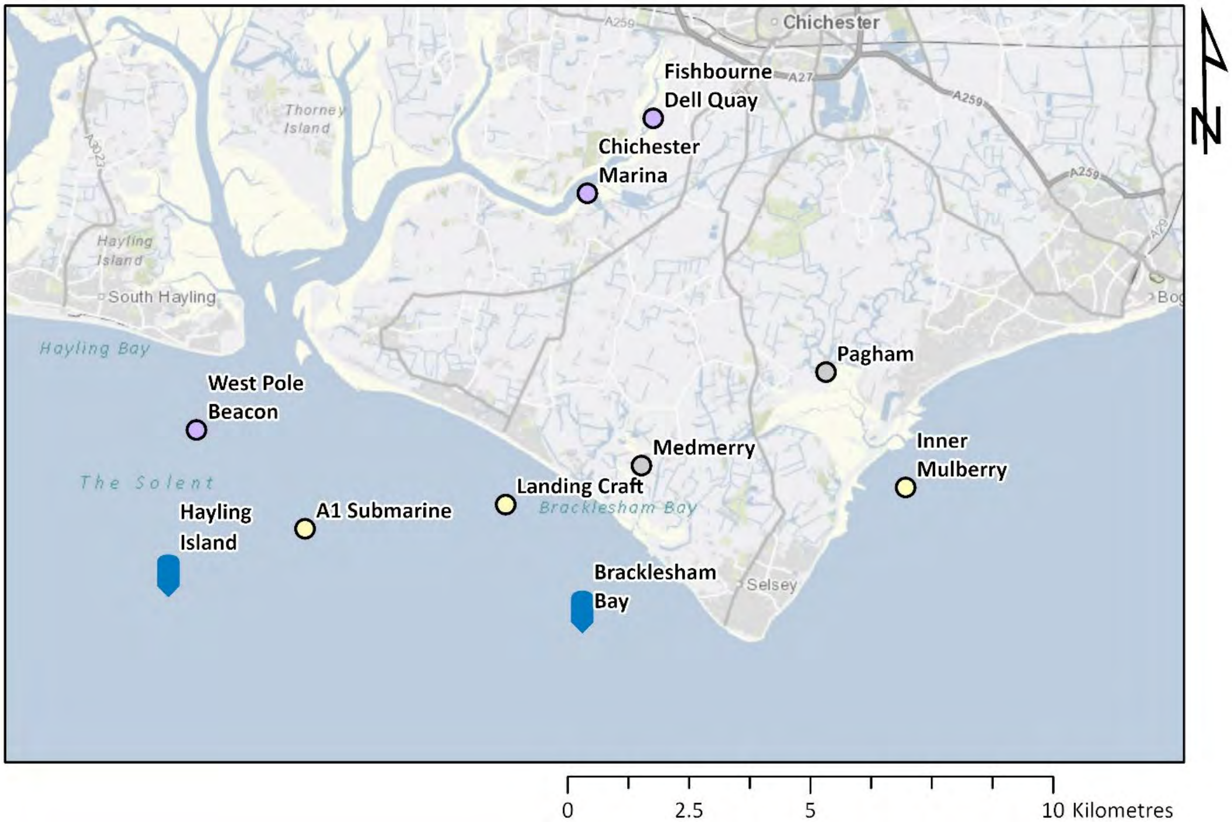
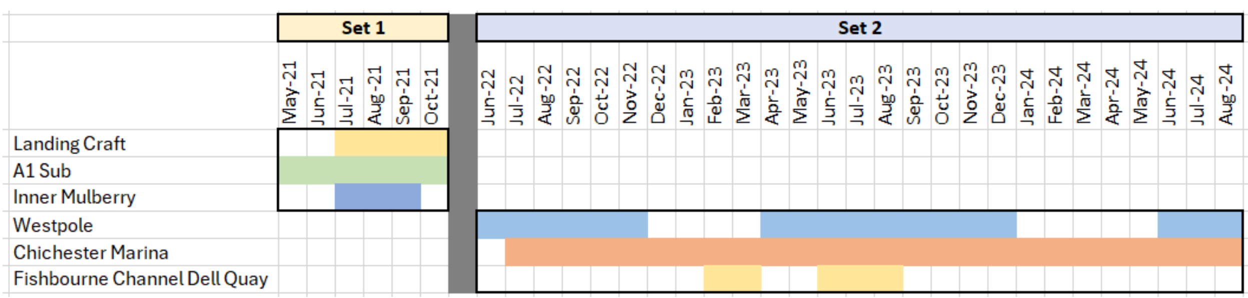


Figure 8 - Site locations for the sonde deployments, Subset 1 shown in yellow and Subset 2 shown in purple - see Table 2 for respective timeframes. Channel Coastal Observatory wave buoys shown as blue pins. Note that the Chimet met station is also located on the West Pole beacon (shown).

Table 3 – Survey coverage at each site.



Each Sonde instrument has the capability to record up to 6 environmental parameters depending on the number of sensors attached to it. The sensors were typically attached to lobster pots sitting approximately 1m from the seabed, with the exception of the West Pole logger which was attached to the structure and positioned higher in the water column than the other loggers. Parameters recorded across all instruments include: temperature, conductivity, turbidity, dissolved oxygen. Additionally, for interim periods records of Chlorophyll were made at A1 Sub, Fluorescent Dissolved Organic Material (FDOM at West

Pole and Chichester Marina, which was also recorded alongside pH and BGA-PC at Dell Quay.

Below each environmental parameter is described:

- **Temperature (°C):** recorded at the near bed (1m above the ground), the temperature sensor reflects the degree of heat that the bottom dwelling species (such as crab and lobster) experience. Temperature is also an important factor for bacteria growth, including harmful types such as *Janickina feisti sp* which are known to affect crab in the Selsey area.

- **Conductivity (mS/cm):** conductivity is recorded for the derivation of dissolved oxygen content. In well mixed environments (such as the sea) it is a relatively constant reading, however in shallow estuarine regions under the influence of river discharge, it can lower (as fresh water dilutes the salty water). Unfortunately, due to biofouling within the sensor the readings of the conductivity faulter after a period of time and it is difficult to pin-point when this happens.

  Turbidity (Formazin Nephelometric Units (FNU)): Of key interest to the CHASM project, turbidity is a relative measurement of the amount of fine suspended sediment within the water column. Higher values indicate higher levels of suspended sediment (cloudier water) whilst lower levels indicate clearer water. As concern has been raised for the fishing ground becoming more silted up over time, this is a key parameter to test whether turbidity (i.e. suspended matter in the water column) has increased over time.

- **Dissolved oxygen content (mg/l or %):** is an important parameter for aquatic life as periods with low oxygen can be a severe stress to aquatic life with the potential to result in death if continued for long periods. Oxygen enters the water column from the atmosphere (and can be assisted by waves and tides) and through photosynthesis (NOAA, 2024). Algal blooms have the potential to smother the aquatic environment, leading to depleted oxygen levels which can be harmful to aquatic life. As this parameter is linked to the conductivity it is difficult to discern trends from the study site, understanding whether they are the result of actual change or biofouling of the conductivity sensor. Low levels of dissolved oxygen can also indicate high levels of suspended sediment.

- **Chlorophyll (µg/l):** Chlorophyll is a biomolecule found in plants, giving them their green colour and playing an important part in photosynthesis (the process whereby plants absorb sunlight and convert it into energy). The presence of high levels of chlorophyll in the water column can be the result of (harmful) algal blooms, which have the potential to damage aquatic life. As algal growth is temperature dependent it is expected that seasonal patterns would be observed, e.g. during the spring algal bloom.

- **FDOM (ppb):** fluorescent dissolved organic matter is a measure of coloured dissolved organic matter (CDOM) in the water column which absorbs blue/UV light and stains water a 'browny' colour. This can be used as a measure for organic content such as sewage. It can also indicate the presence of algae breakdown, following a mass bloom event.

- **pH:** a measure of the acidity of a solution, where a solution with a pH of 0 to less than 7 are acidic, and solutions with a pH of more than 7 are alkaline. Sea water is slightly alkaline (around 8.1) because of the abundance of Hydrogen ions, and this may increase following respiration by plant (algal) life, most notably in spring but also following (harmful) algal blooms which occur later in the year (NOAA, 2024).

The following section of the report details the changes observed in temperature and turbidity from the sonde measurements. Records are compared to environmental parameters, including temperature, wave, windspeed and tide level, to help identify drivers for the changes observed. To do this, the wave buoys at Hayling Island and Bracklesham Beds (part of the National Network of Coastal Monitoring Programmes) and the measurement station at Chichester (chimet.com) are utilized, and their locations can be seen in Figure 8.

Temperature

The first data set (1) was recorded between May and October in 2021 (Figure 9). Over this time period water temperatures gradually increased, reaching their natural arch between June – July at around 17 degrees, whilst a maximum temperature of 22.6 degrees was recorded on the 22/07/2024 at the Inner Mulberry location. This followed the first ever extreme heat warning to be issued by the Met Office on the 19/07/2021 (MetOffice, 2021).

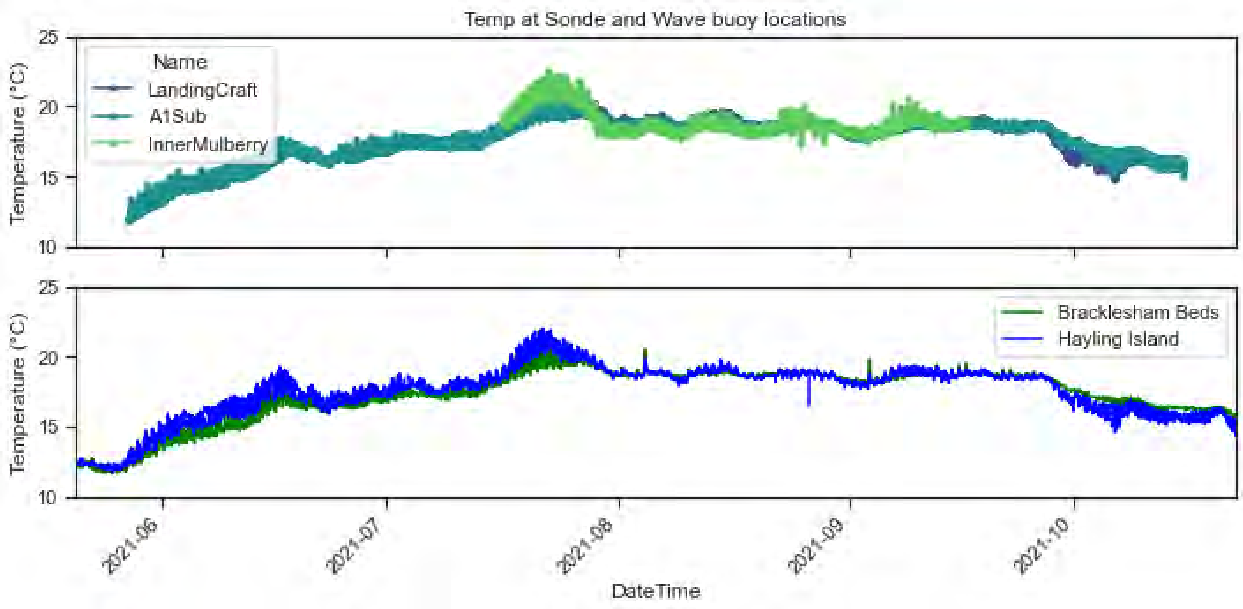


Figure 9 - Set 1: Temperatures at Landing Craft, A1 Sub and Inner Mulberry sonde deployments and Bracklesham Beds and Hayling Island wave buoys between May and October 2021.

The second data set (2) covers a much longer period (June 2022 – present), which to date has captured two winter and three summer periods (Figure 10). This has given us a much better understanding of the long term temperature variations at these locations. Annual highs reach the low twenties whilst annual minimum temperatures are between five to ten degrees. The highest temperature recording was 29.2 degrees Celsius, recorded at Dell Quay on the 07/07/2023. The lowest recorded temperature was 1.077 degrees Celsius on the 06/03/2023. Temperature variability was much higher at Dell Quay than any other location, suggesting a more widely variable water level which may relate to its position in the water table and greater fluvial influence. Ignoring Dell Quay records, the second highest temperature was recorded in Fishbourne Channel at the Chichester Marina site on the 02/08/2024 at 25.6 degrees Celsius. No extreme weather warnings were issued during this period.

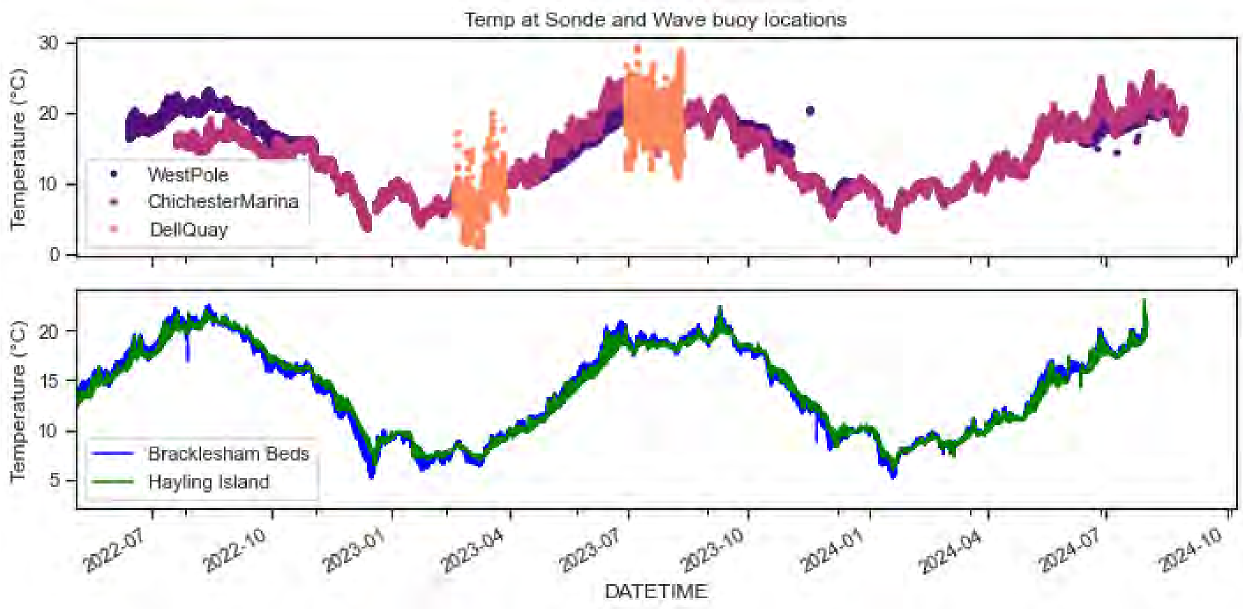


Figure 10 - Set 2: Temperatures at West Pole, Chichester Marina, Dell Quay sonde deployments and Bracklesham Beds and Hayling Island wave buoys between June 2022 and August 2024.

Minimum and maximum temperatures for the first data set (1) ranged between ~13 and ~22 degrees Celsius (Figure 11). For the second data set locations (2) the longer time period meant greater variation – falling between 7 and 23 degrees (Figure 11). Compared to the temperature recordings taken from the wave buoys the first dataset have a good relationship (i.e. they give similar values) whilst the second dataset is both A) much more variable, and B) tends to show warmer temperatures in summer and cooler temperatures in winter (Figure 11). This is most likely due to the fact that the wave buoys are surface measurements taken between 2 and 5 km from the coast whilst the second subset are partially located within the Chichester estuary and subject to greater temperature variations as the water levels are variable (shallow water is able to gain/lose heat more rapidly) (locations shown in Figure 8).

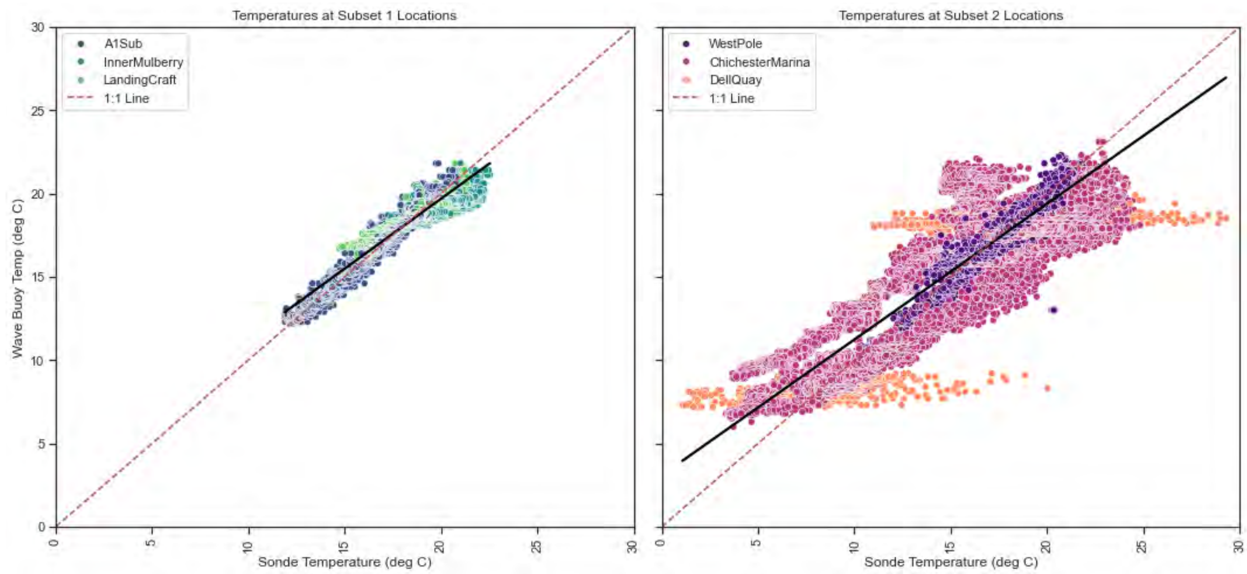


Figure 11 - Temperatures recorded from the Sonde deployments (Set 1 left and Set 2 right) vs the temperatures recorded at Hayling Island wave buoy.

Turbidity

Wave influence

Visually, a clear relationship was found between turbidity and wave energy at all sites, with the exception of the sonde located at West Pole, most likely due to its higher position in the water column. Of the first set of data, peaks in the turbidity can be observed in July, August and October, corresponding to energetic wave conditions at all three wave buoy/station locations (Figure 12).

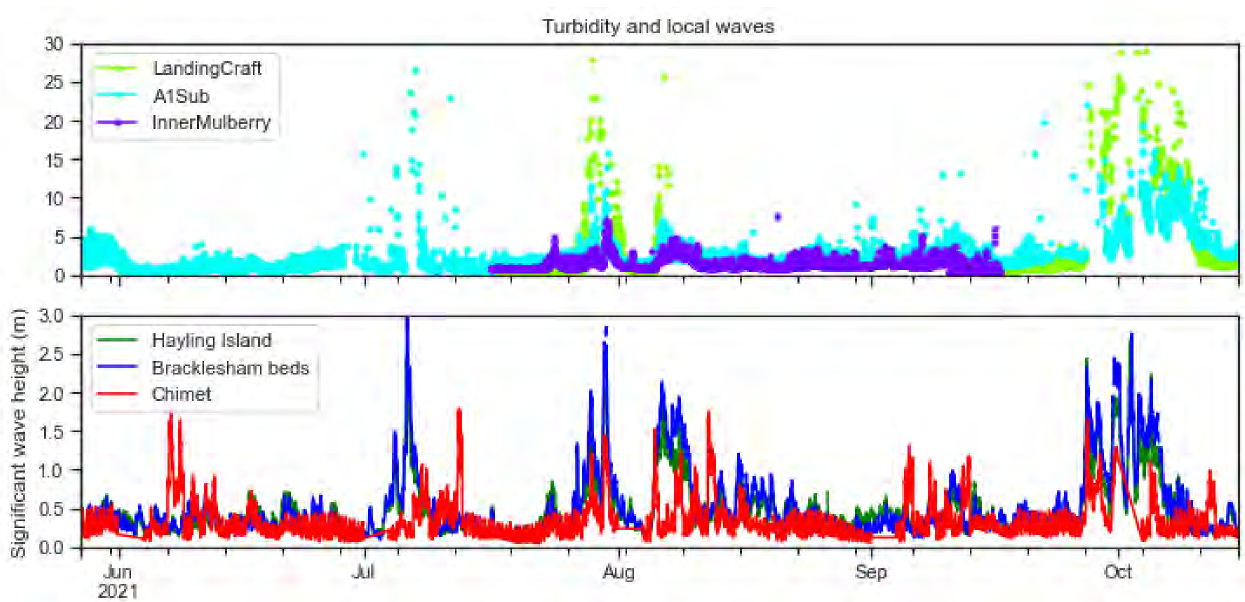


Figure 12 - Set 1 turbidity data record against local wave conditions.

CHASM Crustaceans Habitat and Sediment Movement

For the second dataset, peaks in turbidity and wave height were also observed at Chichester Marina and Dell Quay, however this observation was less clear at the West Pole location, which had two notably large peaks in October 2022 and September 2023 which did not coincide with energetic waves (Figure 13). The two large peaks observed at West Pole indicate that the sediment load is not resuspended material.

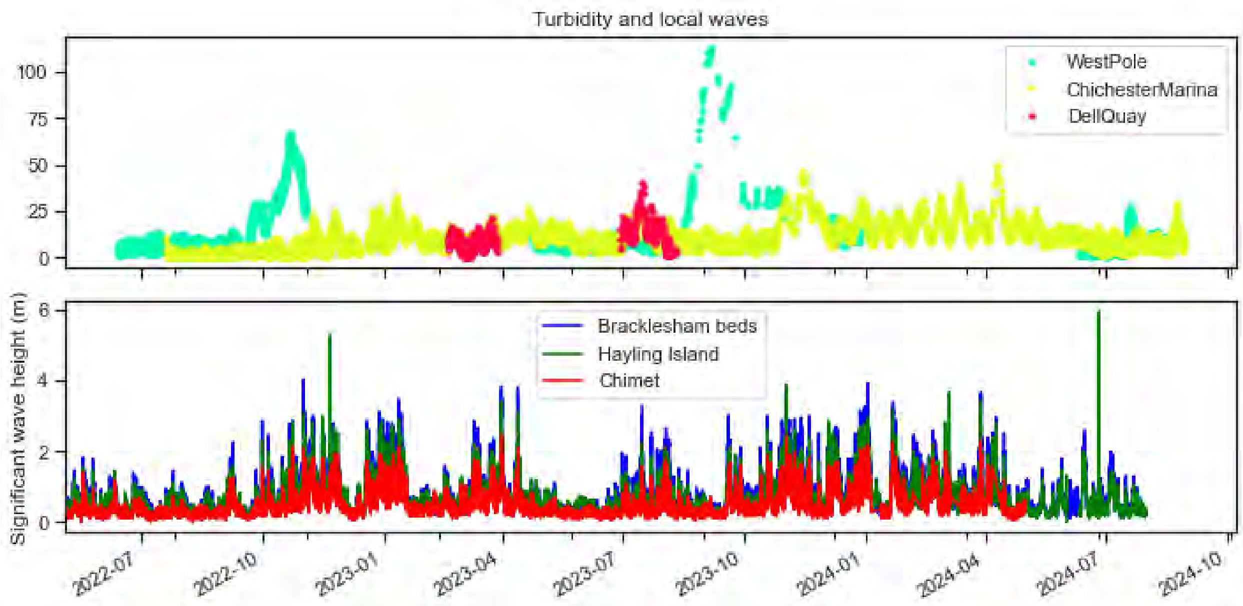


Figure 13 - Set 2 turbidity data record against local wave conditions. Note that the y-axis is greater for the upper graph than for Figure 12.

To better understand the relationship between waves and suspended sediment content the bed orbital velocity was calculated from the Hayling wave buoy and then a linear relationship was determined between this value and the observed turbidity at each of the sites. The bed orbital velocity was calculated following Soulsby's 1997 book the Dynamics of Marine Sands, using pages 75-76. The full method is detailed in Appendix B.

Relationships between the bed orbital velocity and turbidity at each of the 6 sites (per set) are given in Figure 14. The figure shows that there is some weak positive correlation between the first data set (in particular Inner Mulberry and Landing Craft, who both had a R2 value of 0.3), whilst there is no correlation for the other sites. The reason that there is little/no relationship between the bed orbital velocity (although corresponding spikes can be seen between wave height and turbidity in Figures 12 and 13) may be due to several factors. In estuarine settings (i.e. set 2) suspended sediment is likely to be fine, muddy 'cohesive' sediment. One of the properties of these very small grain size sediments is their inability to easily 'settle' in the water column, which can take weeks or longer. Although values of turbidity vary, they are consistently higher in the estuarine set 2 (especially Dell Quay, Chichester Marina). These sites are also potentially under the influence of fresh water outputs which is not be reflected in the calculation of bed orbital velocity from the wave parameters. The most likely reason for the better relationship between bed orbital velocity and turbidity at the Landing craft and Inner Mulberry site is that the grain sizes of the sediments are likely to be larger, which means they will settle out more easily than those estuarine fine sediments and therefore there will be a stronger relationship between energetic-high sediment load and calm-low sediment load conditions. Although there are no strong relationships demonstrated here, waves are still a key physical component in the system for stirring up and mobilising sediment.

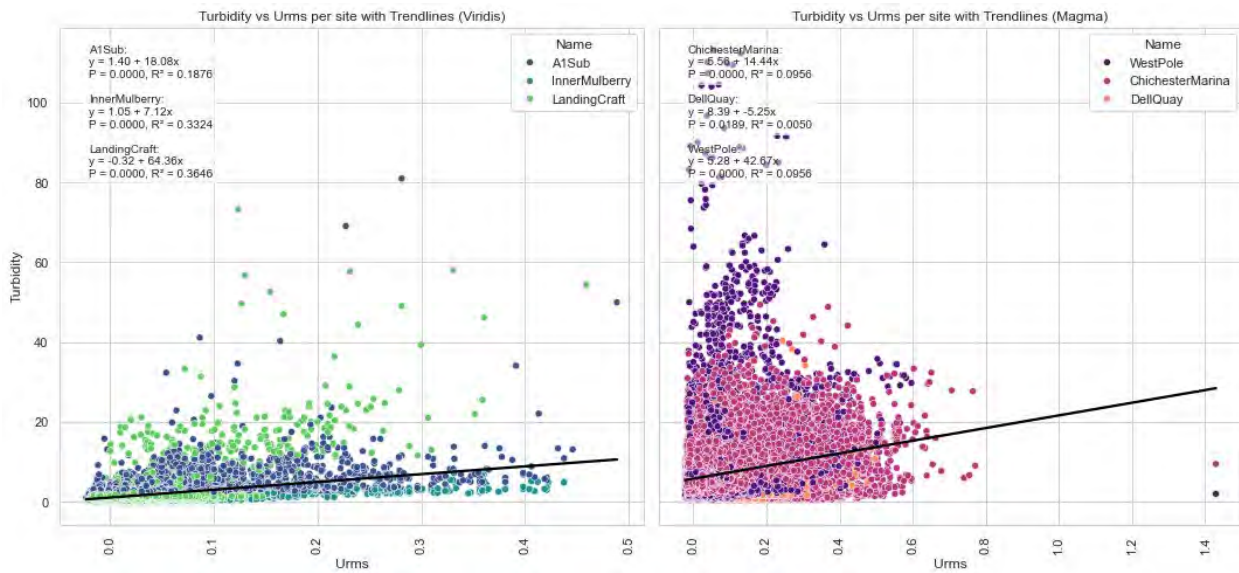


Figure 14 – Plots showing relationship between bed orbital velocity (Urms) and data set 1 (left) and data set 2 (right).

Tidal influence

Whilst waves are an important factor in stirring up sediments from the bed into the water column, the influence of tides is also important. This is true in two ways. **Firstly** the changing water level affects how much the waves 'feel' the bed. Although waves are visible on the surface, they also extend down through the water column proportionately to their size, i.e. bigger waves extend deeper than shallow waves. In water greater than the 'base' of the wave, the sea bed is not disturbed. However in water shallower than the 'base' of the wave, interaction between the wave and the bed occurs (i.e. sediment can be mobilised). Therefore at low tide waves interact with the sea bed more strongly, resulting in more mobilization. **Secondly**, as the water levels change (and the tide moves in and out) currents are generated. In a standing wave system such as this, these currents are greatest at mid-tide.

Here we compare the water/tide levels recorded at West Pole by the Chimet station and the turbidity levels (Figure 15). Except for at West Pole (where the tidal levels are recorded) we might expect slightly different timings for high and low tide, as tide times vary across the coast and can change significantly within estuaries.

The peaks in turbidity can be seen to coincide with low tide across the set 1 sites (Figure 15). As the peak turbidity coincides with the low water level, it is likely that tide acts as a moderator of the trends driven by the waves, rather than the driving force for resuspension of sediments. Notably each of these sites are on the open coast and so the turbidity peaks and low-tide times coincide closely, however, we observed a delay further up the estuary at Dell Quay which is most likely due to modification of the tide as it travels up the estuary. Typically, estuaries are observed to have an asymmetric tidal curve as water flows in slower (due to friction) and out faster than on the open coast.

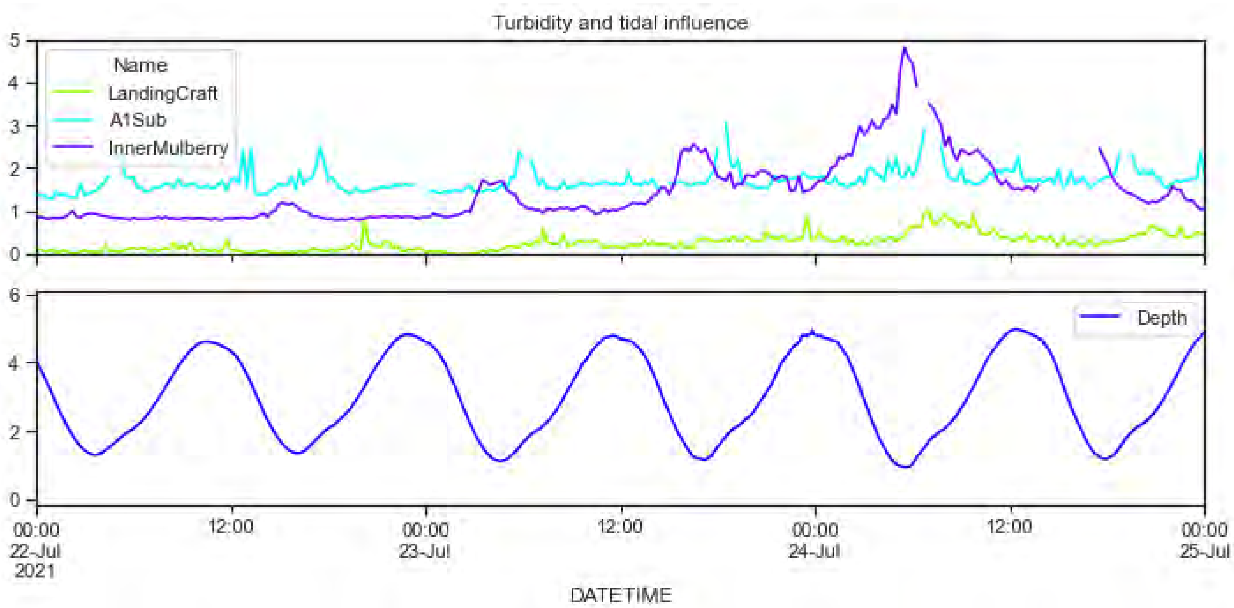


Figure 15 - Set 1 turbidity and water level.

Both the water levels and waves can be seen alongside the turbidity in Figure 16, showing the overall trends relating to the wave events, whilst the tides essentially introduce noise to the dataset.

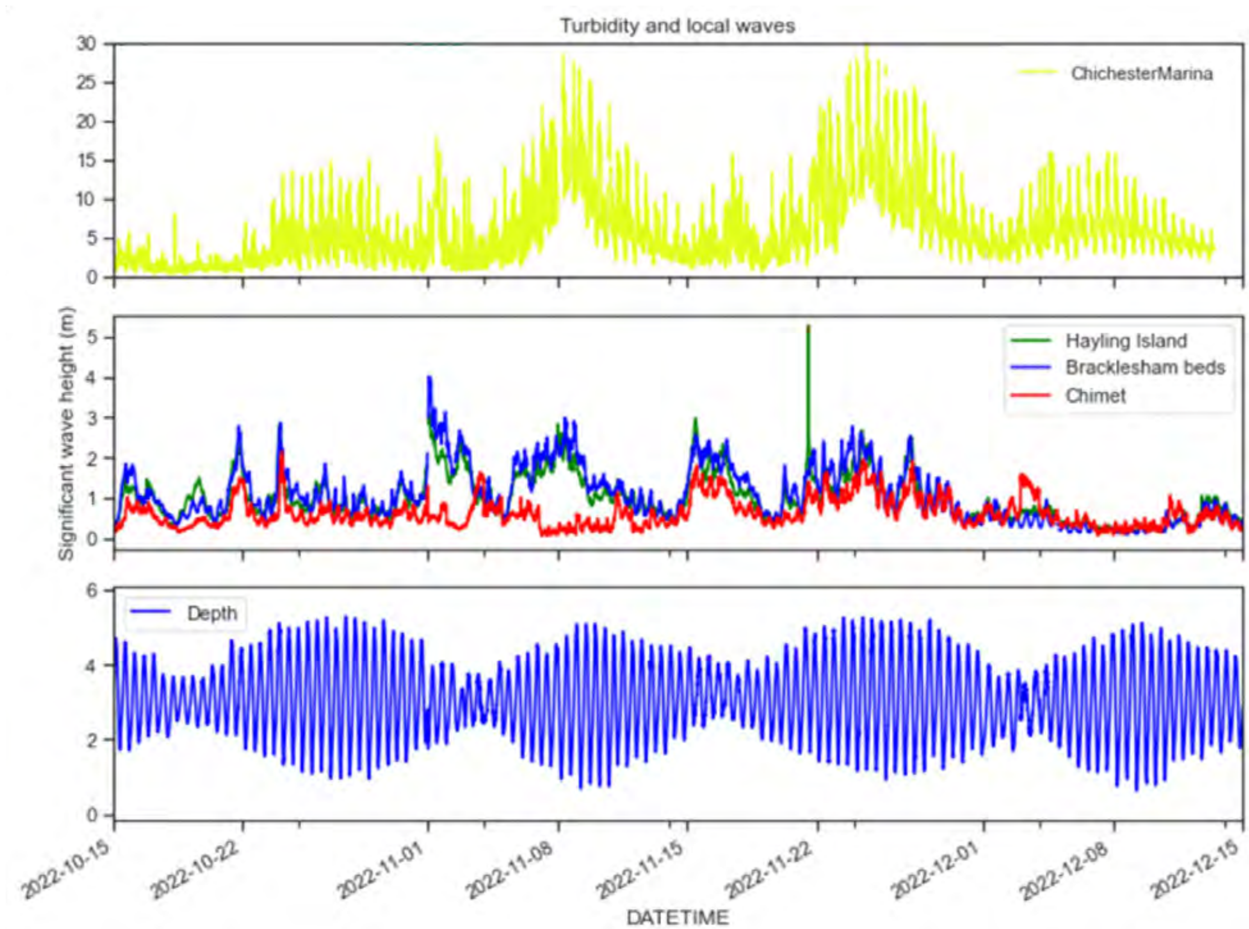


Figure 16 - Turbidity, waves and tides at the Chichester Marina site.

4.2 Satellite analysis

Glob-Colour, a product derived from multiple satellite images was used to determine long term trends in ocean colour (Figure 17; Copernicus, 2024). Data were extracted from the Cefas Eutrophication x-cube viewer (https://eutro-cube.cefas.co.uk/) as an average value of the area under the study site area (study area shown in Figure 1). The approach used mirrors that followed by Cefas (2016) in their report on changing suspended sediment content of UK waters. We focus on two particular sensors:

- (inorganic) Suspended Particle Matter (SPM)
- chlorophyll-a concentration

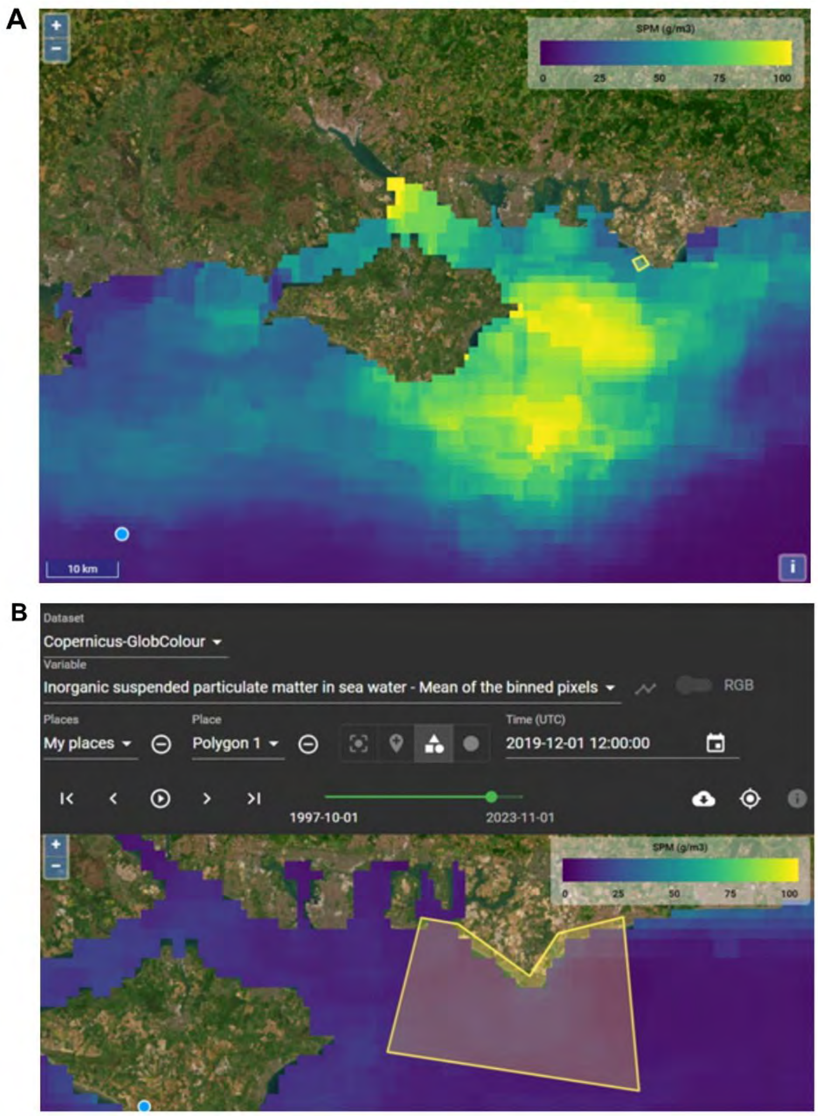


Figure 17 – Clips from the Cefas Globviewer tool (available at https://eutro-cube.cefas.co.uk/). A) example of the highest Suspended Particle Matter event recorded in winter 2002.B) the area analysed below covering the CHASM area of interest.

The SPM values shown in Figure 18 show a strong seasonal pattern, with higher levels of SPM in the winter (October to April) than the summer months (May to September). In areas with large sediment laden rivers this can be attributed to increased precipitation over the winter months, however, within the study site it is much more likely to be due to bed sediments becoming resuspended due to increased waviness. Notably, the winter levels of SPM are much higher in 1998, 2001, 2002, 2003, 2007 and 2014. The peak in winter 2013/2014 SPM may be linked to the storm events that occurred that year.

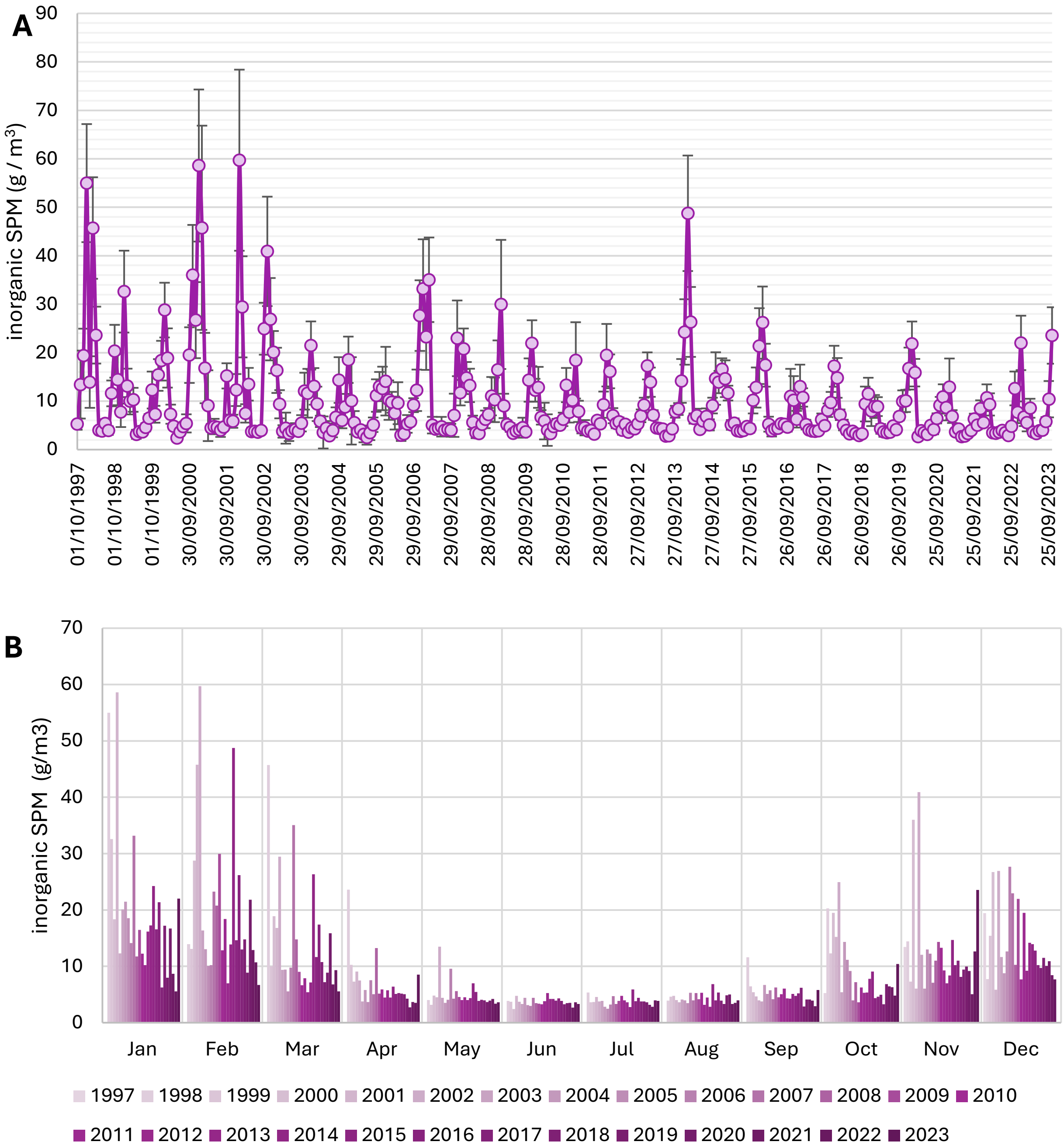


Figure 18 – Monthly values for inorganic Suspended Particle Matter (SPM, g/m³) across the CHASM area of interest between 1997 and 2023 A) overtime and B) per month. Data extracted from the GlobColour viewer.

The Chlorophyll-a values shown in Figure 19 also show a strong seasonal pattern, but this time the values become higher as water temperatures increase in Spring. For the older years this peak was typically in May, however, more recent data suggests that this is now occurring in April (Figure 19 B). Additionally, over time there appears to be a shifting baseline with higher levels of Chlorophyll seen throughout the year. This may be linked to increasing sea temperatures overtime as demonstrated by Kassem et al. (2022).

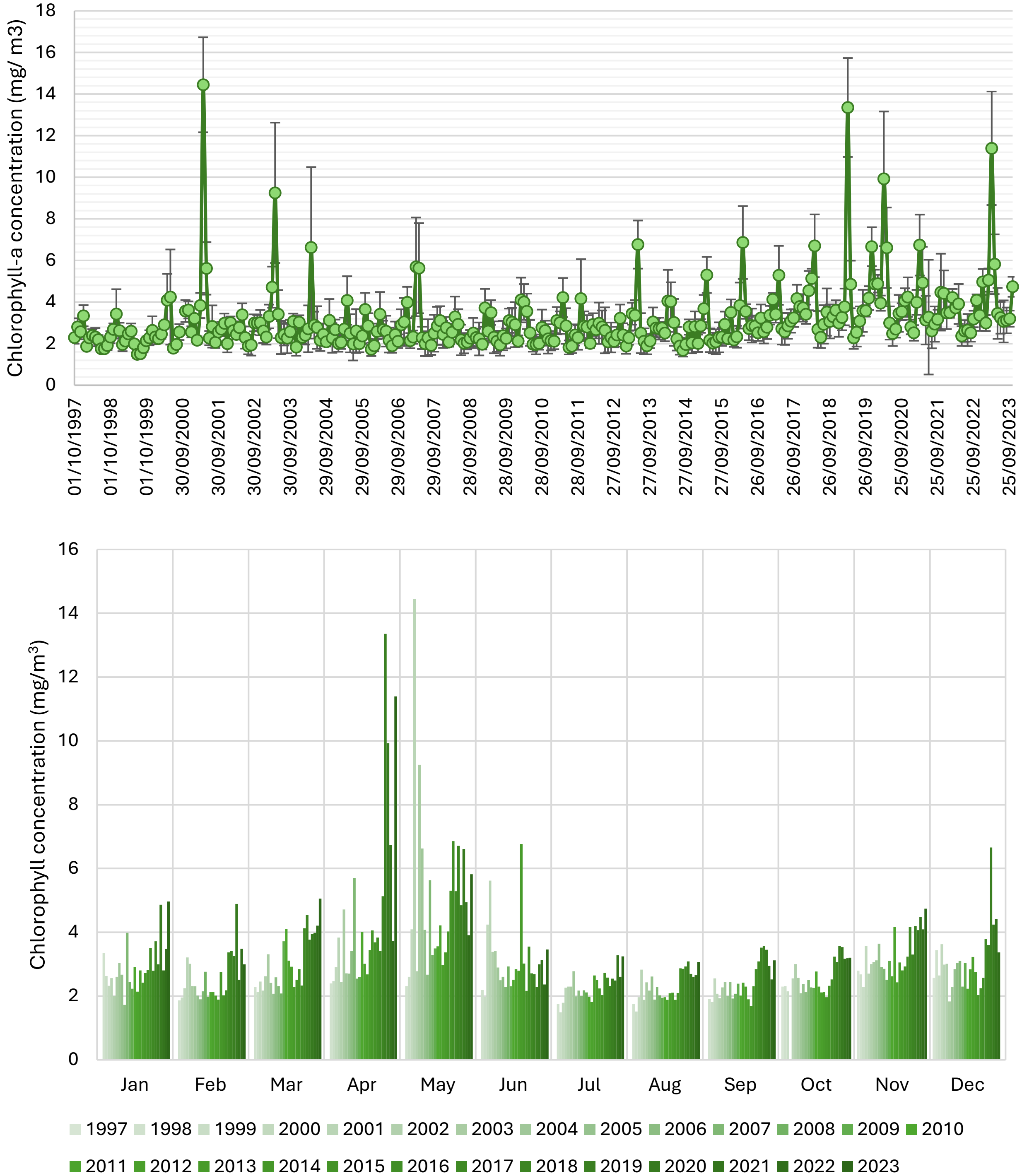


Figure 19 – Monthly values for Chlorophyll-a (mg/m^3) across the CHASM area of interest between 1997 and 2023 A) overtime and B) per month. Data extracted from the GlobColour viewer.

5. Sediment source identification

5.1 Dredging

Dredging disposal records were analysed to determine 1) where the sediment is disposed and 2) how much material is disposed and 3) has the volume changed over time. Data was supplied by Cefas (Centre for Environment, Fisheries and Aquaculture Science) giving date, disposal site, licence number and wet/dry tonne disposal quantity between 1984 and 2022.

The dredging records showed that both the number of disposals and the overall quantity of disposals had increased (Figure 20). The average volume of material per dredge had also increased from less than 5,000 on average to around 20,000 wet tonnes. In 1997 the largest record of material disposed in any one year was recorded at 6.5 million wet tonnes of sediment, seconded by 4.8 million in 2014.

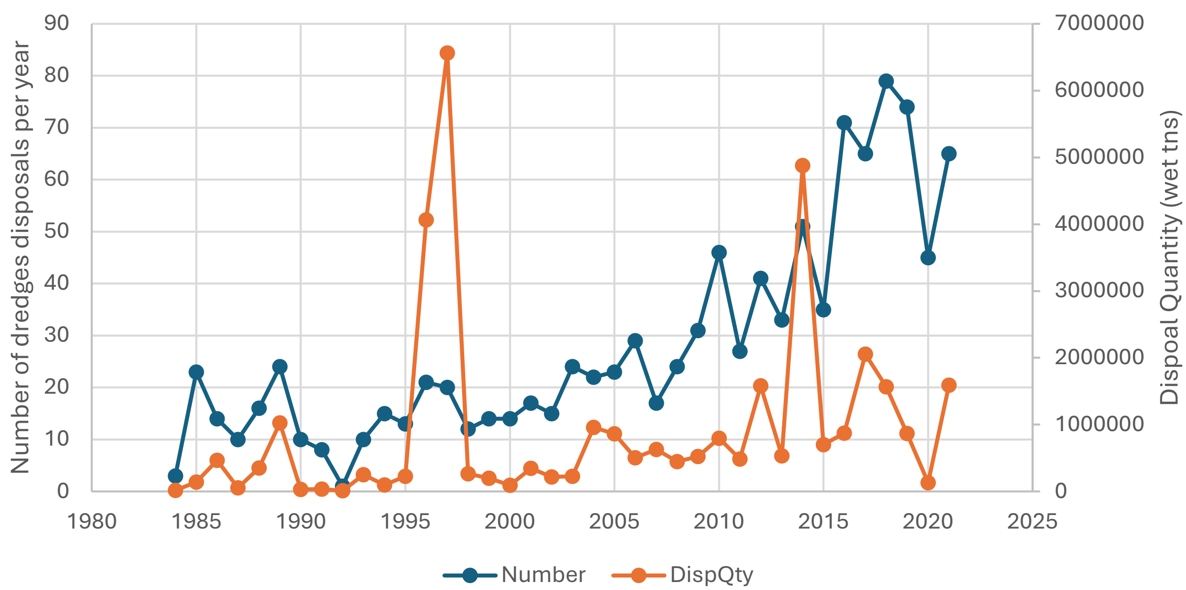


Figure 20 – Number of dredge disposals per year and the quantity (wet tonnes) of dredge disposals each year.

During this time, the vast majority of disposals have been licenced to Nab Tower, the dispersive site, located approximately 13 km southeast of Bembridge, Isle of Wight and approximately (roughly 20km southwest of Selsey), in 30-40m water depth (Figure 21). The site is intended to be a dispersive site, i.e. tidal currents dissipate the material deposited there, so there is no large mass of deposits which could cause any navigation hazard. Due to the large amount of material placed here over the years, Cefas recently carried out some numerical modelling to determine the fate of the sediments that were deposited here (Kelly, 2021).

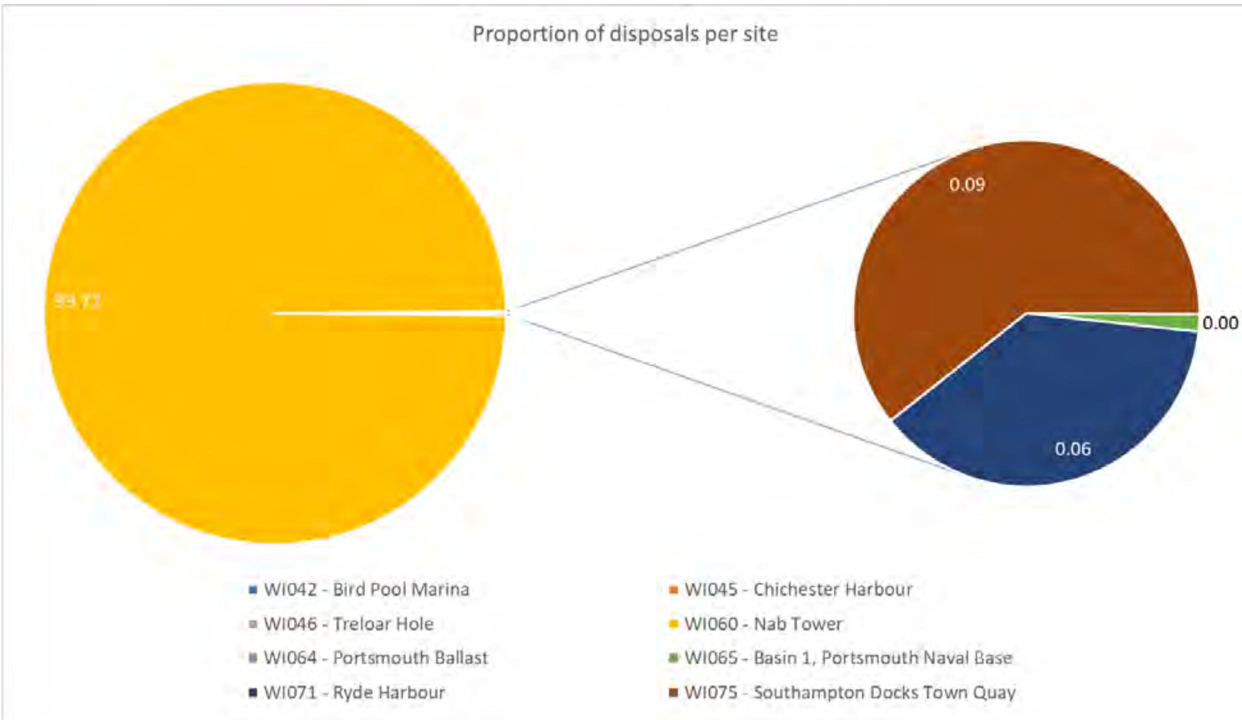


Figure 21 - The proportion of disposals made to each licenced disposal site in the Southern Central region between 1984 - 2022.

As part of the different questions and scenarios investigated by Cefas, they wanted to understand if sediment could reach the nearest shoreline. This was done by modelling the dispersal of four different sizes of sediment, one cohesive (silt 50 μm) and three non-cohesive (very fine sand, fine and medium sand) and under the effect of tidal currents and wind over a 30-day period. The modelled fractions were intended to represent a maintenance dredge which typically have much higher fine content than the capital dredges. The volumes used were intended to represent a large dredge (totaling 380,000m^3) of sediment, of which 70% was cohesive material and 30% was non-cohesive (sand).

The model found that the cohesive material (the silt) was suspended very rapidly and then did not fall out of suspension in the time period modelled, i.e. once mobilised it stayed in suspension. During this time tidal currents dispersed the cohesive sediment widely across the domain, which includes the CHASM area of interest. If any deposition did occur it did not exceed 0.5mm (Figure 22). The smallest non-cohesive material (fine sand) that was modelled was not found to be deposited in the CHASM area in the time period modelled, unless again this level was below 0.5mm (Figure 22).

A

B

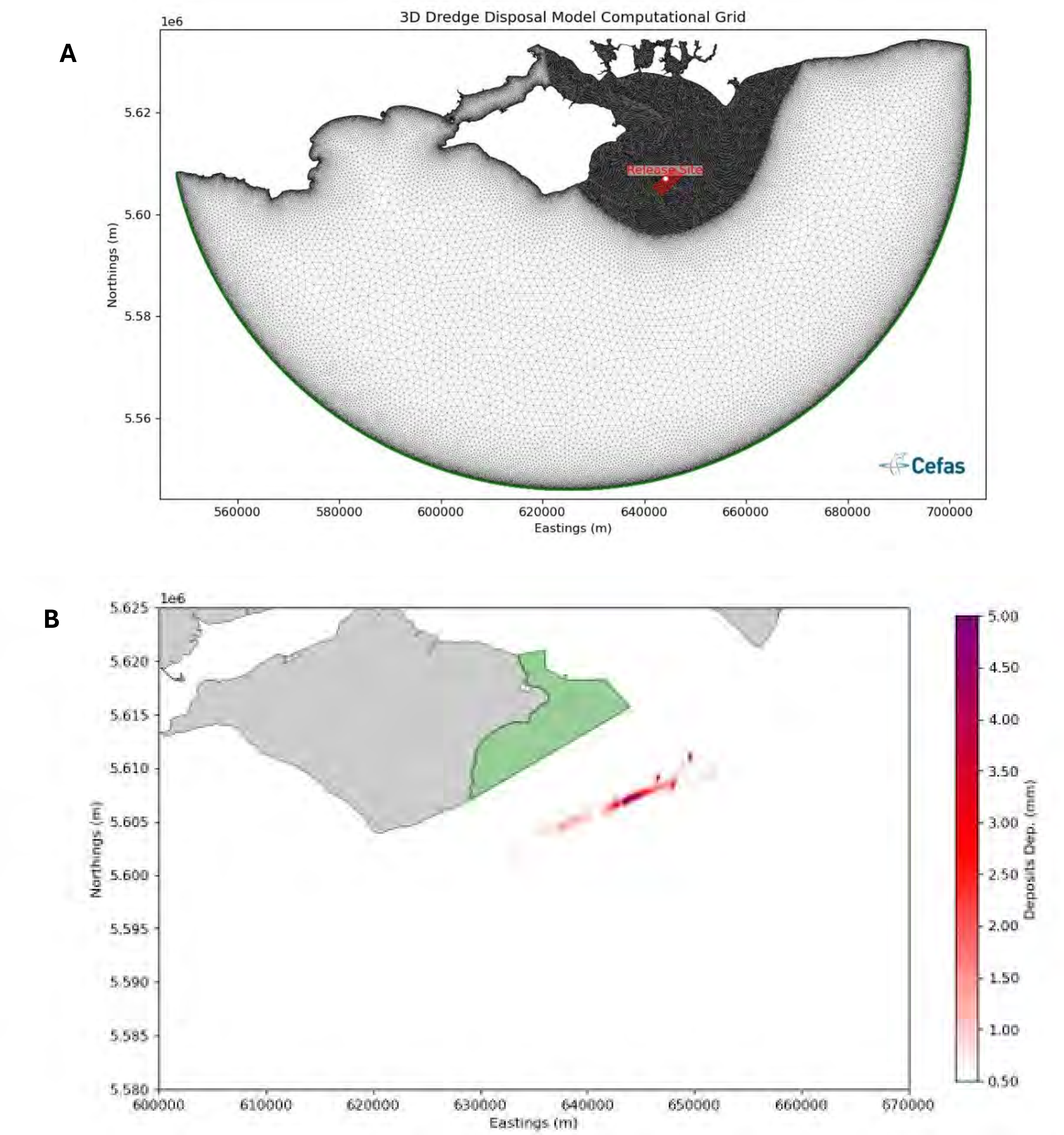


Figure 22 – A) Cefas model domain and release point (Nab Tower) B) Footprint (based on an hourly sample rate) for non-cohesive very fine (125 micrometre) sand - taken from Cefas disposal modelling study (Kelly, 2021)

The dredge disposal volumes and work by Cefas presented above focuses on the disposal of dredge materials at the Nab Tower site only. We should also consider the release of sediments into the wider area from the dredge extraction site (Figure 23). Here we present the locations of the sampling of the dredge sites between 2009 and 2022. The Marine Licence Application numbers are available in Appendix D, and further information on each case is available from the Marine Management Organisation's Public Register:

https://marinelicensing.marinemanagement.org.uk/mmofox5/fox/live/MMO_PUBLIC_REGISTER/. Without an overlap in dates between the dredge extraction or disposal data it is difficult to understand if there is any (or no) relationship between the suspended sediment concent of the water column and dredging activites. Therefore, it may be of value to look carefully at dates of dredge activities during the Sonde deployment period as data become available. Furthermore, it would be valuable to assess the various chemical compounds reported in the dredge extraction sediment samples taken as part of the Marine Licensing process to understand what is contained and the potential impacts of the presence of these chemicals.

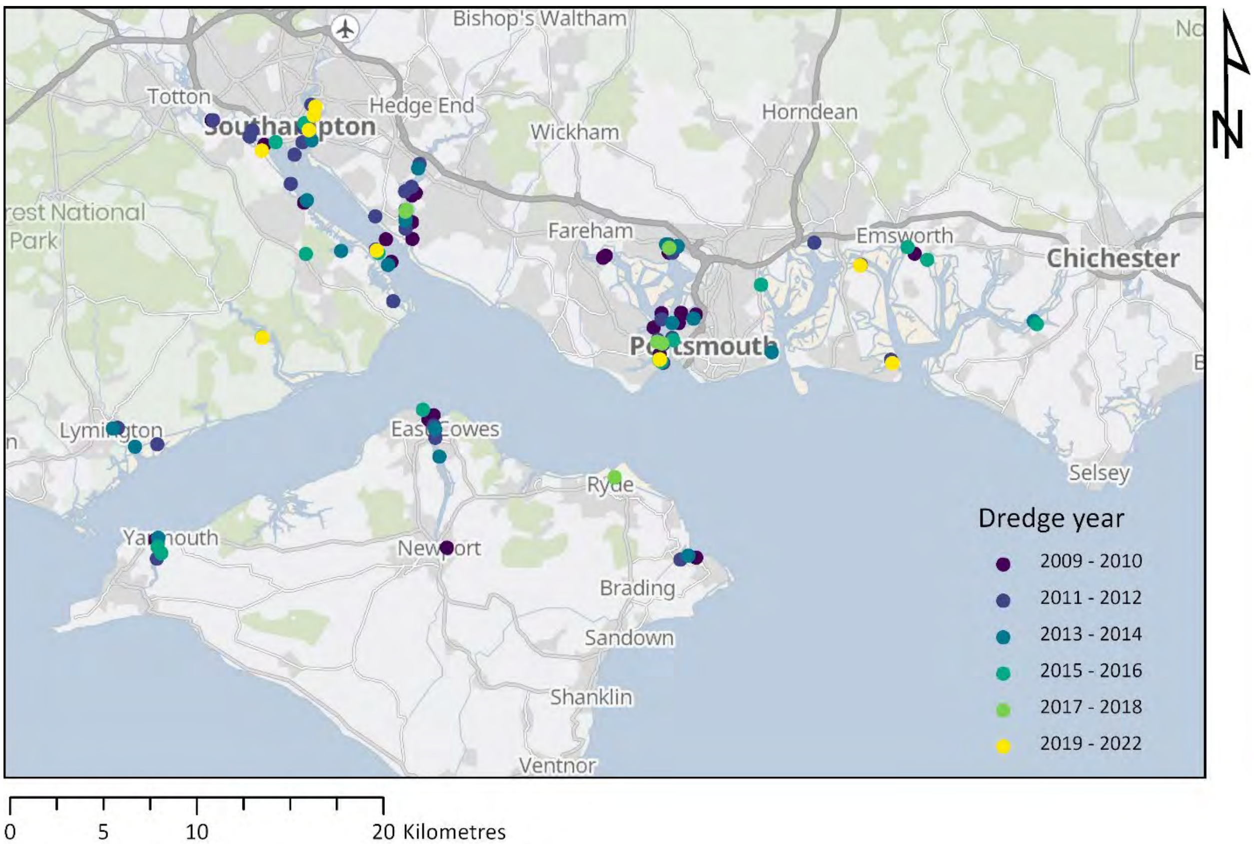


Figure 23 - Dredge locations by year estimated from licence number and shown by year. Background mapping contains OS Data © Crown Copyright and database rights 2023. Contains data from OS Zoomstack.

5.2 Medmerry re-alignment scheme

Following the breach and managed realignment works in 2013, significant change has occurred on the site at Medmerry. We used two 3-D surface models to calculated the change that had occurred between 2013 and 2022 (Figure 24). A full methodology is given in Appendix C. By calculating the difference it is possible to see which areas have gained or lost sediment, however, it is not possible to detect where the sediment has gone to, although this can sometimes be inferred. The results show:

- Since before the breach in 2014, about 600,000 m^3 of sediment has been eroded from the beach face.
- Approximately 66,000m^3 is likely to have comprised shingle and sand 'beach' sediments which rolled backwards, accounting for about 1 tenth of the material which was lost.
- In total an approximate net loss of 543,000 m^3 of sediment has occurred.

Although the data shows there has been a large net loss of sediment, we do not know exactly where it has gone. We can presume that the coarser material which formed the beach rolled backwards, as this is typical behaviour for gravel sediments. It is likely that the majority of the sediment which has eroded was consolidated clay/fine mud sediments which were previously protected by the beach.

What happened next to the fine sediments is unknown. This sediment is most likely to have been mobilised (suspended) and then washed alongshore or offshore. Deposition of fine material is only likely to occur in very low energy environments. It is highly likely that due to the fine nature of the sediment, that it has dispersed and would not be identifiable in any one location. There is a chance that a small ebb-tidal delta may have developed, close to offshore of the main Medmerry channel, as this is found amongst all other estuaries in the area, e.g. Chichester, Portsmouth and Langstone Harbour. An ebb-tidal delta is a deposit of (normally sandy) material on the seaward side of the tidal inlet. If this is the case, this feature should be detectable in the recently collected 2024 bathymetry dataset of this area. Most likely the fine sediments have dispersed and there is no detectable mass of sediment which could be attributed to the loss from the Medmerry area. Note that if the total area of the CHASM area of interest could be said to be approximately 400km^2 if spread out evenly the amount of sediment lost from the Medmerry scheme would be approximately 1.36 mm thick (which is not detectable through the levels of bathymetric surveying error (which are in the region of ±0.3m)).

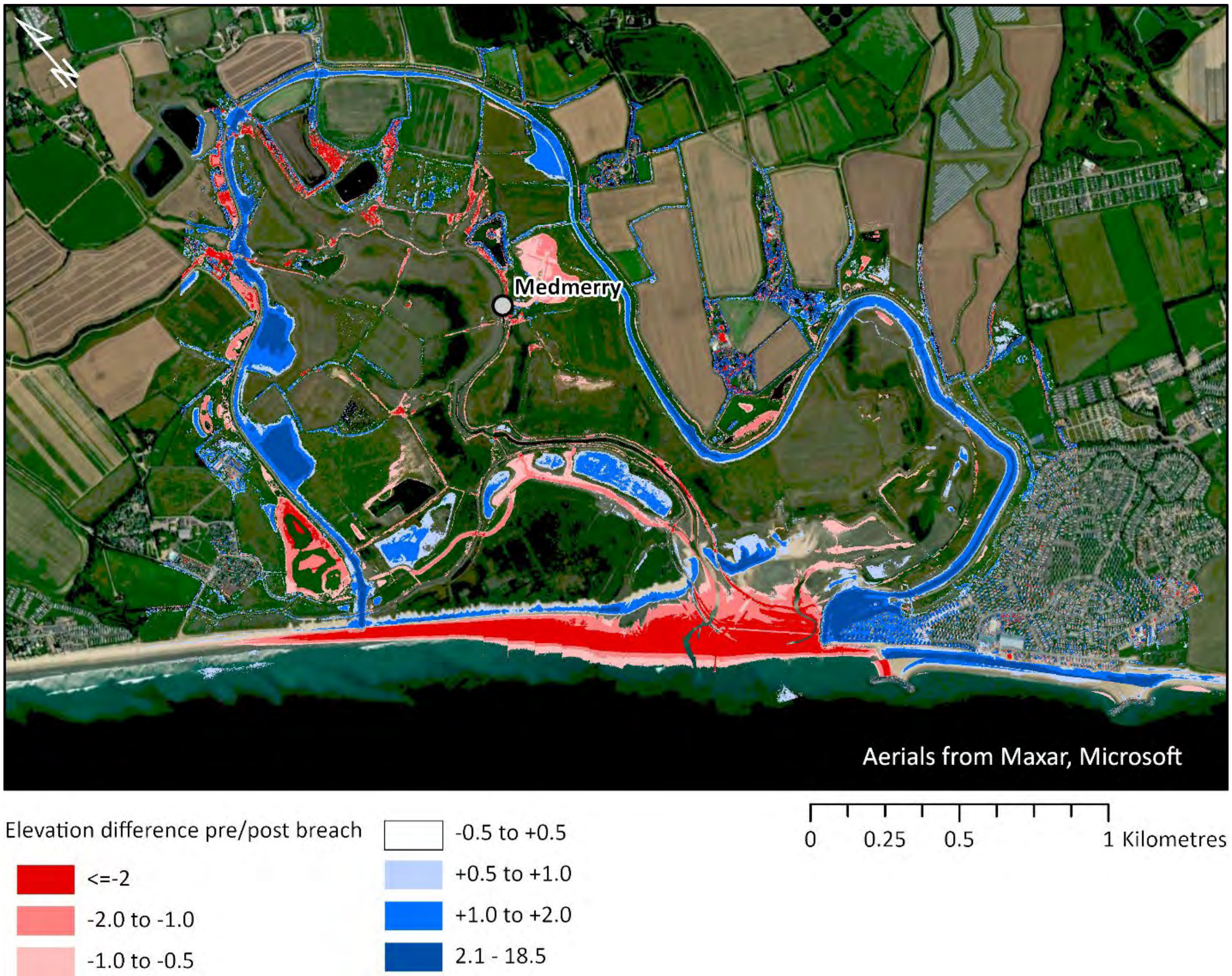


Figure 24 - Elevation difference model of the Medmerry site before the realignment project (2008) and to the most recently available data (2022). Data courtesy of the Channel Coastal Observatory freely available from www.channelcoast.org.uk. Note that the area comprising the newly built bund and outside of this area was not included in the volume calculation.

5.3 Further inputs

The following estimations are sourced from the wider literature, and seek to provide a comprehensive estimation of the sources of sediment overtime.

Table 4 - Sources of sediment input into the CHASM area of interest over time.

Source	Estimate	Reference
English Channel	Velegrakis *et al*. (1999) estimated a background flux of between 2 and 71 million (average 20 million) tonnes/year of material passes through the English channel into the dover Straits. This is a balanced amount of material and can be considered 'background noise'.	Velegrakis *et al*. (1999)

Coastal erosion (outside Medmerry)	Following the construction of defences, which began in the 1960's at Selsey, the ongoing contribution of beach and cliff sediments to the nearshore area is becoming smaller and smaller each year.	SCOPAC, 2012
Beach recharge	There is an annual recharge to Selsey Bill in the order of 6,000 m3/year of pebbles from an inland source. If 1-5% of this were fine sediment, that would introduce 60-300 m^3	SCOPAC, 2012
Construction in the marine environment	Disturbance of the ground by construction activities such as piling, excavation etc on the coast may have a very local short term effect on the suspended sediment content within a local water body, however this is not anticipated to be greater than would occur during a natural winter storm event.	-
Aggregate Dredging	Approximately 4 million tonnes per year of sand and gravel is extracted in the south coast dredging sites. This could release around 40,000 – 50,000 tonnes/year of fine sediment into the water column although this is over a wide offshore area.	Crown Estate, 2020.
Trawling	Impact unknown, but 'no trawl zones' implemented within key sensitive sites. Thought to be small in comparison to that readily mobilised by storms.	-
Rivers	Each river contributes '8,000 to 9,000 tonnes/ year, and very low in comparison with marine sediment sources.'	HR Wallingford, 2023
Pluvial	Not known, however considered to be small due to large expanse of urban areas and not thought to have increased over the recent past.	-
Aeolian	In their 2016 report Cefas considered the inputs of aeolian (wind-blown) sourced sediment onto the environment. Saharan dust reaches the UK following large dust storms. Cefas concluded that the effect of this source would be negligible.	Silvas *et al.*, 2016.
Sewage (organic material)	Currently unknown. At present the water companies make publicly available the dates and numbers of hours that sewage is released into the sea, however the volume of waste is not quantified. This is a key area for further investigation, and consideration of local population growth overtime should be considered.	-

6. Discussion

The following discussion revisits each question that was set out at the beginning of the report and seeks to answer it with the results and interpretation of the analysis alongside the wider literature.

1. **What sediments make up the seabed and has this changed overtime?**

   A wide selection of surface samples were taken across the CHASM area of interest, both close to shore and offshore. The vast majority of the samples consisted of non-cohesive sediments, i.e. gravel and sand. This was typically around 70% gravel and 30% sand with a small proportion of fine sediment (typically less than 5%). Some sites were in exception to this – some samples from Medmerry bank, Medmerry breach and near Hounds Reef were all largely sandy samples, although it should be noted that sheets of sand can sometimes be deposited and remobilised rapidly, and that the samples only represent a snapshot in time. The only sites which were distinctly cohesive were 'Medmerry DO1' and 'Medmerry S5' which were taken from the Medmerry site, within the intertidal area. As these sediments are from within the realignment site this is expected.

   The grab samples captured here represent a single point in time. Following the release of the Channel Coastal Observatory bathymetry data (recorded summer 2024) should be compared with older data (pre breach) to understand whether bed elevations have changed in and around the breach area, and whether the surface roughness (which is indicative of sediment bed type) has changed.

   Overall, the fact that fine sediments are typically scarce across the study site suggests that any fines are kept in suspension. The samples do not indicate that the area of interest is becoming more muddy overtime.

2. **What is the water quality (temperature, turbidity *etc.*) like within the study site and has it changed overtime?**

   The sonde data captured across the CHASM area of interest gives a detailed picture of the water quality parameters within the spatial realm, and demonstrates differences in behaviour between records on the open coast and those sheltered within the Chichester estuary. Typically, we found that the sondes within Chichester Harbour experienced greater fluctuations in temperature (most likely due to the shallower water being able to gain/lose heat more easily) and turbidity was consistently higher than outside the estuary (most likely due to the increased wave-bed interaction during low tide, and also greater sediment stirring caused by greater tidal currents within the estuary). Outside Chichester Harbour, the sondes showed more consistent temperate readings (which correlated well with (surface) buoy readings further offshore) and less turbid water, although a stronger relationship between waves and turbidity was found, which was attributed to a lower background level of turbidity outside the harbour.

Whilst the sondes describe the variation within the site well, the limited time coverage cannot explain the longer term trends, so here we looked to the available satellite data (using Cefas' GlobColour viewer). We inspected monthly records of inorganic Suspended Particle Matter (SPM) and Chlorophyll-a from 1997 to 2023. Both parameters demonstrated seasonal trends – with SPM becoming higher in winter months (October to April) most likely due to resuspension of material due to waves, and Chlorophyll peaking in spring likely as water temperatures increased. Over the long term, SPM did not appear to be increasing, which agrees with the previously analysis of long term wave buoy trends, which also did not see a long-term increase (Searle and Thompson, 2021). In contrast, Chlorophyll-a has shown a shift in baseline overtime, showing increases in each month, and additionally the peaks in Chlorophyll-a occur much earlier (April) than the older records. This colludes with the findings by Kassem *et al.* (2022) which showed increases in sea surface temperature.

3. **What are the sources of (fine) sediment in the system and has their magnitude changed over time?**

To answer this question an array of sources were considered and two sources of particular local concern were examined more closely.

Firstly, it was shown that the quantity and frequency of dredge disposals (which largely occur at Nab Tower) has increased overtime since the early 1980s when records began. However, a modelling study carried out by Cefas investigating the fate of the sediments disposed of at the site, found that it was unlikely that sediment disposed at the site would be deposited at any of the nearby coastal sites. The modelling did however show that the fine material was suspended and widely dispersed throughout the model domain. Further information of volumes and dates from dredge extraction/disposal is required over the sonde monitoring period time period to investigate whether there is a correlation between dredging activities and suspended sediment content.

Secondly, a quantification of volume change from the Medmerry scheme was calculated, which could represent a significant input of sediment locally. It was found that a net loss of 543,000 m^3 had occurred following the realignment scheme. This loss most likely consisted of fine cohesive material, which had previously been protected by the beach. Despite this being a locally significant sum of material, spread evenly over the approximate area of the study site, little over a millimetre of burial would occur, and it is likely that (following the satellite imagery analysis and Cefas modelling report) once suspended, the fine cohesive material remains in suspension. Further investigation should be carried out to investigate if a ebb-tidal deposit has formed fronting the new channel mouth at Medmerry, which may have potentially altered the bed sediments (which were previously recorded as rock in the 2013 Channel Coastal Observatory survey).

Numerous other sources of sediment were considered, however, none were identified as having changed significantly overtime, or they were not in close enough proximity to be significant, or they were simply not large enough to be considered significant.

4. **How might what we have learnt about the sediment system have influenced the decline in crab and lobster populations?**

The evidence given in this report suggests that overall there has not been an increase in inorganic sediment to the site overtime. This is important because increase in inorganic sediment can a) lead to the burial or 'smothering' of marine habitats, b) can act as a vector for other environmental pollutants, for instance TBT which can be found in flecks of certain types (now banned) of antifouling paint. That said, there is a small likelihood that the Medmerry realignment scheme has caused the formation of an ebb-tidal delta deposit, just offshore of the main channel. This should be further examined by comparing the (soon to be released) bathymetry data captured earlier this year, with the previous dataset, recorded ten years previously. If a significant bed deposit has formed here, this should be detectable in a difference model calculation. Additionally, analysis of the associated backscatter data may be able to identify if the area is covered by rock (as previously) or mud.

The report does however indicate an increase in chlorophyll-a levels across the study site over the long term, which is thought to be linked to long-term increases in temperature. Better quantification and understanding of the satellite derived parameters should be understood. Other opportunities to examine potential important factors for chlorophyll-a growth (such as sources of nitrogen and phosphate) should be examined, primarily sewage and agricultural run-off over-time.

7. Summary and conclusion

The work carried out as part of this result suggests that there has not been a significant increase in inorganic sediment (i.e. gravel, sand or mud) overtime over the larger study area. Further investigation into the Medmerry breach should be undertaken to explore any changes in the nearshore area which might have changed in response to the changing morphology and current flows in this area post breach. This may have resulted in some local changes.

It is also recommended that a better understanding of the organic/biotic component of the environment and water quality is sought. The long-term trend analysis of chlorophyll-a from satellite data suggested that there was a shifting baseline, with algal blooms occurring earlier in the year, and elevated background levels (in comparison to earlier records). This may be linked to the long-term temperature increase. An understanding of the limiting factors should be sought, namely through understanding changes in nutrient sources (i.e. from agricultural run-off and sewage). Algal blooms can lower oxygen levels and cause potentially damaging environmental factors for aquatic life.

8. References

Bateman, K.S., Stentiford, G.D., Kerr, R., Hooper, C., White, P., Edwards, M., Ross, S., Hazelgrove, R., Daumich, C., Green, M. J., Ivory, D., Evans, C., Bass, D. (2022) Amoebic crab disease (ACD) in edible crab Cancer pagurus from the English Channel, UK. Diseases of Aquatic Organisms, vol 150, (1-16) https://doi.org/10.3354/dao03668

Cope, S.N., Bradbury, A.P. and Gorczynska, M. (2008) SOLENT DYNAMIC COAST PROJECT Main Report (A tool for SMP2) TR 10. Channel Coastal Observatory. Available at : https://coastalmonitoring.org/reports/admin/index.php?link=&dla=download&id=687&cat=103/TR011_2008_SDCP_Main.pdf [Last Accessed: 12/09/2024]

Copernicus (2024) https://doi.org/10.48670/moi-00279

Dale, J., Burgess, H.M. and Cundy, A.B. (2017). Sedimentation rhythms and hydrodynamics in two engineered environments in an open coast managed realignment site. *Marine Geology*, *383*, pp.120-131. https://doi.org/10.1016/j.margeo.2016.12.001

Dale, J. (2018). The Evolution of the Sediment Regime in a Large Open Coast Managed Realignment Site: A Case Study of the Medmerry Managed Realignment Site, UK. Unpublished PhD Thesis. School of Environment and Technology, University of Brighton., UK (2018). https://research.brighton.ac.uk/files/4784884/JDale_Thesis_Final.pdf

Environment Agency (2014) Working with Natural Flood Management: Evidence Directory: Case study 50. Medmerry Managed Realignment (SC150005). Available at: www.therrc.co.uk/sites/default/files/projects/50_medmerry.pdf [Last accessed: 27/10/2024]

Filbee-Dexter, K., and Wernberg, T. (2018). Rise of turfs: a new battlefront for globally declining kelp forests. Bioscience 68, 64–76. https://doi.org/10.1093/biosci/bix147

HR Wallingford (2023). Sussex coast sediments and kelp: coastal sediments. HR Wallingford report DES1299-RT001-R04-00.

Institute of Civil Engineers (2015) Managed realignment at Medmerry, Sussex. Available at : https://www.ice.org.uk/engineering-resources/case-studies/managed-realignment-at-medmerry-sussex [Last accessed: 12/09/2024]

Kassem, H., Amos, C. L., and Thompson, C. E. L.: Sea Surface Temperature Trends in the Coastal Zone of Southern England, J. Coast. Res., 39, 18–31, https://doi.org/10.2112/JCOASTRES-D-22-00027.1, 2022.

Kelly, D. M., Fernand, L., and Rees, J.: Modelling the Fate of Dredged Material Following Disposal at the Nab Tower Disposal Site, 2021. https://assets.publishing.service.gov.uk/media/62cd844e8fa8f54e855dfe97/2020-2021_Dredged_material_disposal_site_monitoring_round_the_coast_of_England-_Nab_Tower.pdf

Met Office (2021). Extreme heat warning issued. https://web.archive.org/web/20210719222318/https://www.metoffice.gov.uk/weather/warnings-and-advice/uk-warnings#?date=2021-07-20&id=1d72be9d-b78d-43c1-bf94-aa376b441b0f&details

Natural England (2022). A Historical Investigation of Solent Saltmarsh as Key Coastal Nursery Habitat Areas. Research Report NECR404. Available at: https://publications.naturalengland.org.uk/publication/4884906542104576

NOAA (2024) Monitoring Estuaries. https://oceanservice.noaa.gov/education/tutorial_estuaries/est10_monitor.html#:~:text=Knowledge%20of%20pH%20is%20important,alter%20pH%20in%20an%20estuary.

SCOPAC (2012) https://www.scopac.org.uk/sts/eh-pa.html

Searles, K., Thompson, C. (2021) CHASM Project Report (2020-2021): https://peninsulapartnership.org.uk/abd/wp-content/uploads/2022/01/CHASMreport_FINAL_reducedSize.pdf

Silva, T., Biermann, L., and Rees, J (2016) Suspended Sediment Climatologies around the UK https://assets.publishing.service.gov.uk/media/5a80b954e5274a2e8ab51cc7/CEFAS_2016_Suspended_Sediment_Climatologies_around_the_UK.pdf

Sussex Kelp Recovery Project (2019) https://sussexkelp.org.uk/about-the-skrp/our-history

The Crown Estate (2020). The area involved – 22nd annual report. BMAPA report. https://bmapa.org/documents/BMAPA_CE_22nd_Ann_Rep_2019.pdf

Williams, C., Rees, S., Sheehan, E. V., Ashley, M., & Davies, W. (2022). Rewilding the Sea? A Rapid, Low Cost Model for Valuing the Ecosystem Service Benefits of Kelp Forest Recovery Based on Existing Valuations and Benefit Transfers. Frontiers in Ecology and Evolution, 10. https://doi.org/10.3389/fevo.2022.642775

Velegrakis, A. F., Michel, D., Collins, M. B., Lafite, R., Oikonomou, E. K., Dupont, J. P., Huault, M. F., Lecouturier, M., Salomon, J. C., & Bishop, C. (1999). Sources, sinks and resuspension of suspended particulate matter in the eastern English Channel. Continental Shelf Research, 19(15–16), 1933–1957. https://doi.org/10.1016/S0278-4343(99)00047-3

Appendix A – Sonde Records

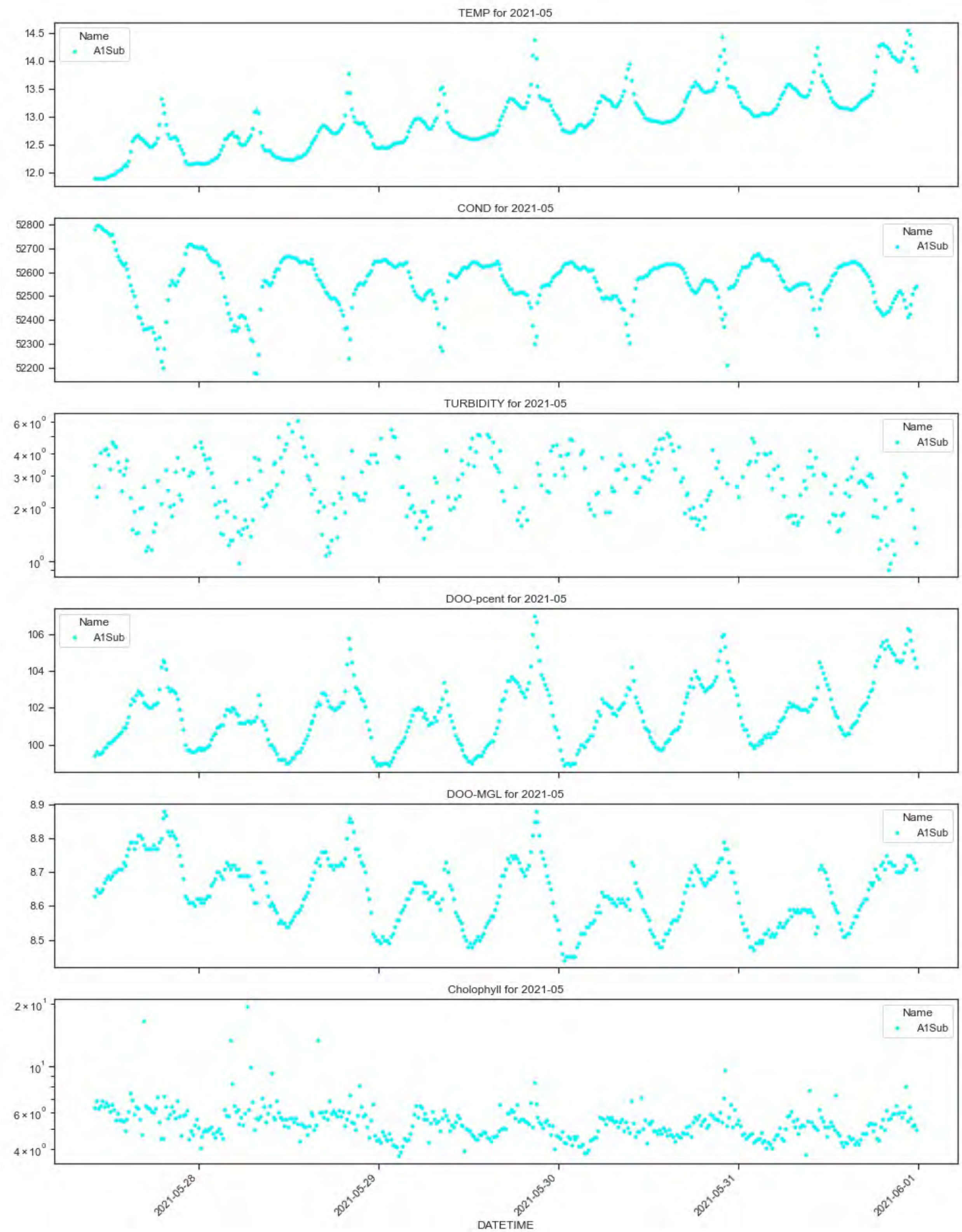


Figure A-1 - Subset 1 May 2021

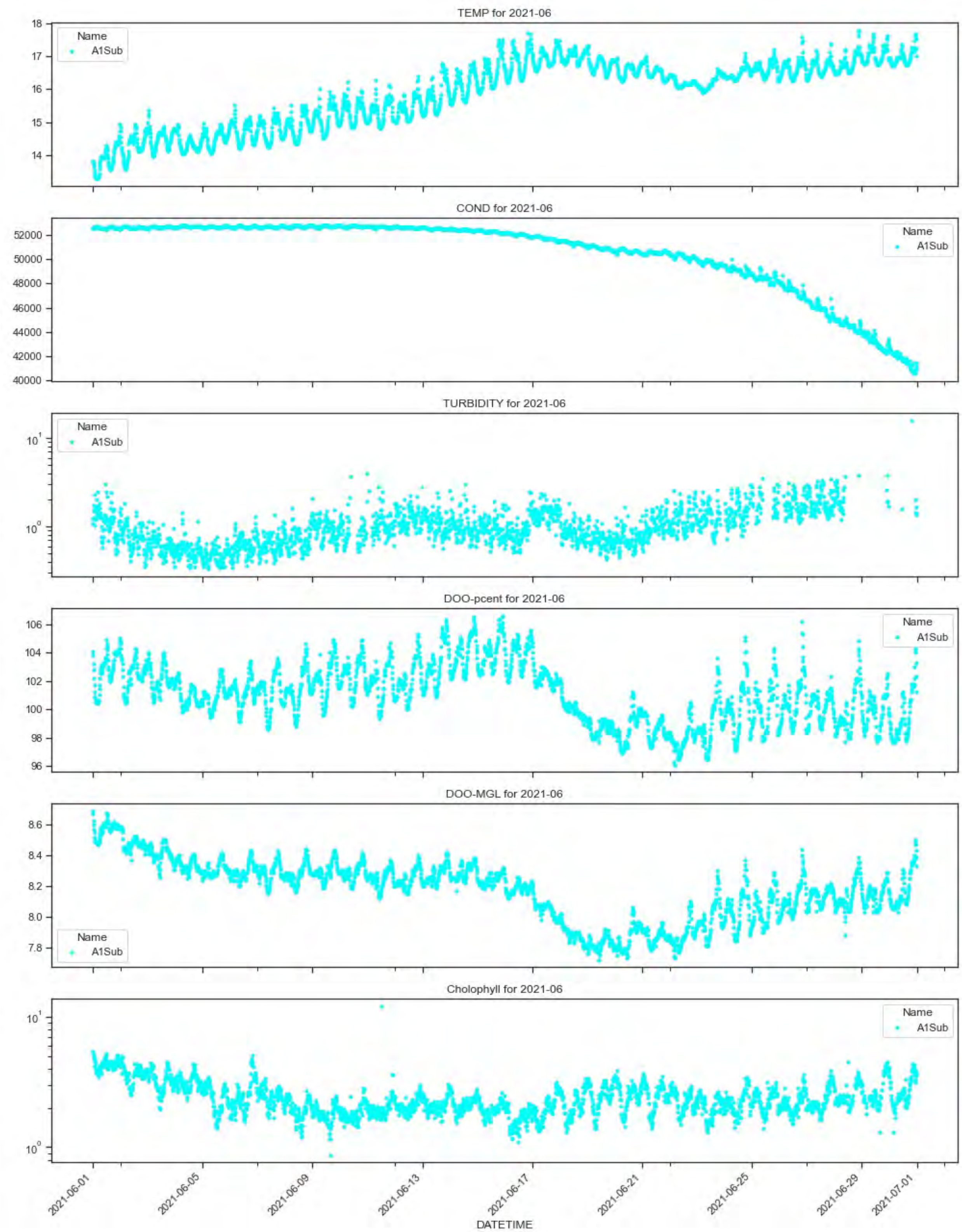


Figure A-2 - Subset 1 June 2021

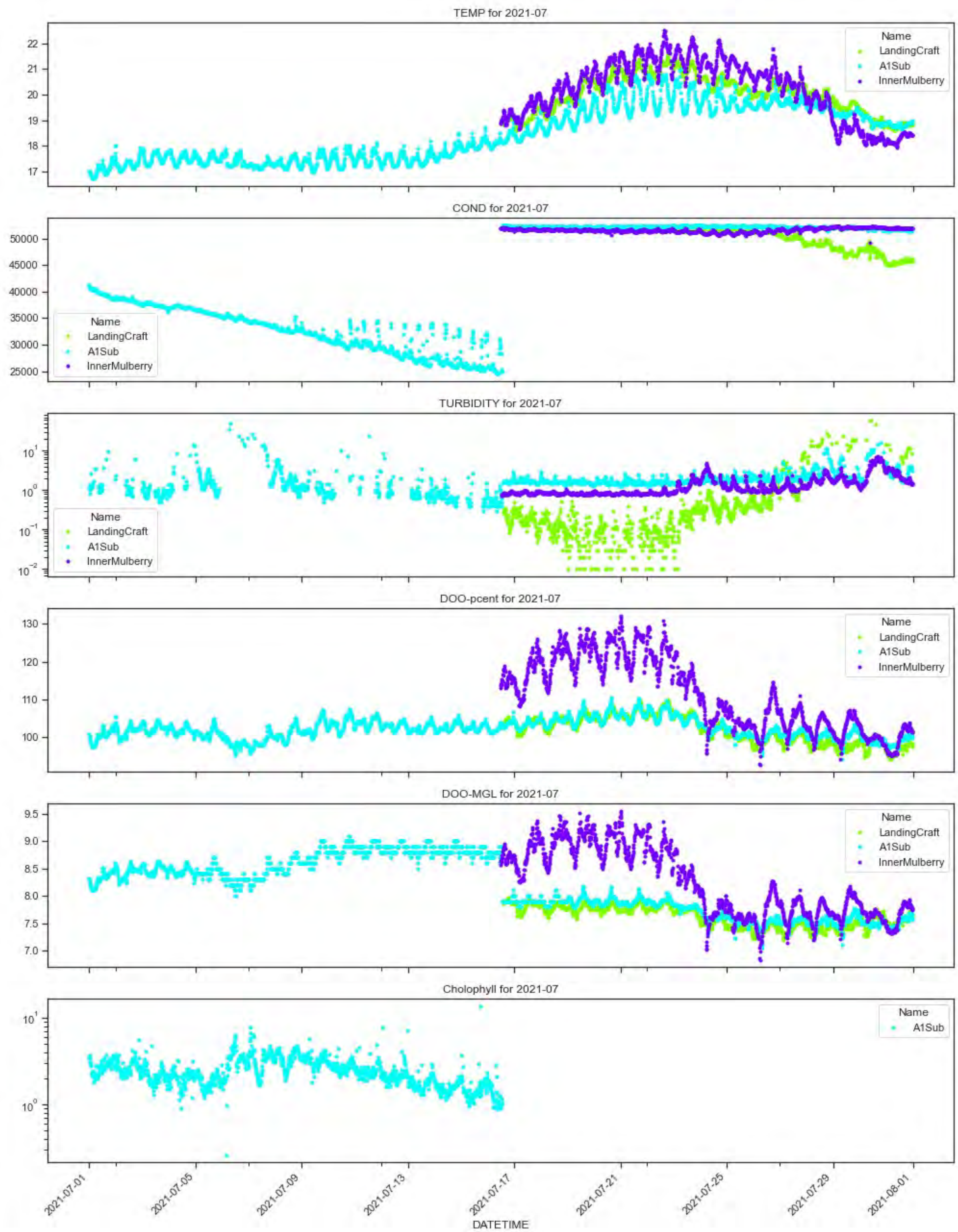


Figure A-3 - Subset 1 July 2021

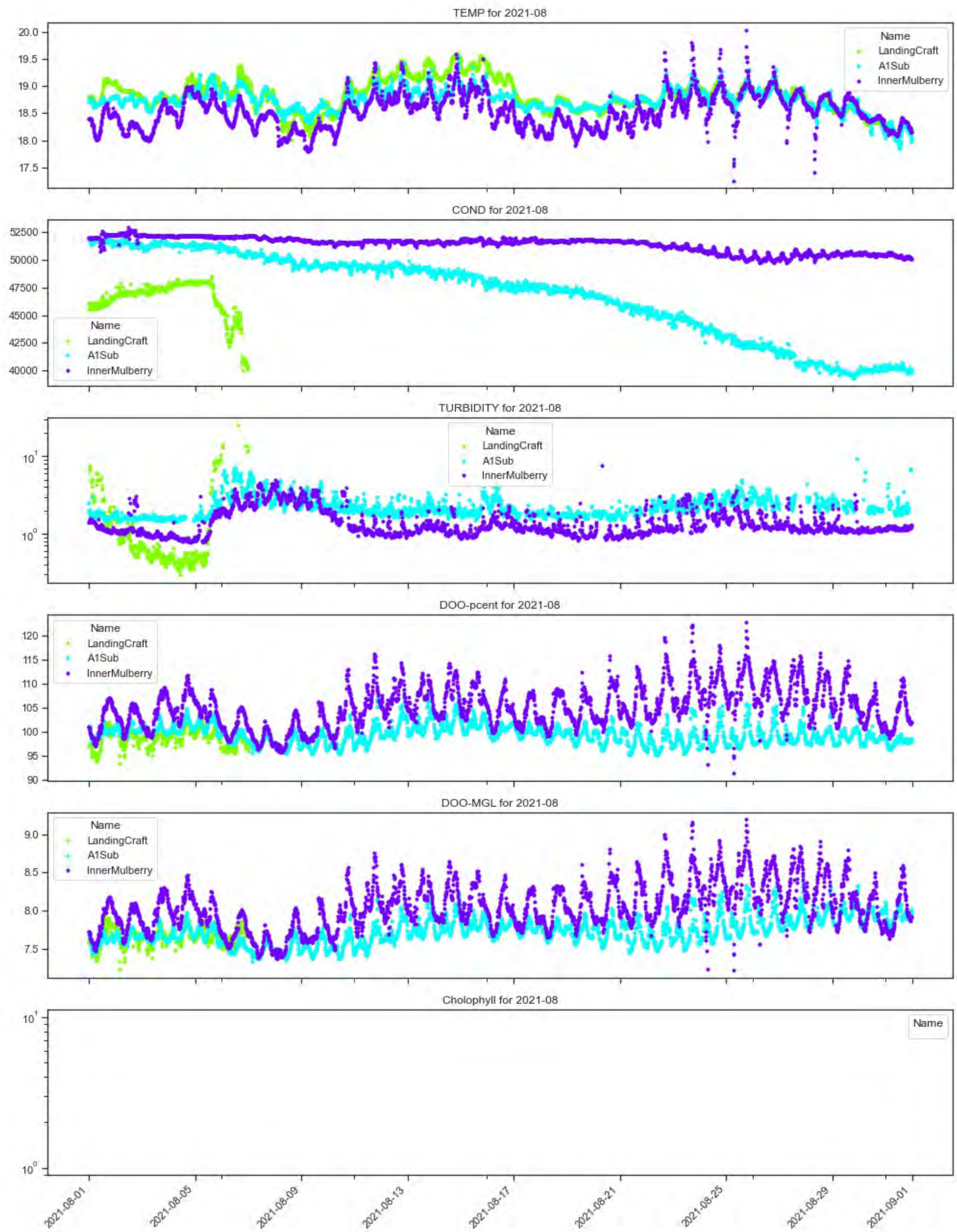


Figure A-4 - Subset 1 August 2021

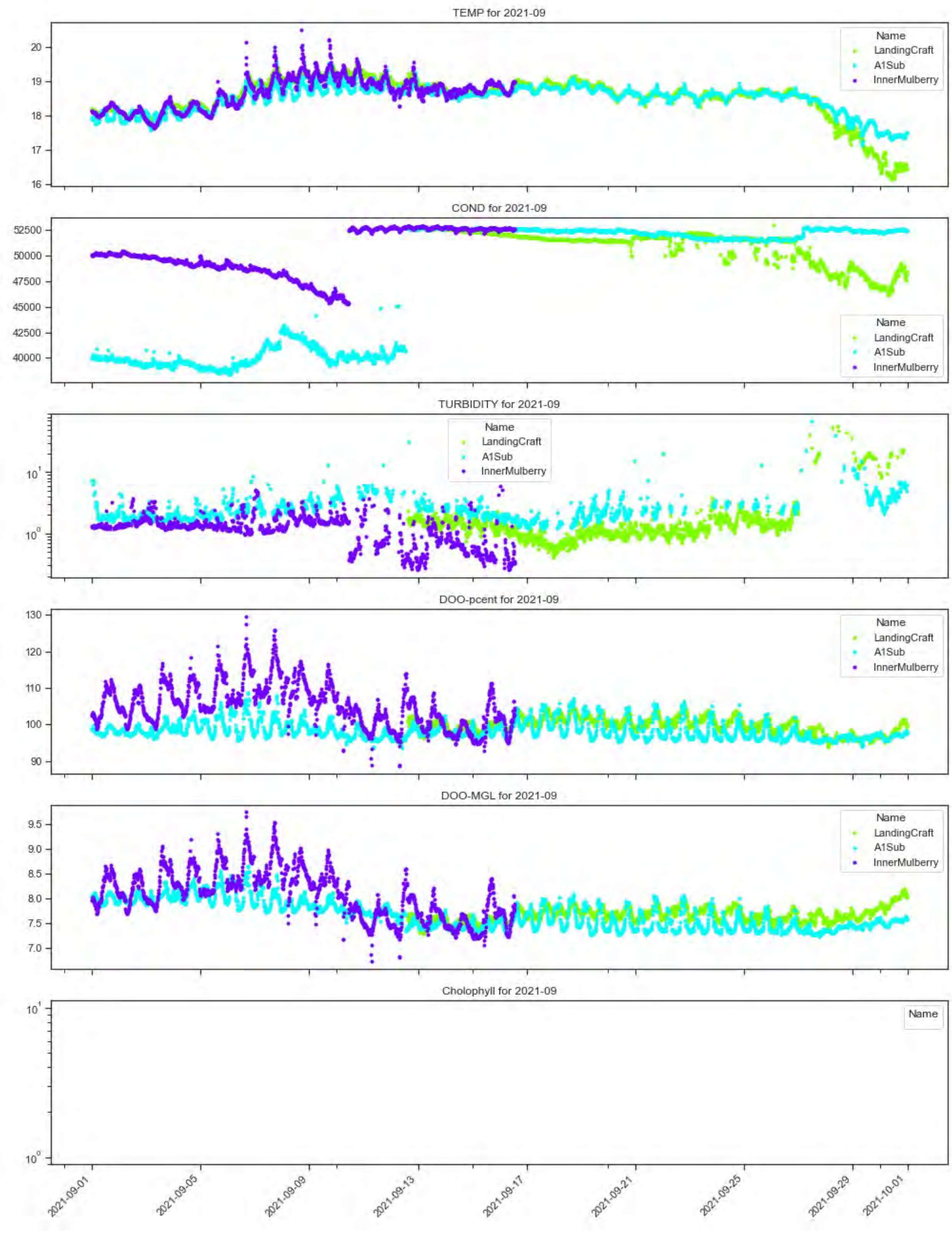


Figure A-5 - Subset 1 September 2021

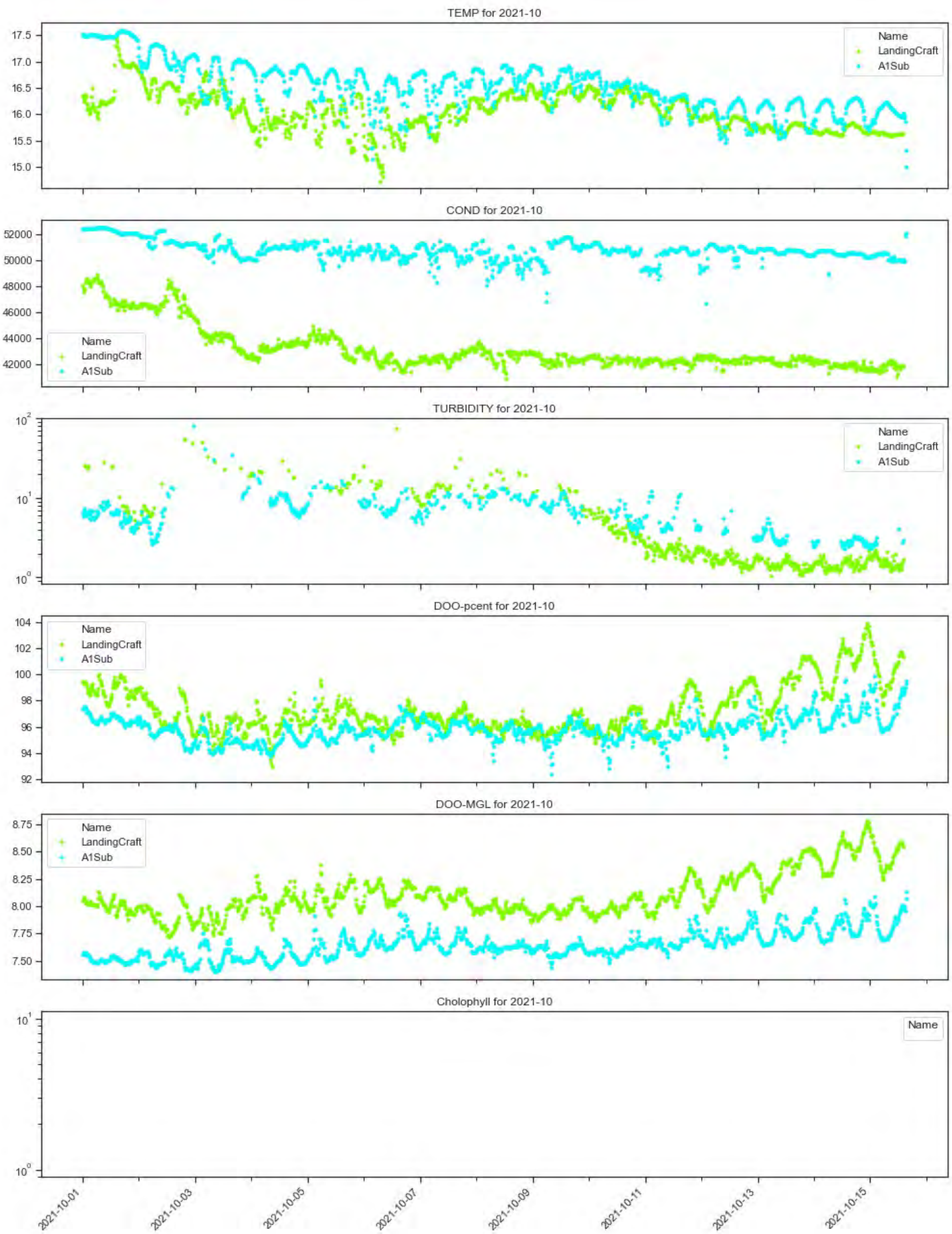


Figure A-6 - Subset 1 October 2021

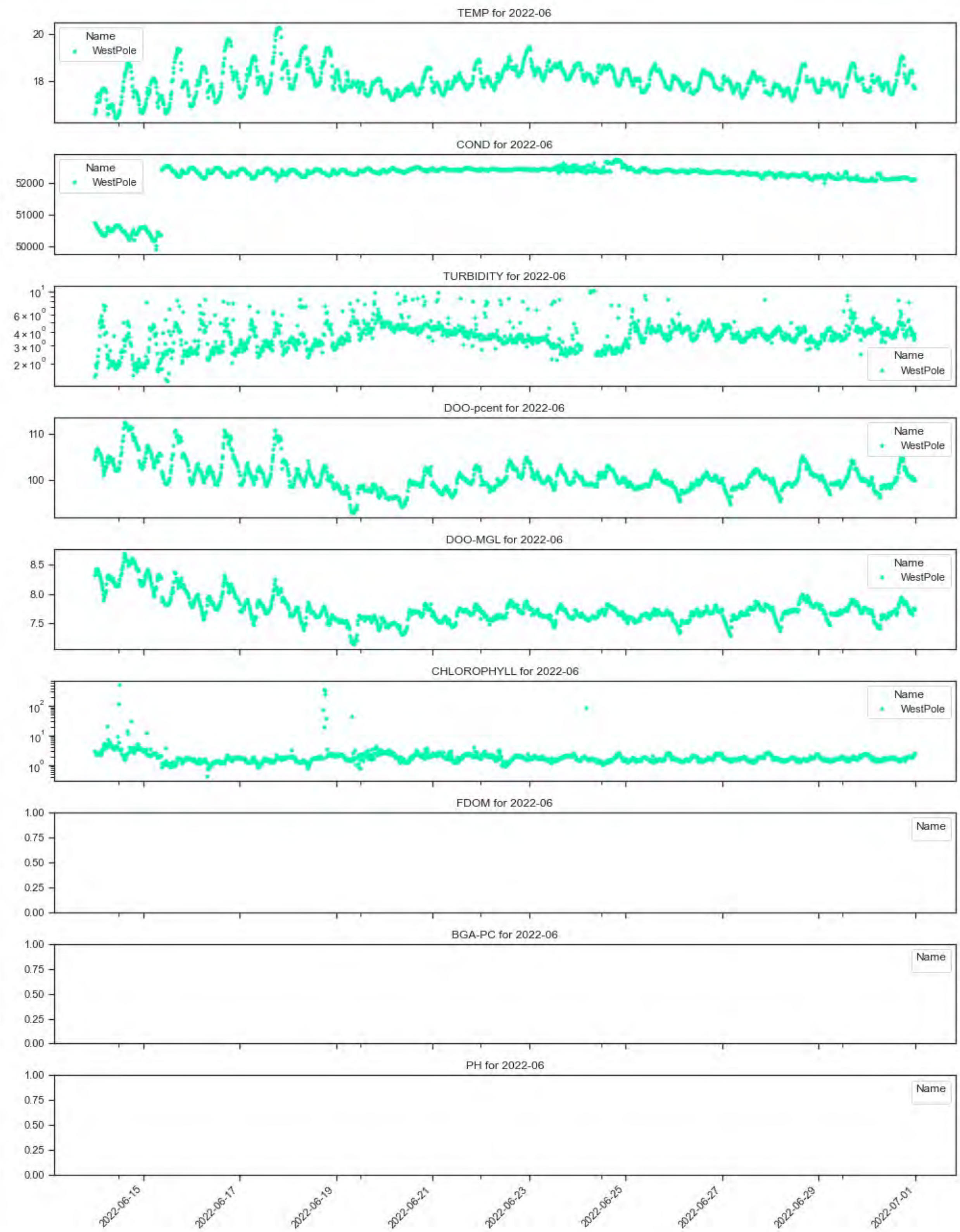


Figure A-7 - Subset 2 June 2022

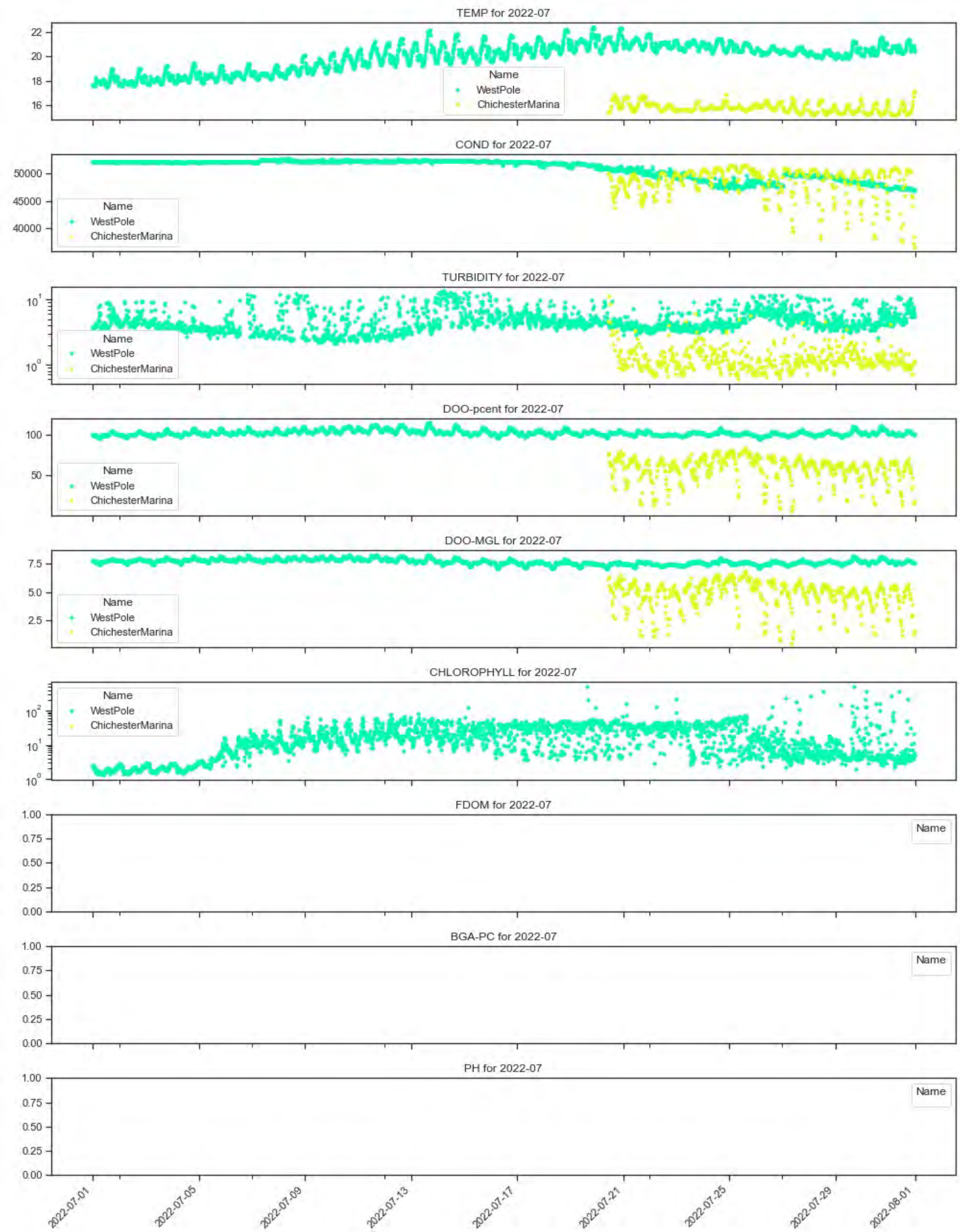


Figure A-8 - Subset 2 July 2022

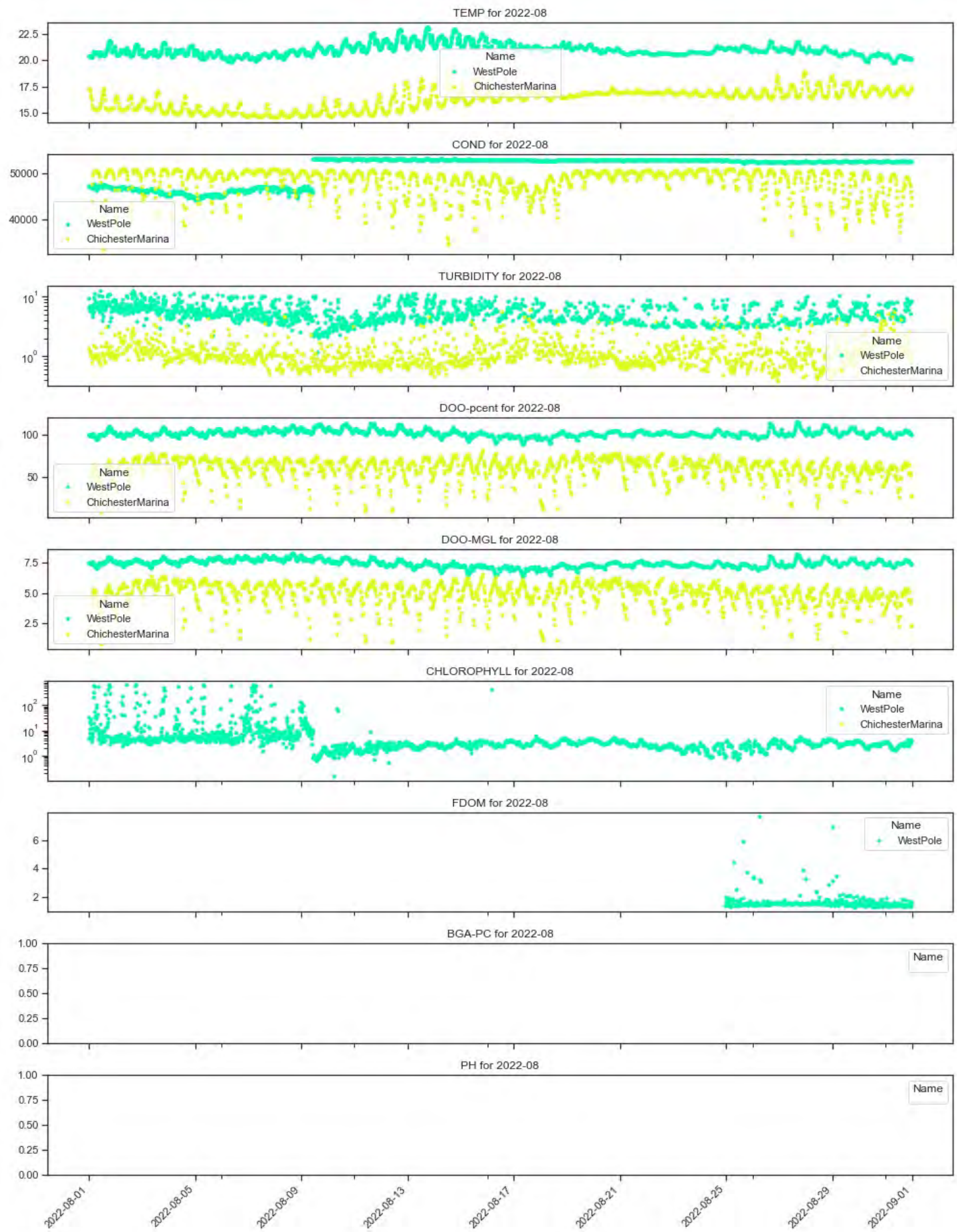


Figure A-9 - Subset 2 August 2022

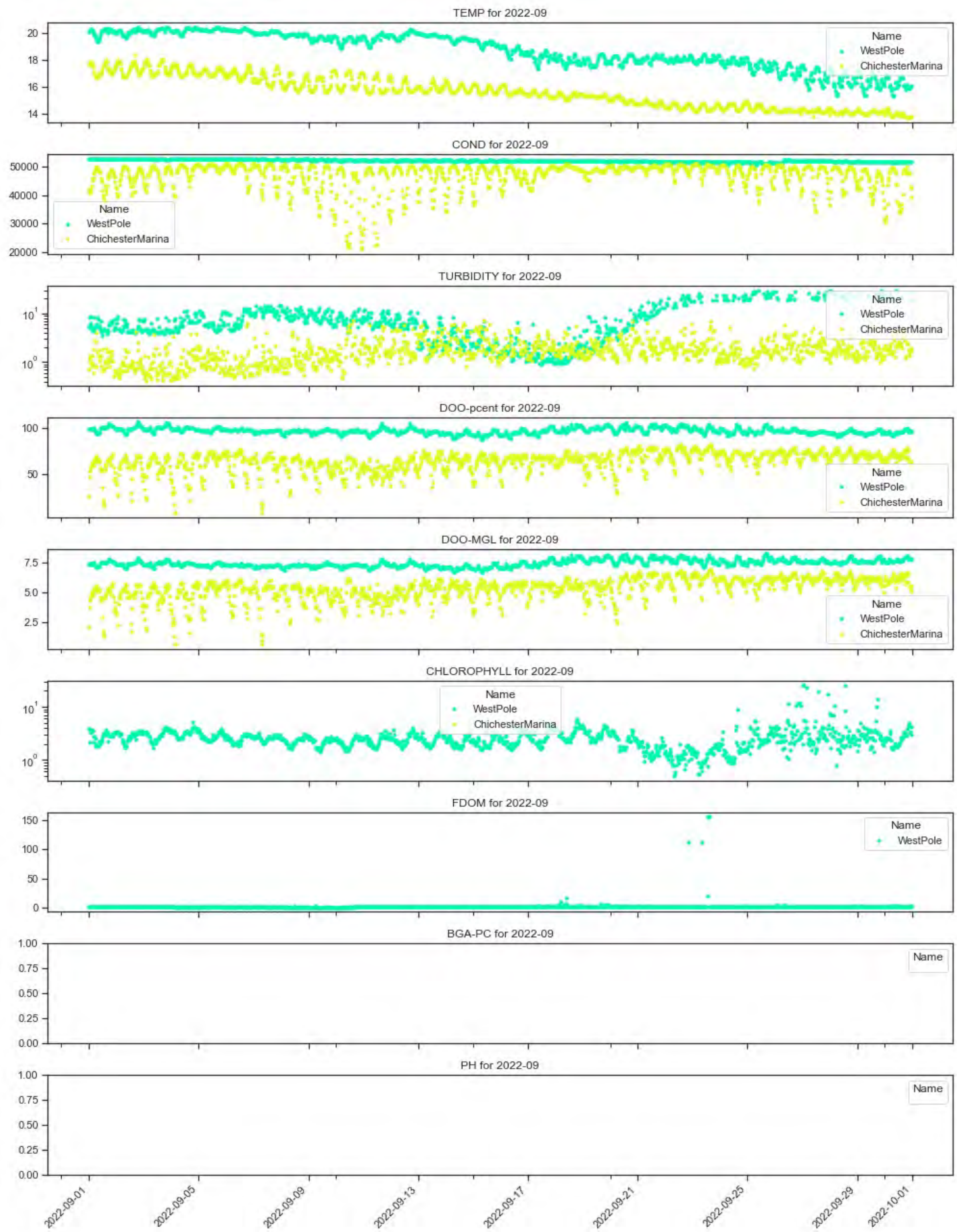


Figure A-10 - Subset 2 September 2022

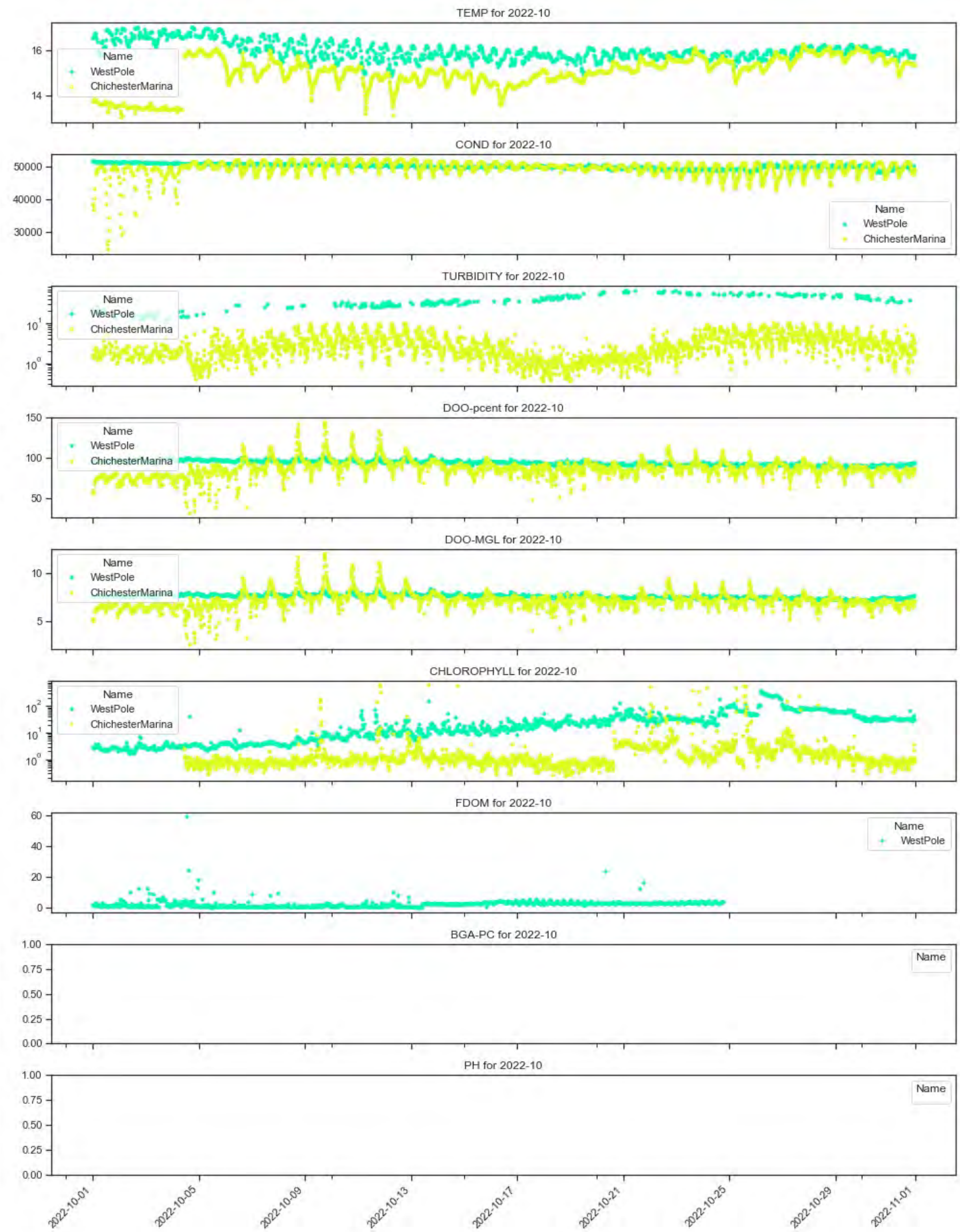


Figure A-11 - Subset 2 October 2022

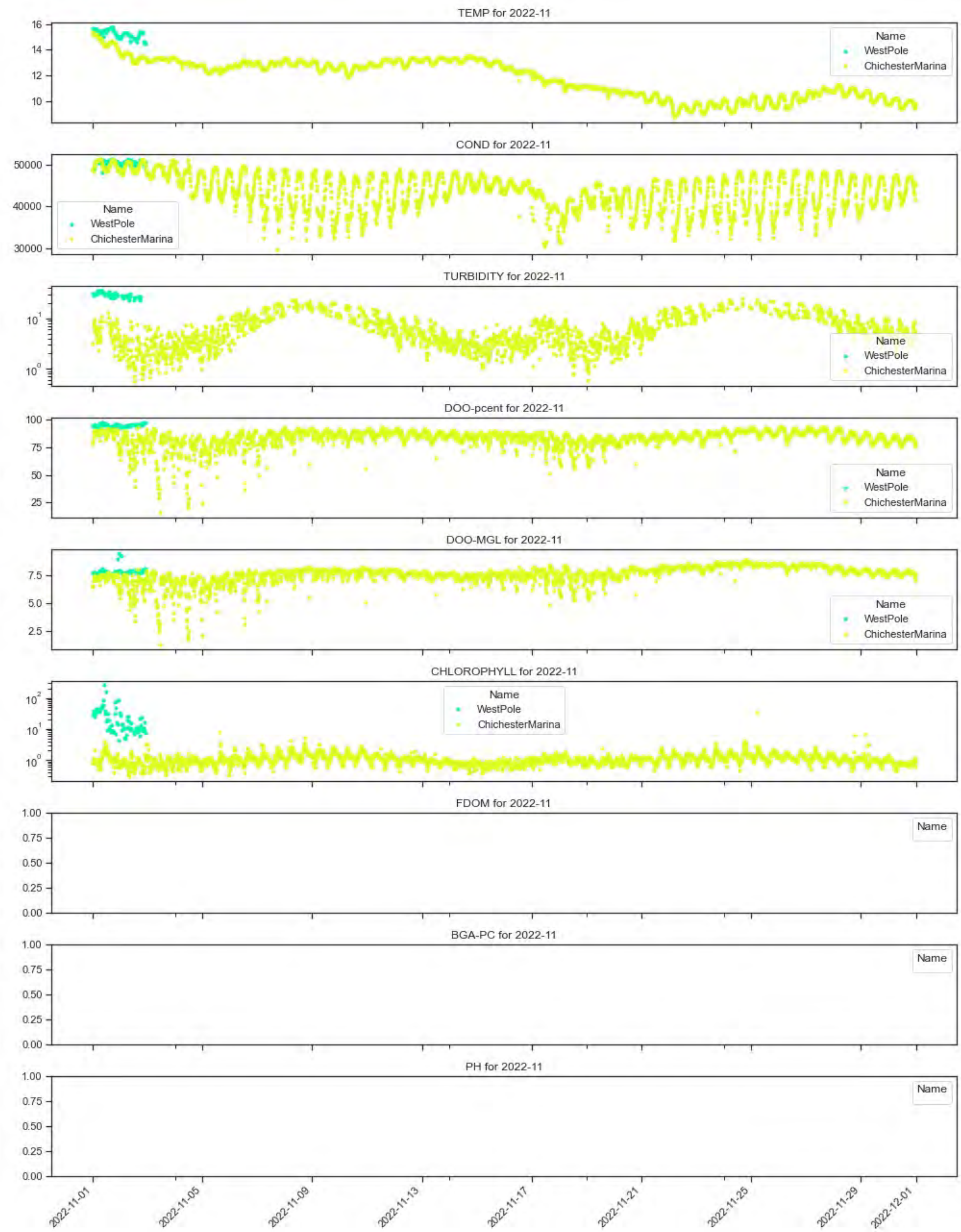


Figure 12 - Subset 2 November 2022

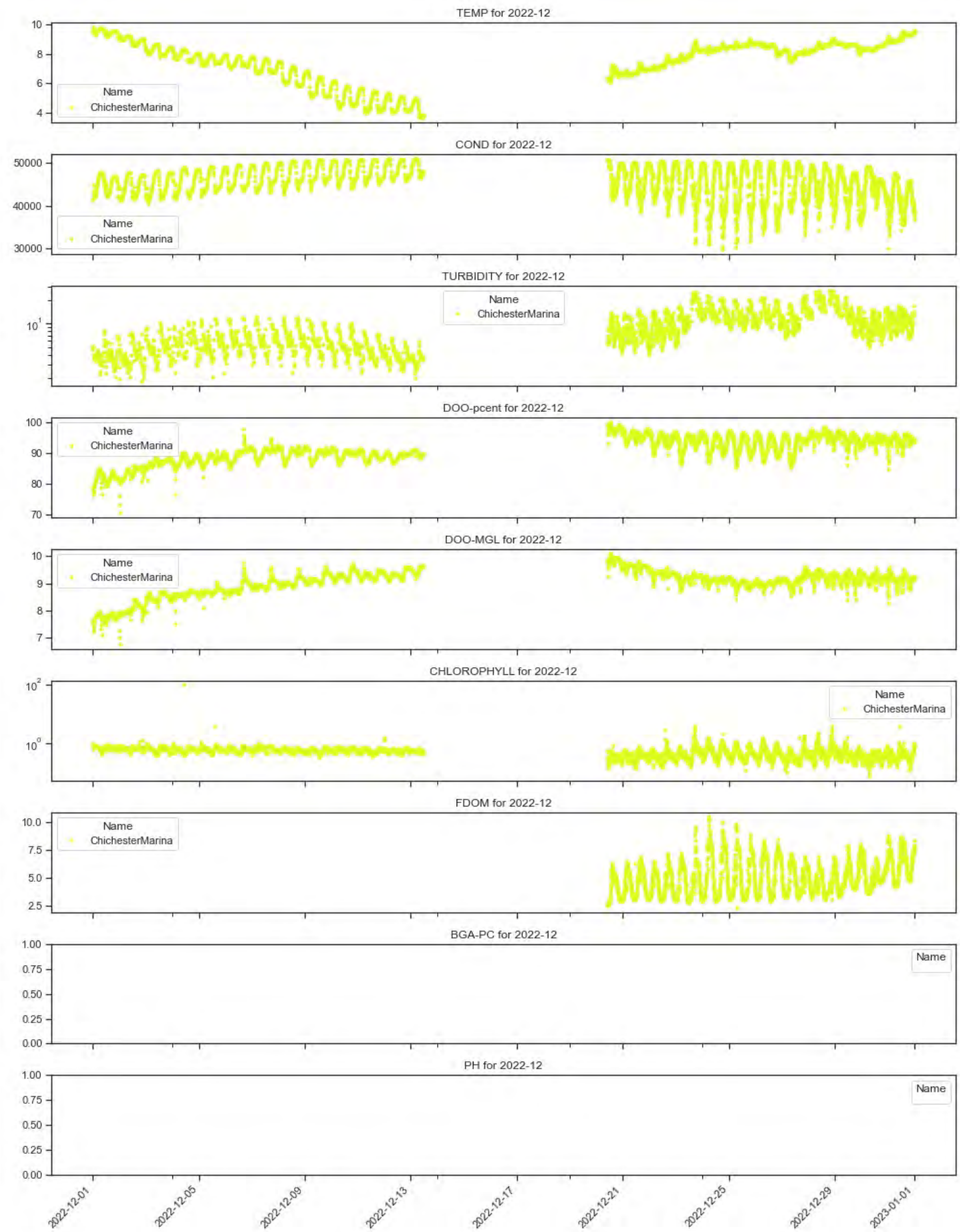


Figure A-13 - Subset 2 December 2022

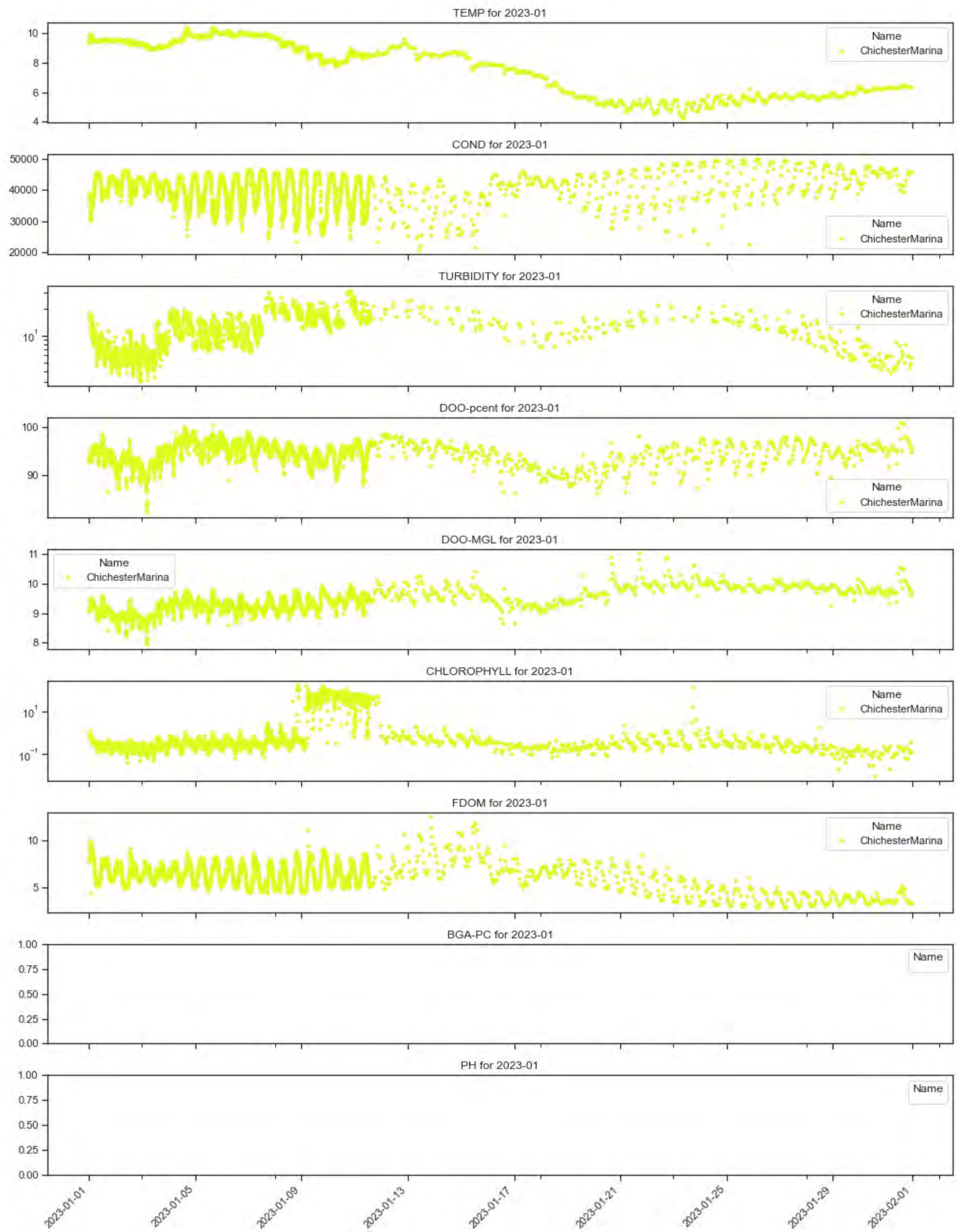


Figure A-14 - Subset 2 January 2023

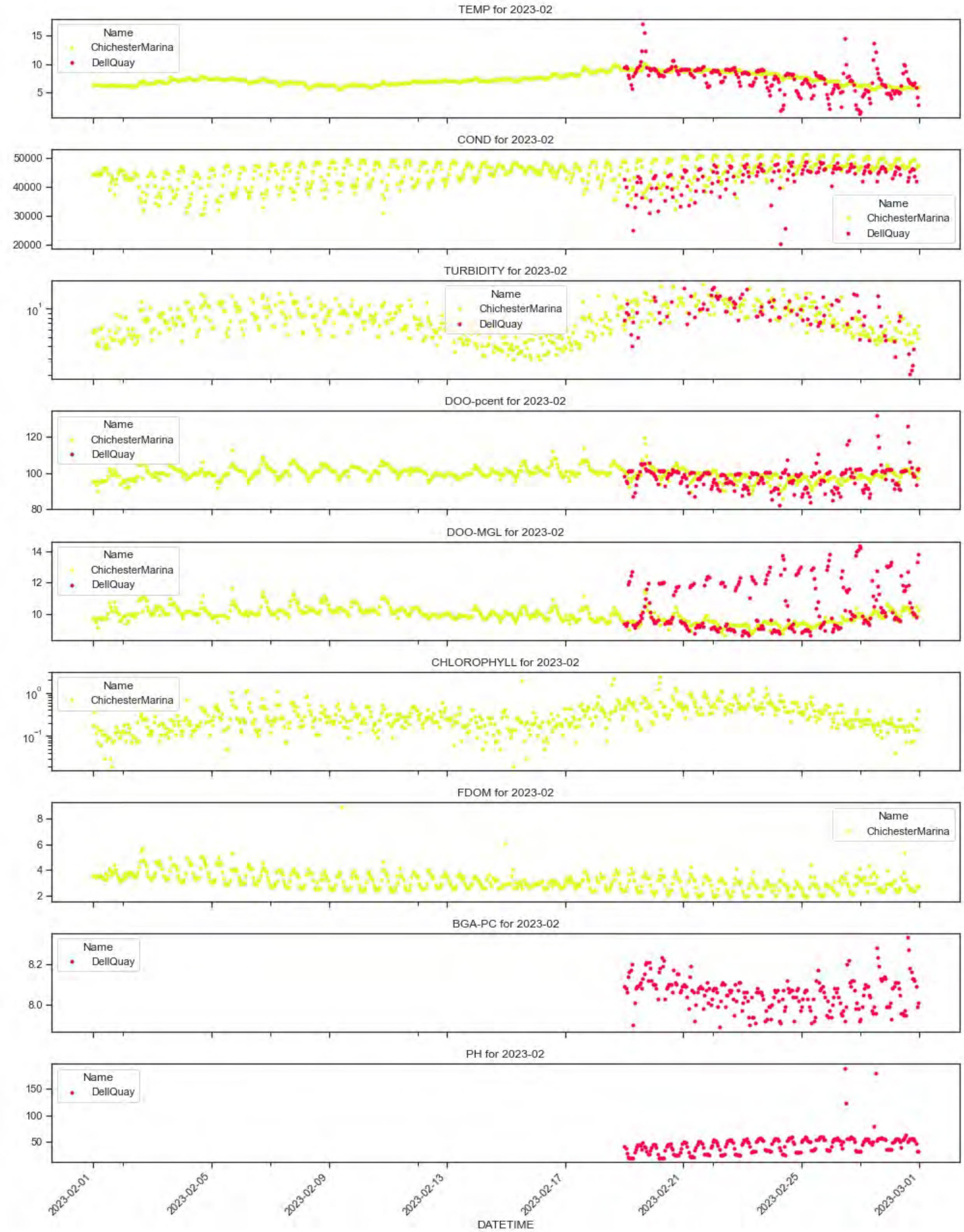


Figure A-15 - Subset 2 February 2023

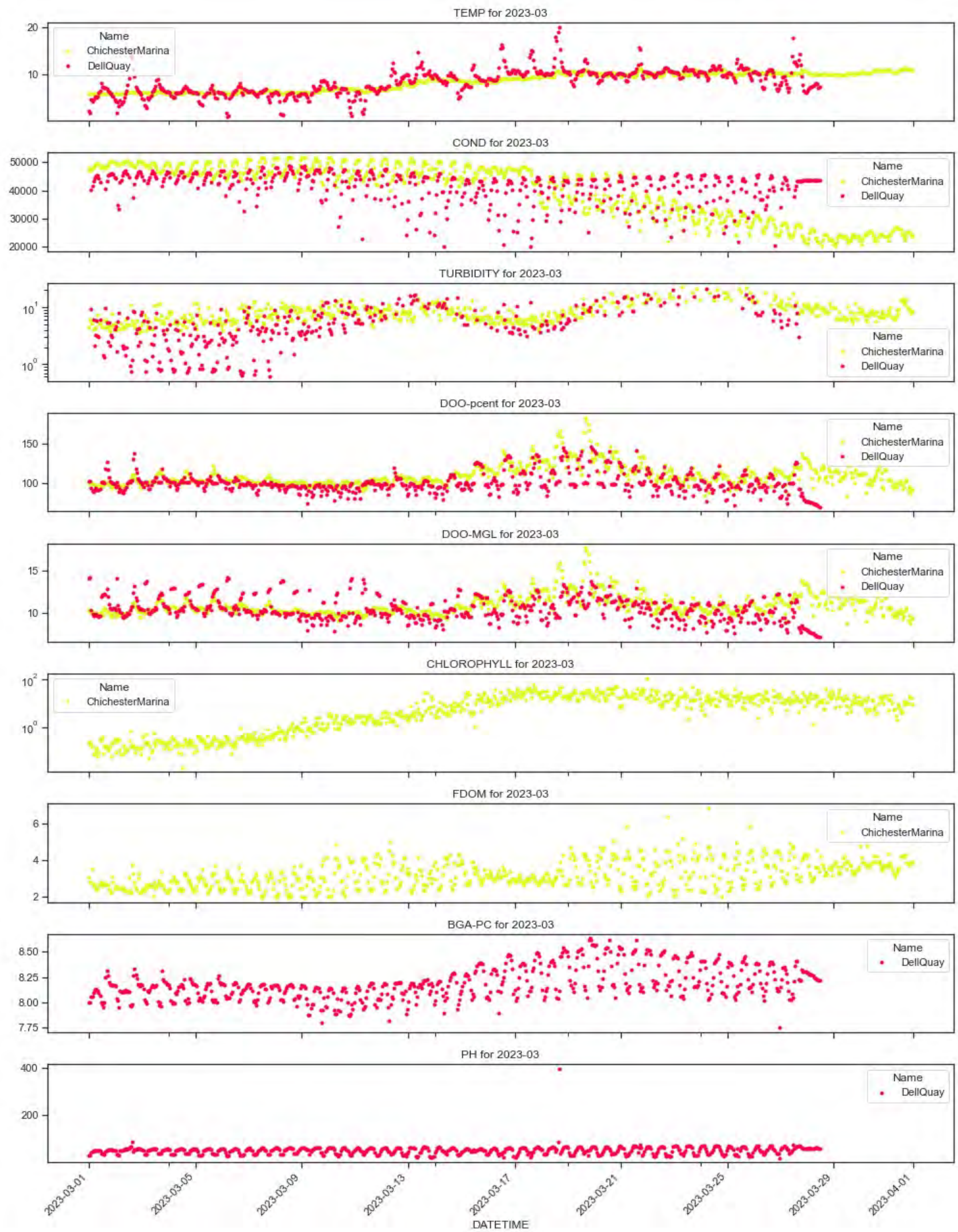


Figure A-16 - Subset 2 March 2023

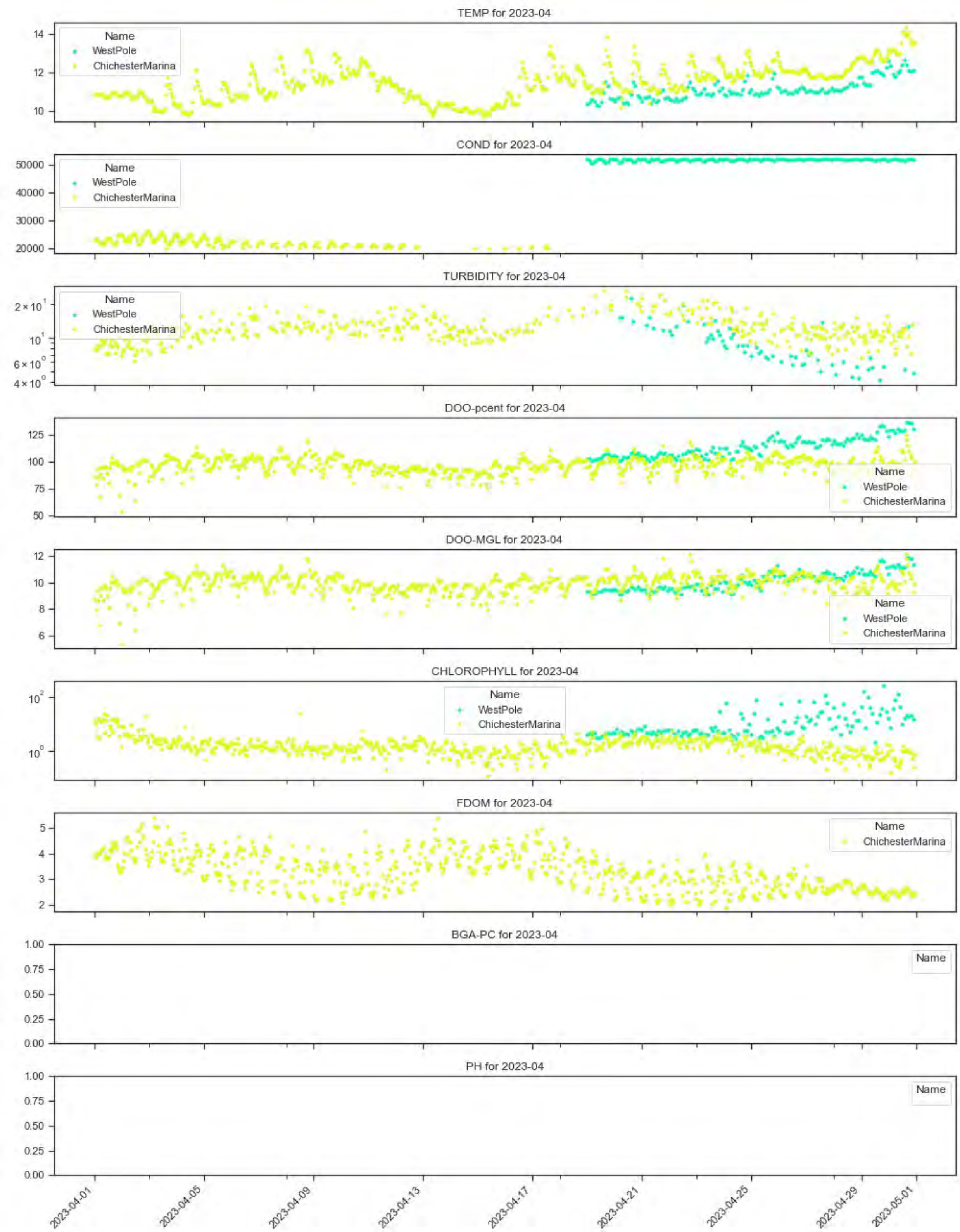


Figure A-17 - Subset 2 April 2023

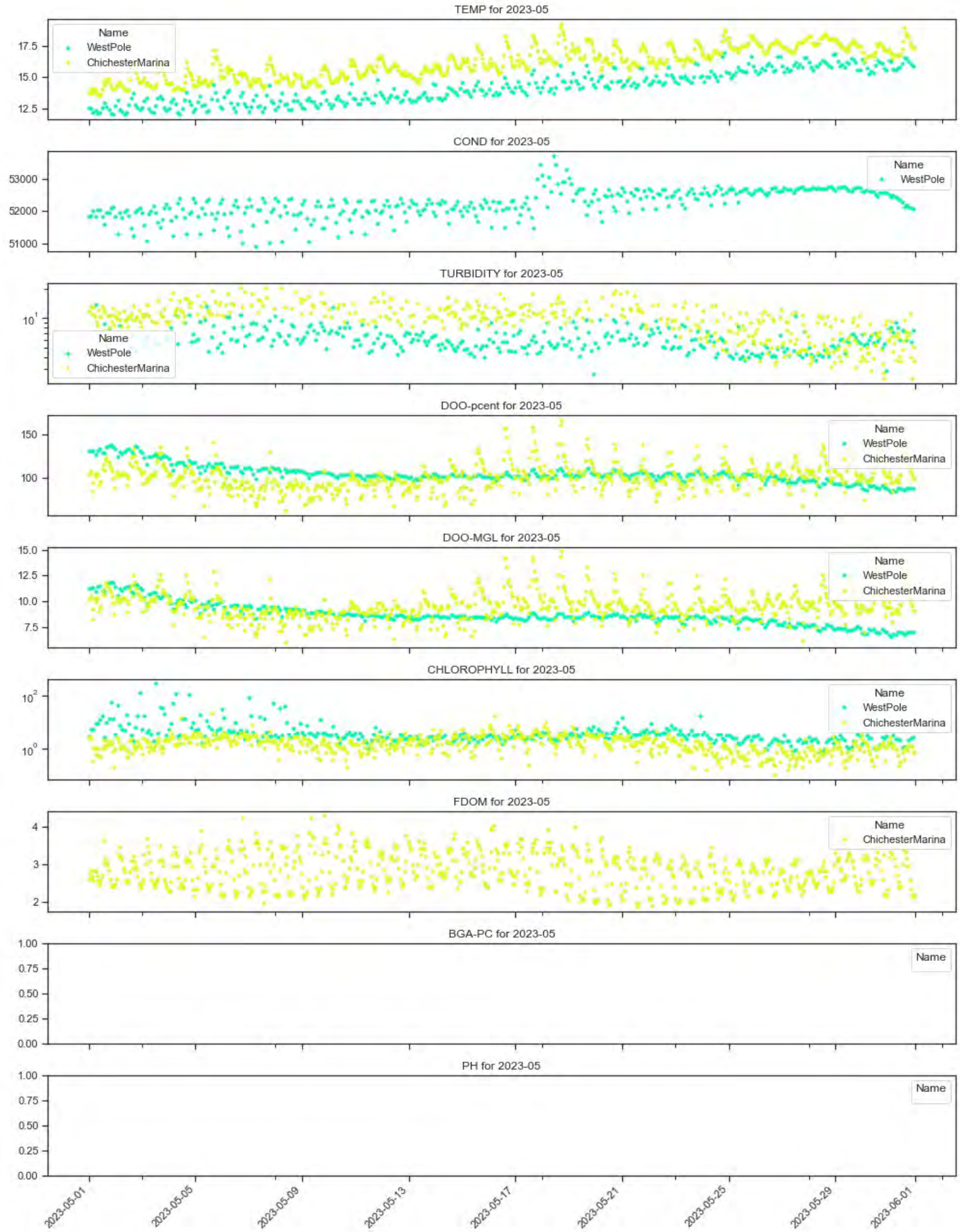


Figure A-18 - Subset 2 May 2023

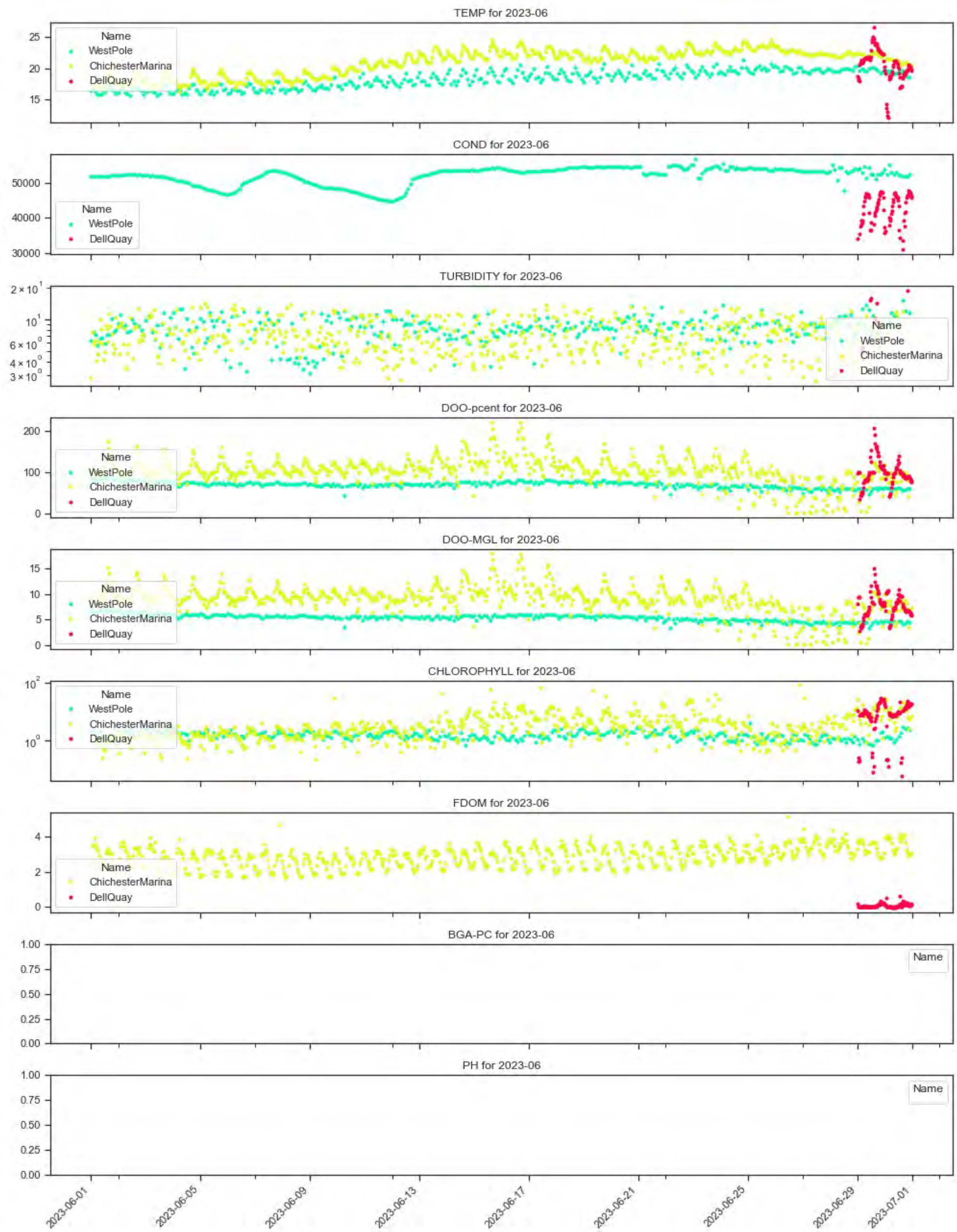


Figure A-19 - Subset 2 June 2023

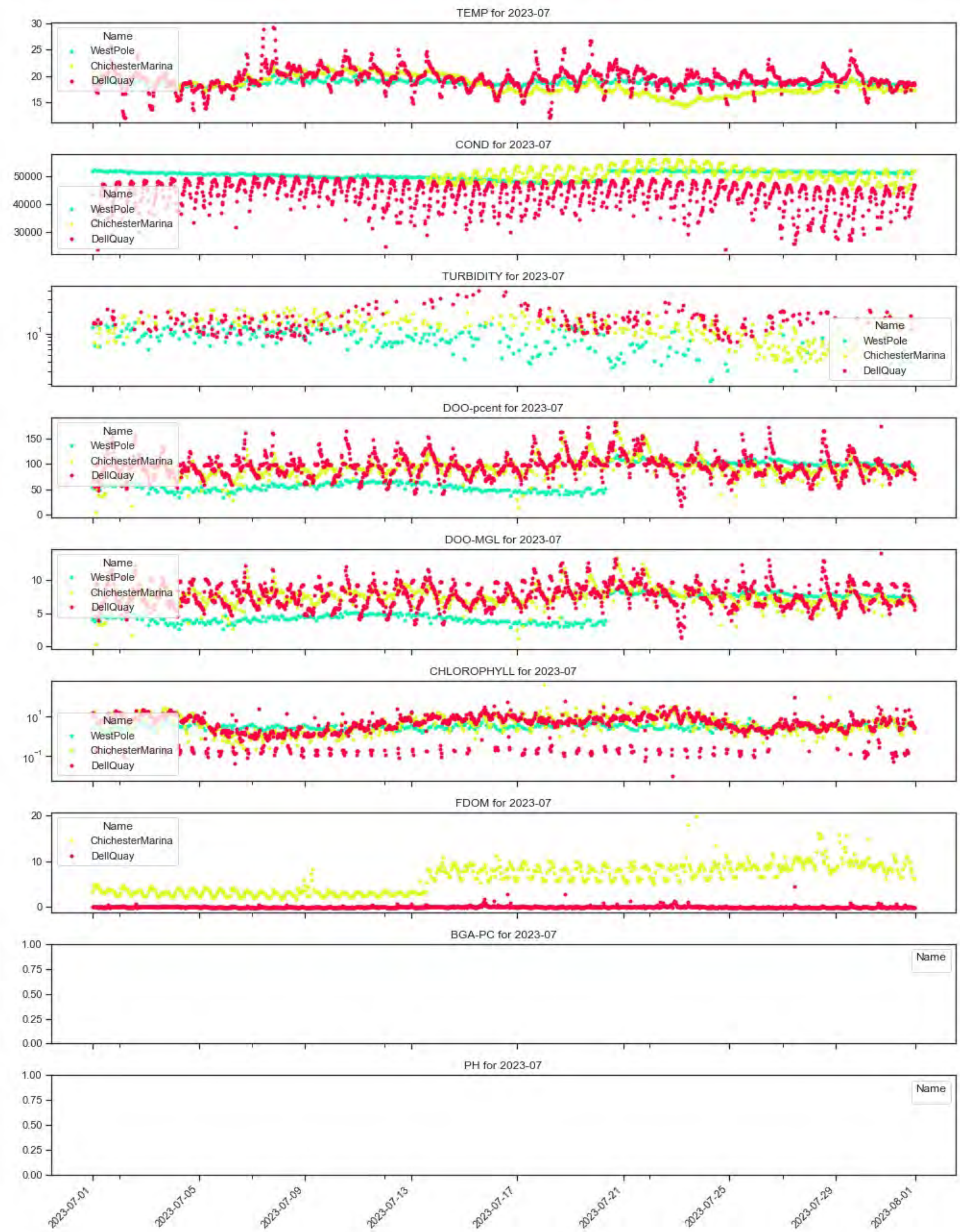


Figure A-20 - Subset 2 July 2023

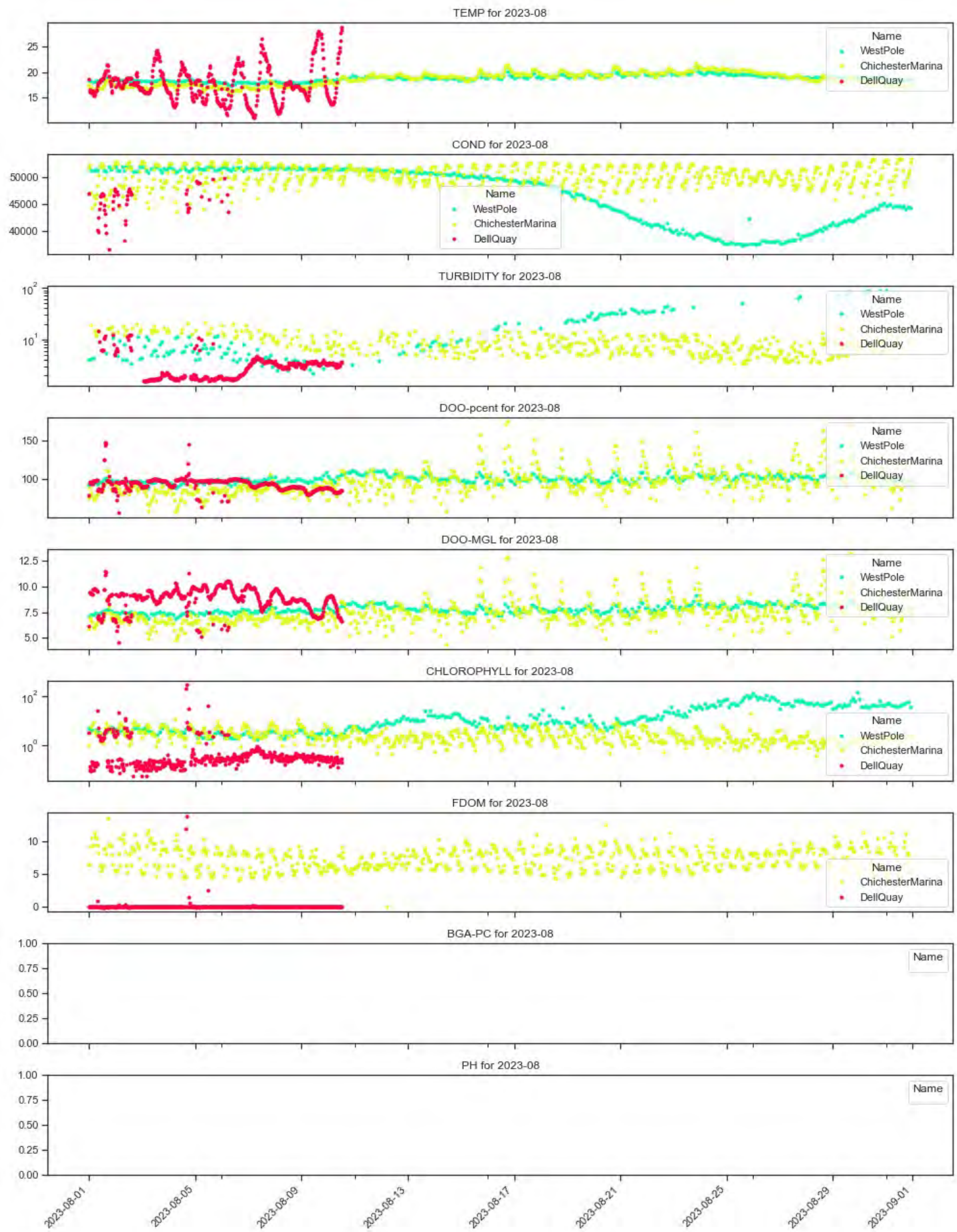


Figure A-21 - Subset 2 August 2023

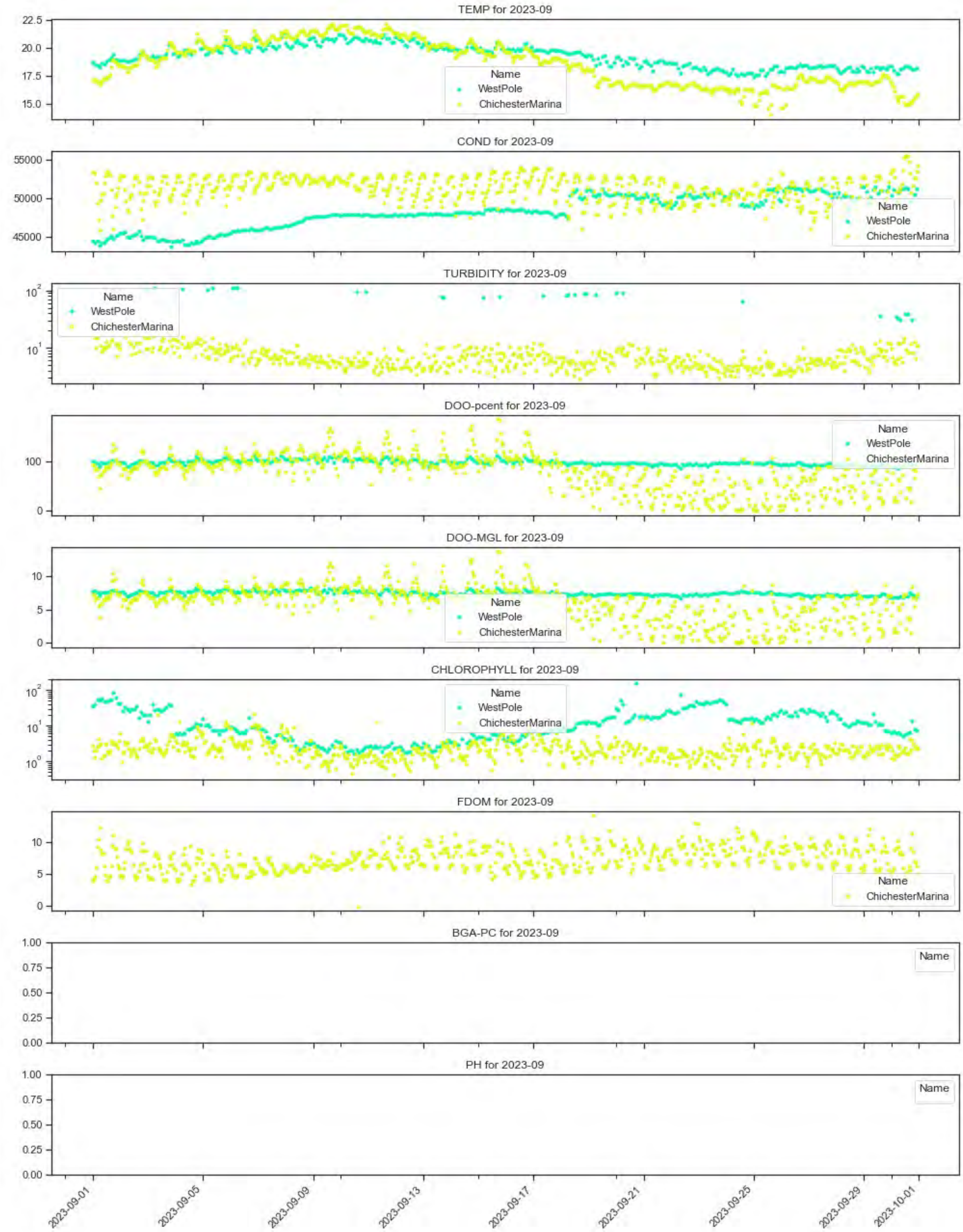


Figure A-22 - Subset 2 September 2023

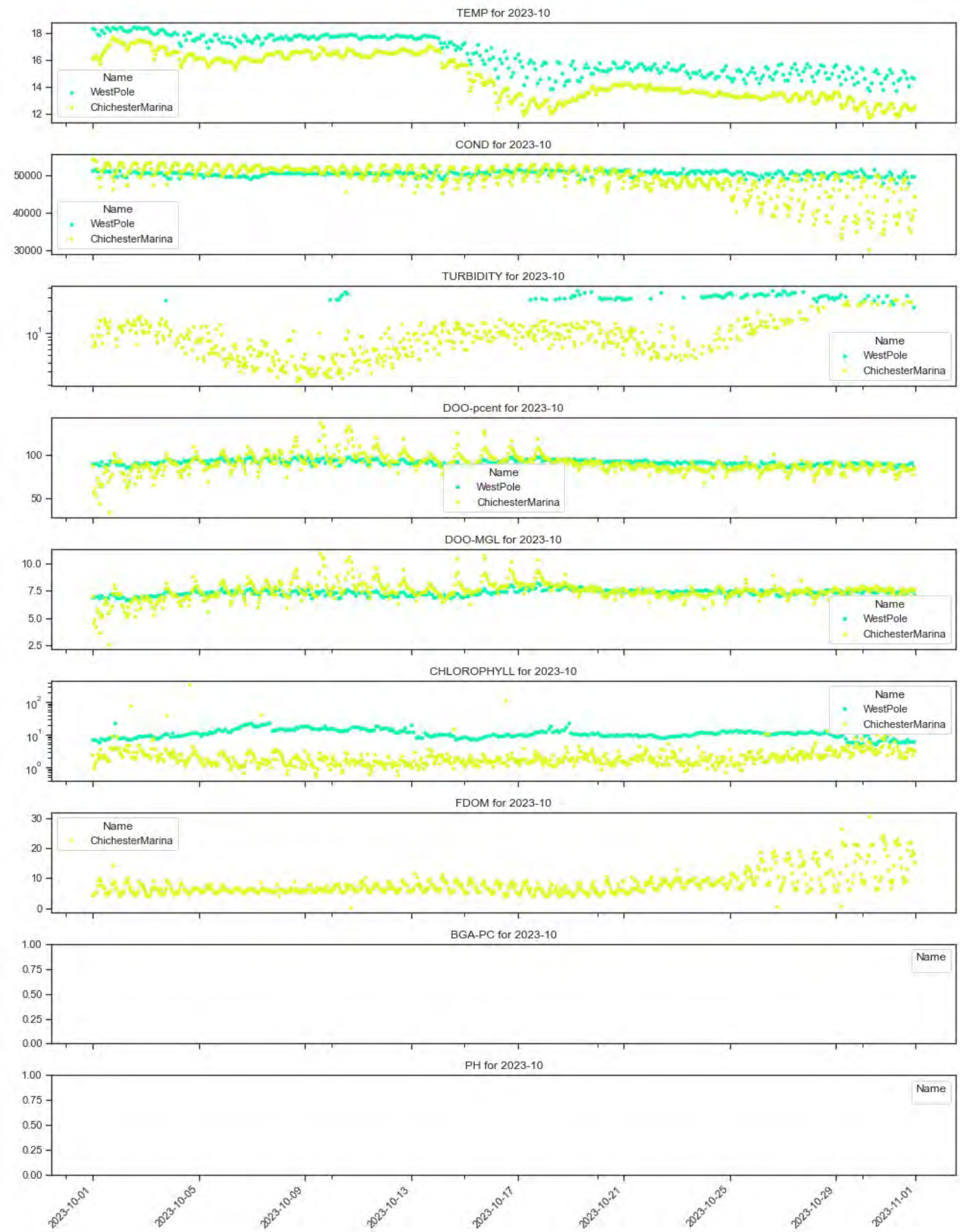


Figure A-23 - Subset 2 October 2023

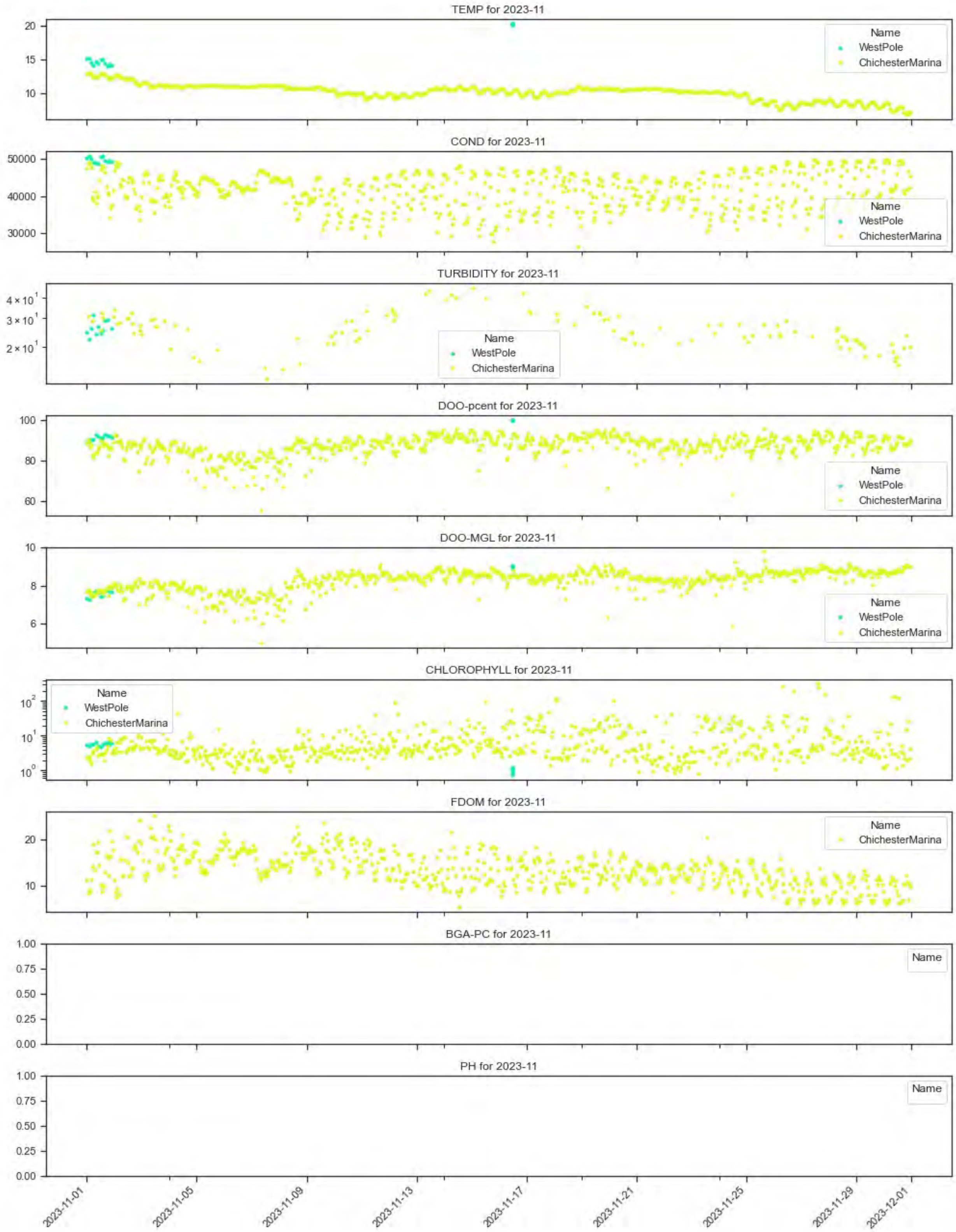


Figure A-24 - Subset 2 November 2023

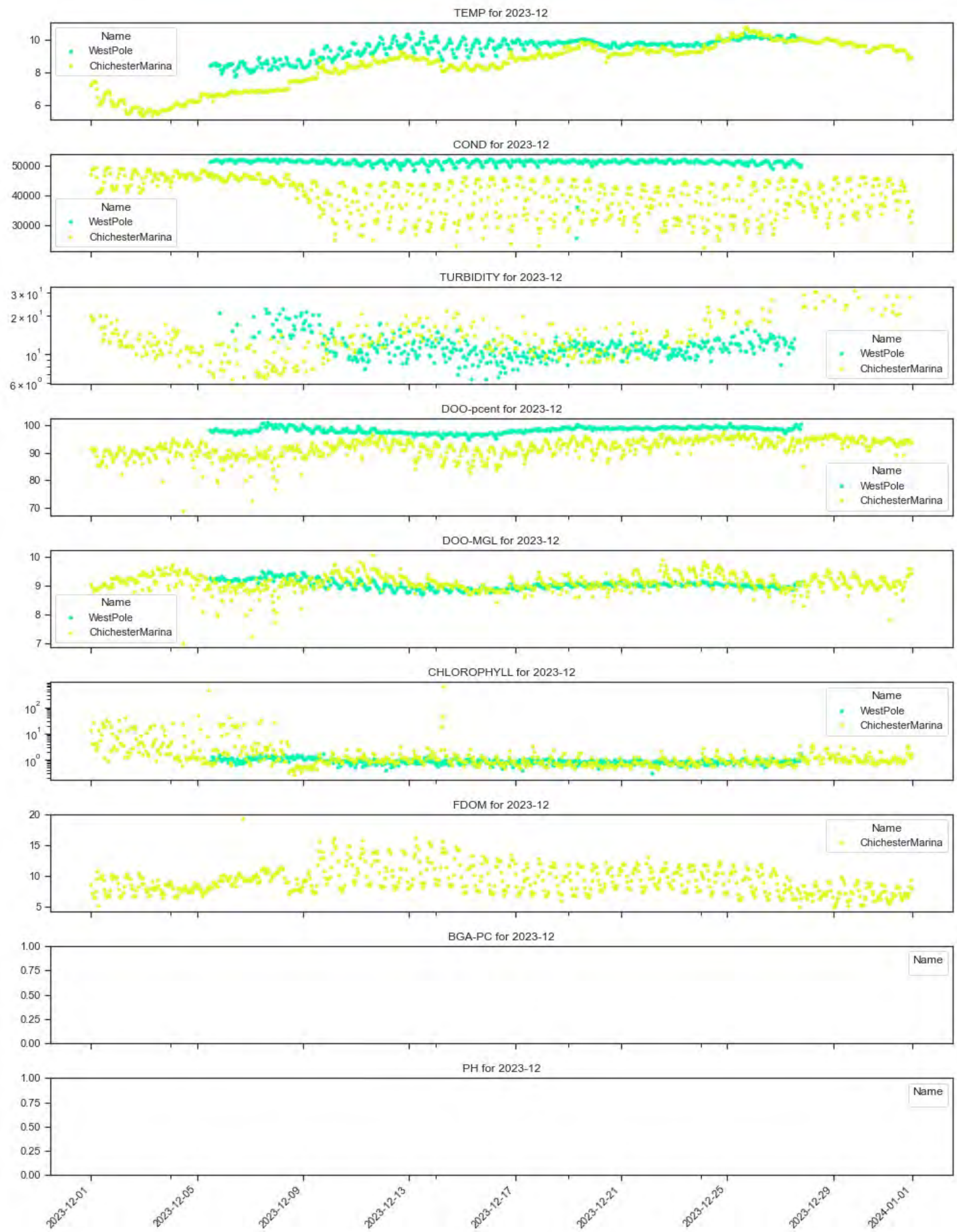


Figure A-25 - Subset 2 December 2023

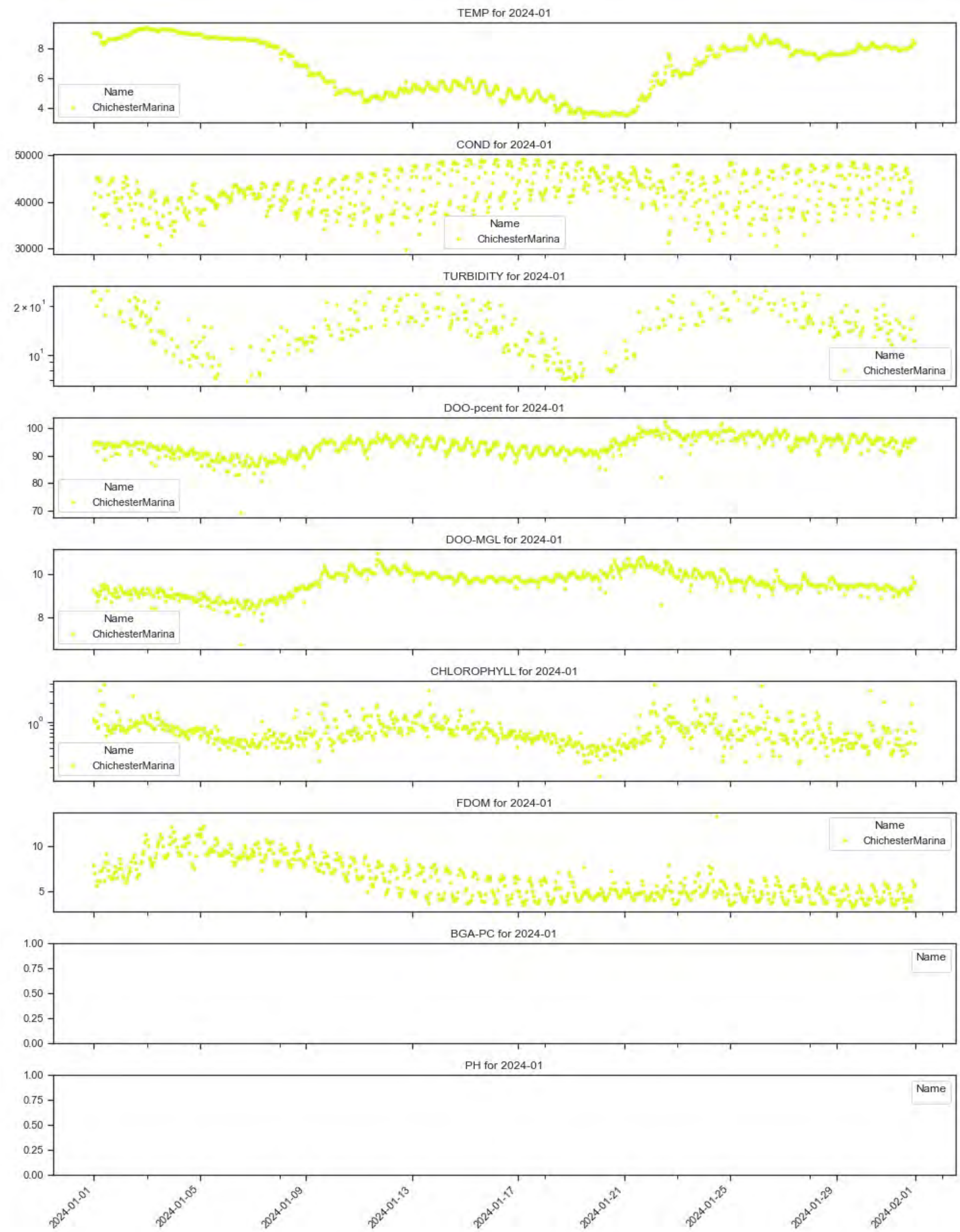


Figure A-26 - Subset 2 January 2024

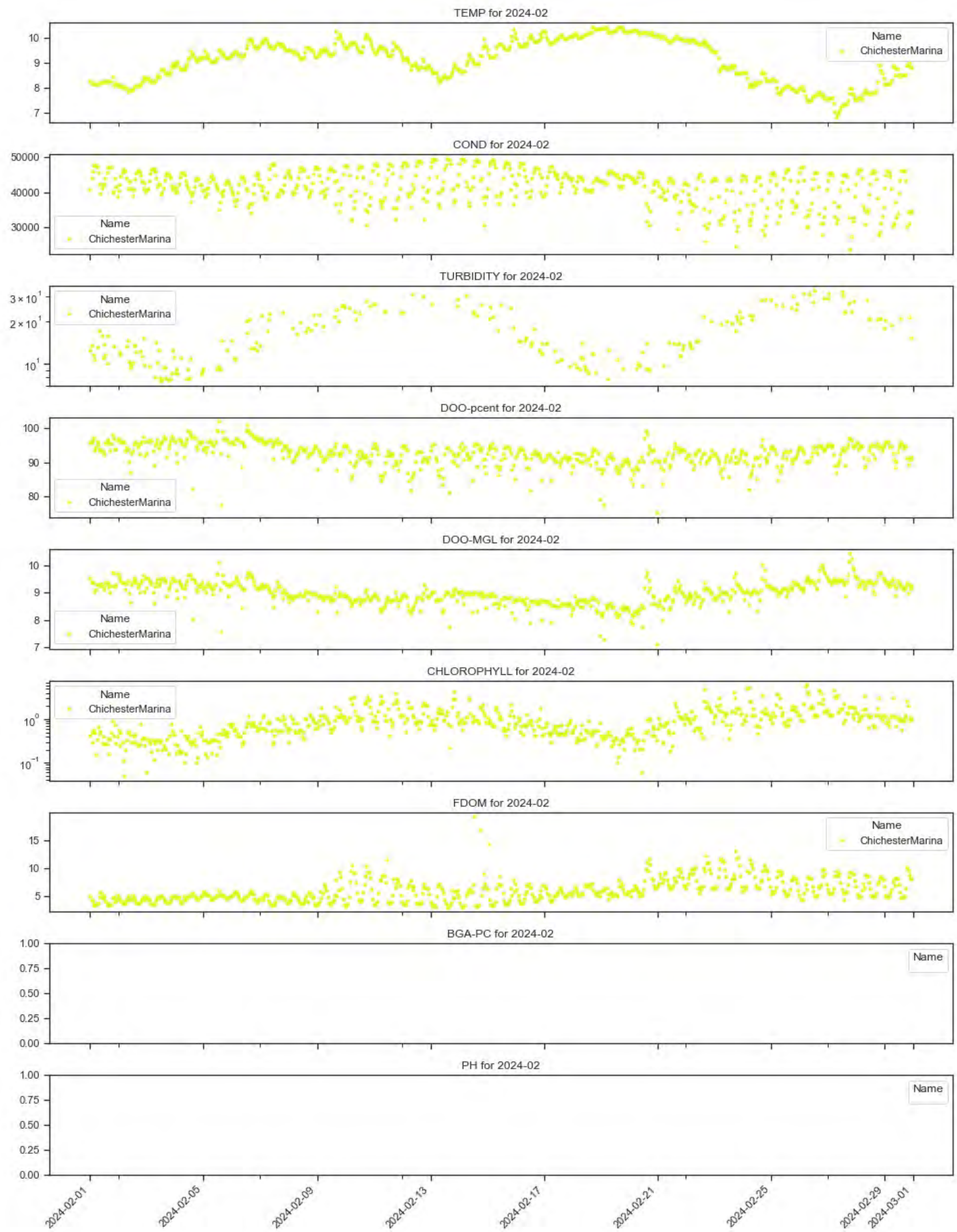


Figure A-27 - Subset 2 February 2024

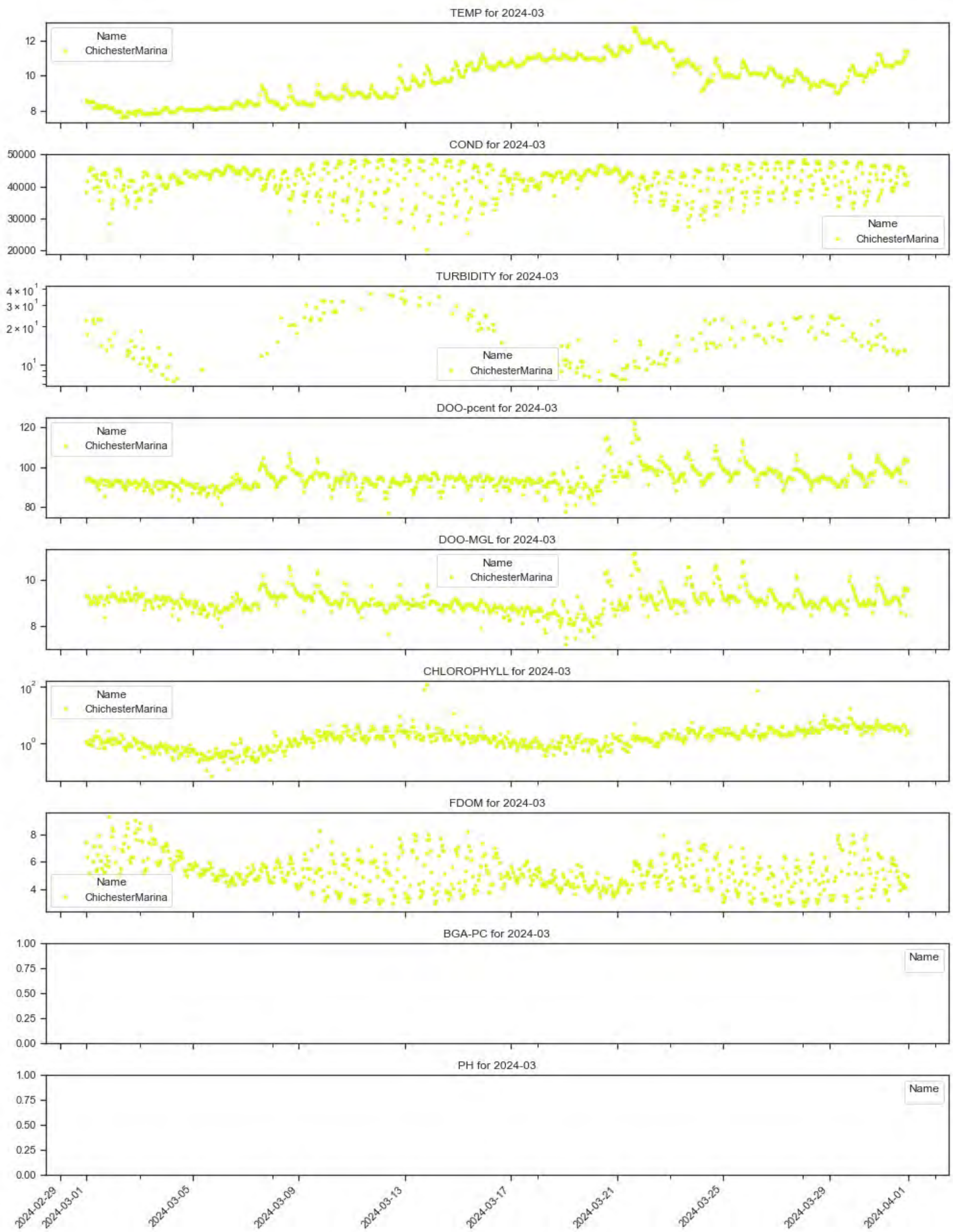


Figure A-28 - Subset 2 March 2024

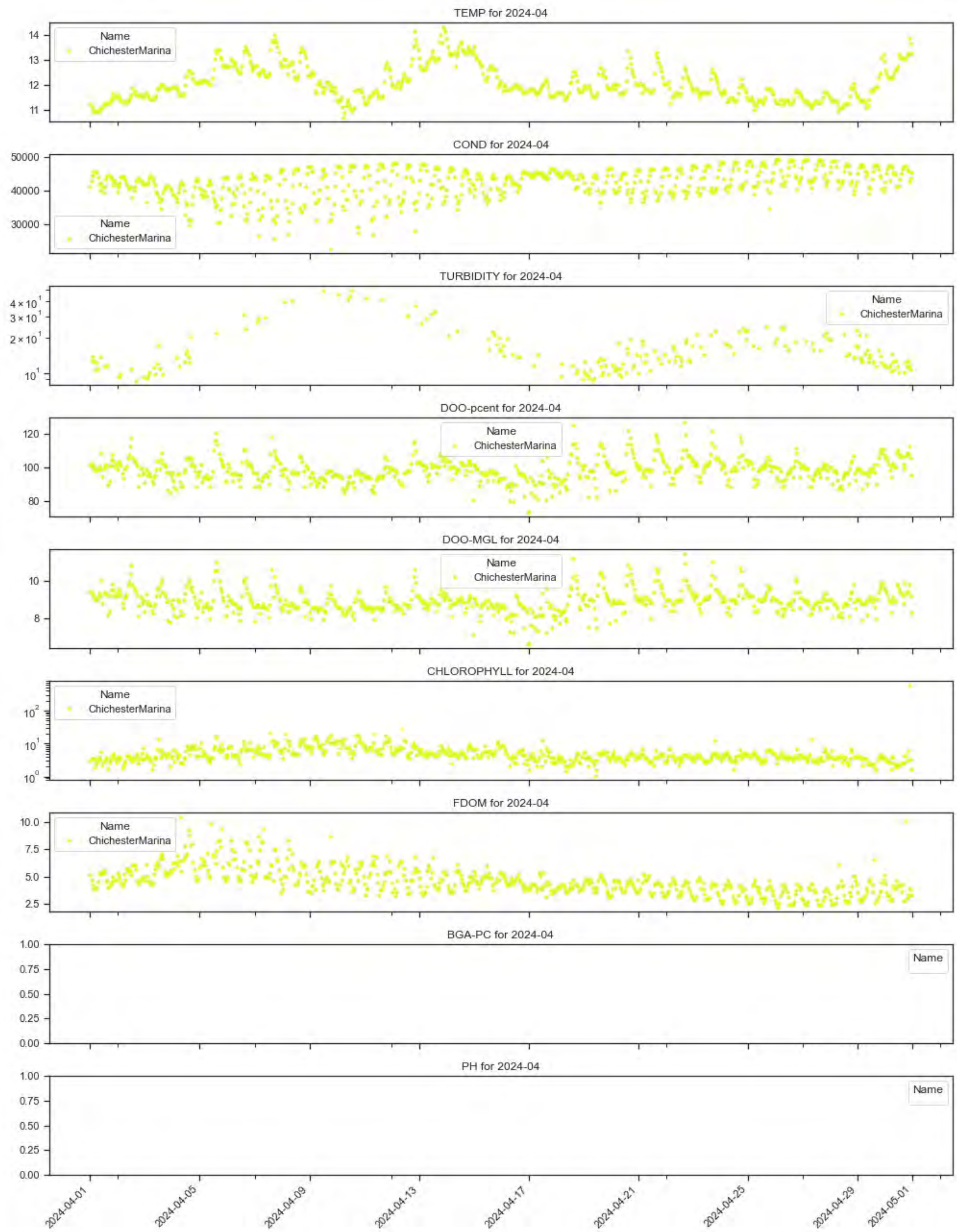


Figure A-29 - Subset 2 April 2024

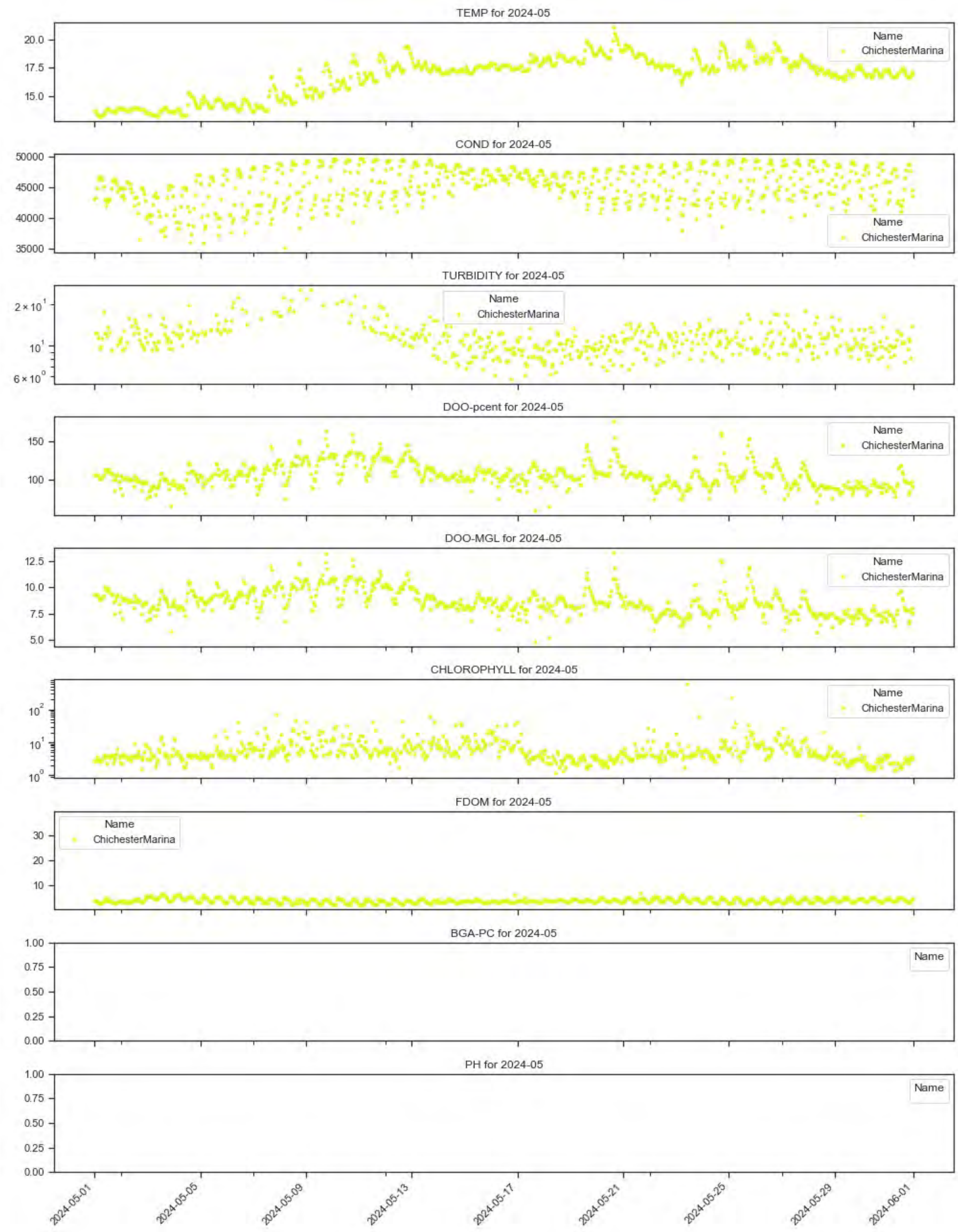


Figure A-30 - Subset 2 May 2024

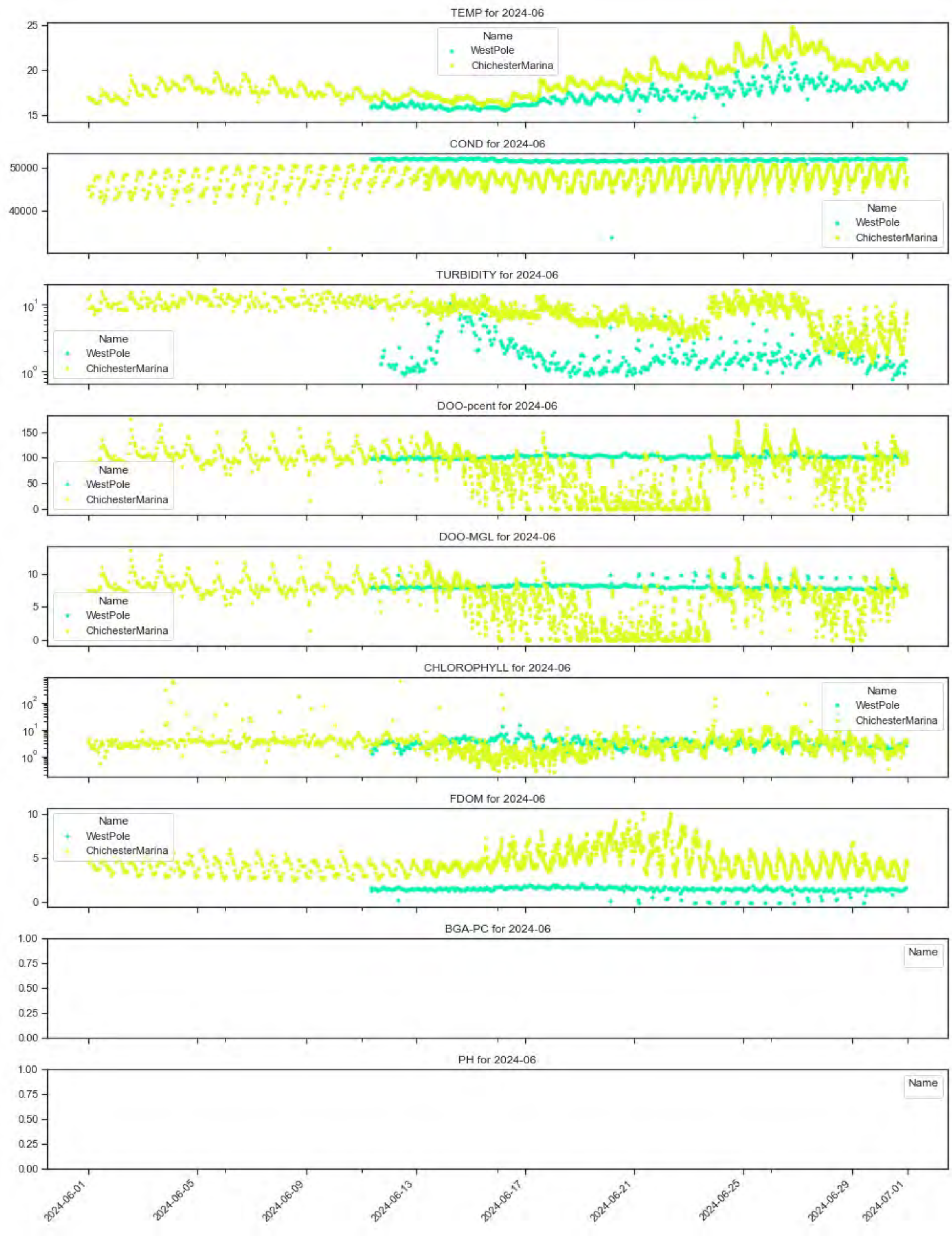


Figure A-31 - Subset 2 June 2024

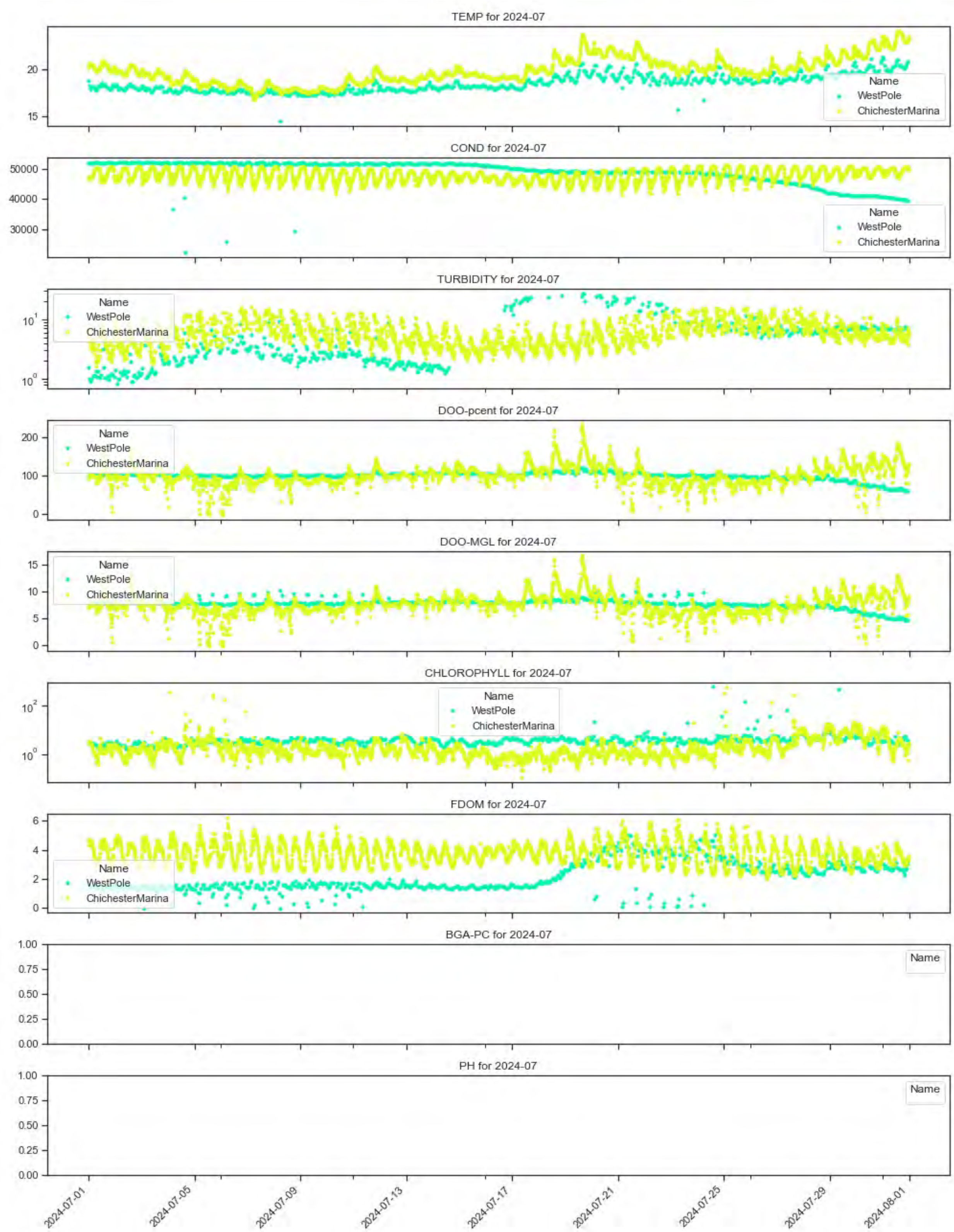


Figure A-32 - Subset 2 July 2024

Appendix B – Bed Orbital Velocity Calculation

The bed orbital velocity was calculated following Soulsby's 1997 book the Dynamics of Marine Sands, using pages 75-76. To do this firstly calculate:

$$Tn = \left(\frac{h}{g}\right)^{0.5}$$

Where h is water depth (10m), g is gravitational acceleration (9.81ms^{-1}). Next divide by the zero upcrossing period Tz. Use the equation of the line from the JONSWAP curve provided in Figure 13.

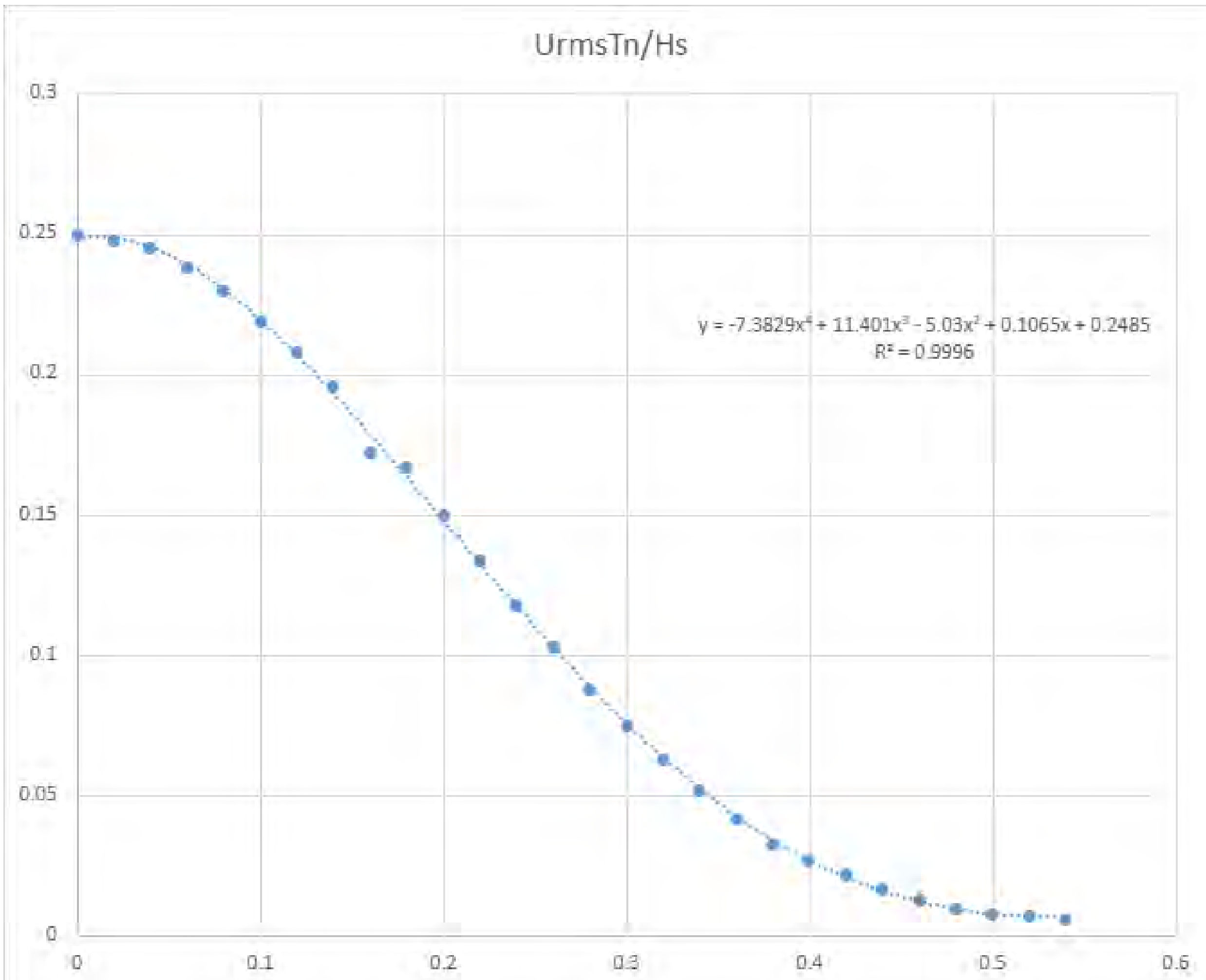


Figure B-1 – JONSWAP curve. Data taken from HR Wallingford https://eprints.hrwallingford.com/112/1/SR76-method-calculating-orbital-velocity-waves.pdf

Finally, to obtain the orbital bed velocity (ms^{-1}):

$$Urms = Urms\left(\frac{Tn}{Hs}\right) * \left(\frac{Hs}{Tn}\right)$$

Appendix C – Difference model methodology

The Channel Coastal Observatory regularly collects 1m spatial resolution LiDAR data as part of the wider National Network of Regional Coastal Monitoring Programmes. LiDAR data is gridded elevation data with a given accuracy of +/-0.15m. Here we compare two datasets, one collected in 2008 (before the realignment project) and in 2022 (9 years after the breach).

To calculate the difference (i.e. the change) between these two datasets, the newest dataset is subtracted from the older dataset to give the change in elevation over time. This process is demonstrated in Figure C-1, where each pixel value from InRas2 (in this case the 2008 LiDAR image) is subtracted from the corresponding pixel value from InRas1 (the 2022 LiDAR) to produce a continuous surface of change values (OutRas).

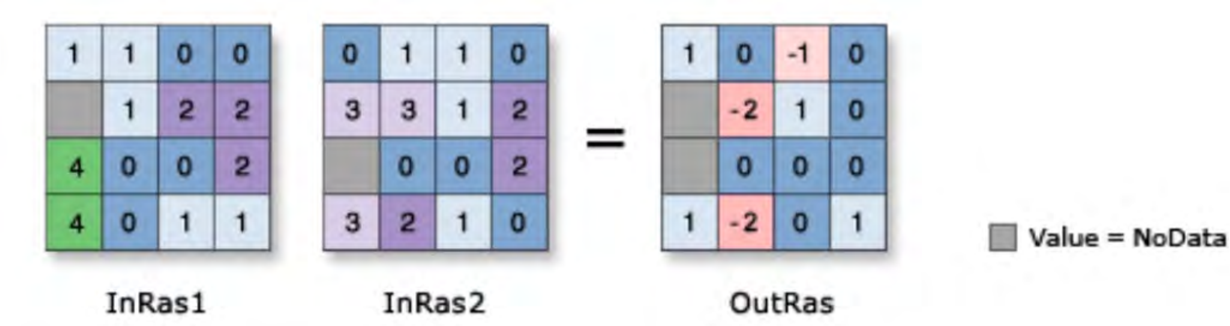


Figure C-1 – Visual representation of the Lidar change analysis method. Image from www.pro.arcgis.com/en/pro-app/help/data/imagery/minus.htm

Once this calculation had been performed, a summing exercise is carried out to approximate volumetric change over this time period. This is done by using the GIS software to sum the areas within two distinct polygons shown in Figure C-2, namely the entire area and the beach area.

Figure C-2 – The two areas for volume calculation – namely the entire realignment area (which does not include the newly constructed bunds) and the beach area (which covers the newly accumulated/rolled back beach).

The results from this exercise were as follows:

- Entire realignment area volume change = -600,000 m^3
- Beach area change = +66,000 m^3
- Net change = 534,000 m^3

Appendix D – Marine Licence Application numbers for dredge extractions (2009 – 2022)

34254/081119	34894/100713	MLA201200053	MLA2013/00148	MLA/2016/00471
34314/090123	34842/100604	MLA2011/00287	MLA2013/00321	MLA/2016/00484
34341/090219	34813/100426	MLA201100171	MLA2013/00342	MLA/2017/00105
34319/090127	34883/100706	MLA201200086	MLA2013/00440	MLA/2017/00478
34302/090114	34921/100809	MLA2012/00131	MLA/2013/00371	MLA/2018/00167
34401/090417	34875/100625	MLA2012/00164	MLA2013/00437	MLA/2017/00308
33832/071002	35045/110110	MLA201200227	MLA/2013/00418	MLA/2018/00082
34363/090316	34997/101125	MLA2012/00306	MLP/DC9841	MLA/2017/00377
34354/090305	35026/101220	MLA2012/00326	MLP/2014/00139+140	MLA/2018/00378
34511/090710	35038/101224	MLA2012/00280	MLA/2014/00367	MLA/2014/00388/1
34436/090513	35009/101213	MLA2012/00338	MLP/2014/00160	MLA/2021/00456
34530/090727	35048/110112	MLA2012/00285	MLA/2015/00216	MLA/2014/00004/5
34521/090722	MLA2011/00053	MLA2012/00474	MLA/2014/00420	MLA/2021/00366
34520/090722	MLA2011\00068	MLA2012/00423	MLP/2014/00259	SAM/2020/00048
34523/090722	MLA201100108	MLA2012/00279	MLA/2015/00183	SAM/2017/00068 MLA/2015/00287
34522/090722	34989/101109	MLA2012/00281	MLP/2014/00369	MLA/2018/00082/1
34512/090710	MLA2011/00172	MLA2012/00459	MLA/2015/00426	MLA2021/00530 SAM/2021/00023
34531/090727	MLA2011/00171	MLA2012/00335	SAM2015/00014	MLA/2014/00208/1
34495/090624	MLA2011/00173	MLA2012/00472	SAM2015/00003	MLA/2016/00025/3
34560/090828	MLA2011/00174	MLA2012/00228	SAM2015/00018	MLA/2016/00216/1
34577/090918	MLA2011/00247	MLA2012/00489	SAM/2015/00047	L/2017/00148/1
34586/091005	MLA2011/00263	MLA2012/00502	MLA/2016/00093	MLA201900370
33663/070418	MLA201100292	MLA2013/00029	MLA/2016/00195	
34648/091207	MLA2012/00024	MLA2013/00019	MLA/2016/00355	
34814/100426	MLA201200046	MLA2013/00092	MLA/2016/00421	
34901/100716	MLA201200048	MLA2013/00170	MLA/2016/00509	

Table 9 Table of Changes to Species Populations from Records of *Fishermen* Interviews in 2020

	Crustaceans			Sea Snails	
Species Name -->	**Crabs**	**Lobster**	**Spider Crab**	**Whelks**	**Winkles**
Year					
2020	Not as healthy	P			IO
2019		MR/BR/G/H/E			IO
2018		SP			
2017					
2016	Crabs not as affected by water quality, don't hide from storms. Not sure where this came from	Bb			
2015					
2014					
2013					
2012		linked w/			
2011		increase in			
2010		smooth hounds			
2009					
2008					IO
2007					
2006	Crabs not as affected by water				
2005					
2004					
2003					
2002					
2001					
2000					
1990-1999					
1980-1989		Bb/SY/P/MR			
1970-1979					
1960-1969					
1950-1959					
1940-1949					
1930-1939					
1900-1929					
1800s					
1700s					

Sea weed						
Kelp	**Weed**	**Lace Weed**	**Seaweed**	**Bootlace Weed**	**Black weed**	**Japanese Weed**
		SY/EB	SY/EB		P	BR/MR
					P	
				BR	P	
				BR		
H/S/P/MR						
PH/G/P						
		SY	SY			MR/BR
MR (storm)			SY			SY
Everywhere			SY			SY
		EB/IO				

	Sea Snails		Starfish and Sea Urchins	
Species Name -->	**Whelks**	**Winkles**	**Brittle Stars**	**5 fingered starfish**
Year				
2020		IO		
2019		IO		
2018				
2017		IO		
2016				
2015				
2014				
2013				
2012				
2011				
2010				
2009				
2008				
2007				
2006				
2005				
2004				
2003				
2002				
2001				'Wipe out' mussel beds, brittle stars and whelks Correlate with spider crabs
2000				
1990-1999				
1980-1989				
1970-1979				
1960-1969				'Wipe out' mussel beds, brittle stars and whelks
1950-1959				
1940-1949				
1930-1939				
1900-1929				
1800s				
1700s				

Species Name -->	**Cuttlefish**	**Herring**	**Skate**	**Cod**	**Whiting**
Year					
2020					
2019					
2018					
2017					
2016	MH				
2015					
2014					
2013					
2012					
2011					
2010					
2009					
2008					
2007					
2006					
2005					
2004					
2003					
2002					
2001					
2000					
1990-1999					
1980-1989					
1970-1979					
1960-1969					
1950-1959					
1940-1949					
1930-1939					
1900-1929					
1800s					
1700s					

Species Name -->	Plaice	Soles	Mackerel	Mullet	Smooth-hounds
Year					
2020			SY	SY	
2019					
2018					
2017			SY		
2016					
2015					
2014					Mm
2013					
2012					
2011					
2010					
2009					
2008					
2007					
2006					
2005					
2004					
2003					
2002					
2001					
2000					
1990-1999					
1980-1989					
1970-1979					
1960-1969					
1950-1959					
1940-1949					
1930-1939					
1900-1929					
1800s					
1700s					

Feed on lobsters, crabs, small fish

Thrive in warm conditions Weed eaters - no weed, mullet die or migrate

Thrive in warm conditons Weed eaters - no weed, mullet die or migrate