Advanced Ecosystem Analysis in Environmental Management (AEF-EM019)

Contribution of automated ferrybox chlorophyll-a data in monitoring of Eutrophication of German Bight.

Module taught by: Prof. Dr. Felix Müller
Institute for Natural Resource Conservation
Department of Ecosystem Management

Report Prepared by: Razeeb Sarker
Student Id: 1139932
Stu Number: stu 218072

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Motivation:

Anthropogenic nutrients supply is a threat to the coastal ecosystem, and approximately 24% of the global nitrogen nutrients is estimated to go into the coastal and estuarine watersheds (Malone and Newton, 2021). It is our duty to keep our environment in a good environmental status, and exploit it in sustainable ways to ensure the long term benefits.

Germany has 43,098 km² of EEZ in the North sea also called as German Bight. It is the mandatory requirement and obligation by various European and German laws to regularly monitor and assess the environmental status of the **German Bight.** Establishing a successful, effective, and economically viable monitoring system is the key component of ecosystem management. It requires lots of resources and effort. My aim in this analysis is to check how can COSYNA (Coastal Observing System for Northern and Arctic Seas) database and coastal monitoring system reduce this cost significantly by providing automated data collected by their ship and fixed station mounted devices to the policy makers, also for the facilitation of further research.

Introduction & background:

Legislative Requirements:

It is required by almost all the legislative instruments and policies to protect our environment. European countries have come up with a few conventions, like the Marine Strategy Frame directive (2007), Common Agricultural Policy. Sustainable Development Goal is also such an instrument that is obligatory for all countries around the world, and its goal no 14 is about water and life in water. As a common practice in Europe to adopt all the common environmental policies to the national policy. And Germany has incorporated MSFD in the Federal Water Act (Wasserhaushaltsgesetz, WHG) for better monitoring and implementation purposes.

Common Agricultural Policy:

European Commission's "Common Agricultural Policy" CAP lays the legislative framework for the reduced use of fertilizers that also relates to the Eutrophication. The new CAP policy stresses on ensuring food security considering the sustainable, resilient and competitive framing sector (Future of the EU's agricultural policy: what about nutrient management? - Fertilizers Europe, 2021)

CAP proposes three steps to implement Green Architecture of sustainable farming. The second step says that *"an obligatory nutrient management tool, designed to help farmers improve water quality and reduce ammonia and nitrous oxide levels on their farms"*. If we interpret the statement, we can infer that it talks about the nutrient input in the environment, and it's monitoring, and evaluation.

Sustainable Development Goal:

SDG's (Sustainable Development Goal) goal no. 14 dictates about "Life below water" and is one of the 17 Sustainable Development Goals directed by the United Nations in 2015. Goal SDG 14 has 10 targets, among them target 14.1.1 talks about the monitoring by using index eutrophication and plastic debris density (United Nations, 2017)

MSFD, Marine Strategy Framework Directives:

MSFD, established in 2008, targets to achieve and maintain GES, good environmental status of the marine environment across the europe. It has adopted a cyclical order of tasks to implement this target. One of the cyclical tasks includes regular monitoring, **"The establishment of a monitoring programme for the ongoing assessment and the regular update of targets"** (MSFD 2008).

Federal Water Act (Wasserhaushaltsgesetz, WHG):

Federal Water Act also stipulates the requirements of continuous monitoring the Good Environmental Status, GES of the by restricting the influx of nutrients in the Water in article 21. The provisions stipulated in the MSFD, CAP, and SDG also to be incorporated in the WHG in near future as the EU commision requires that all the EU Environmental rules should be also implemented as National Rules.

Article 20 Compensation
Article 21 Monitoring
Article 21a Commissioning Planned Delegates for Water Pollution Control
Article 21b Tasks

Fig: Monitoring requirement by the Federal Water Act, article 21.

Eutrophication:

The word Eutrophication roots from Greek word “eutrophos” which literally means "well-nourished". It is a gradual process in which a water body is subject to high inflow of nutrients, in other word, overabundance of nutrients and minerals (mainly from nitrogen and phosphorus variants) with help of sunlight (in the photic zone) and low or less mixing on the surface area results to excessive growth of algal family, resulting algal bloom, subsequently a low light penetration in the deep water column, oxygen depletion in the underneath water column.

Eutrophication Process in Graphics:

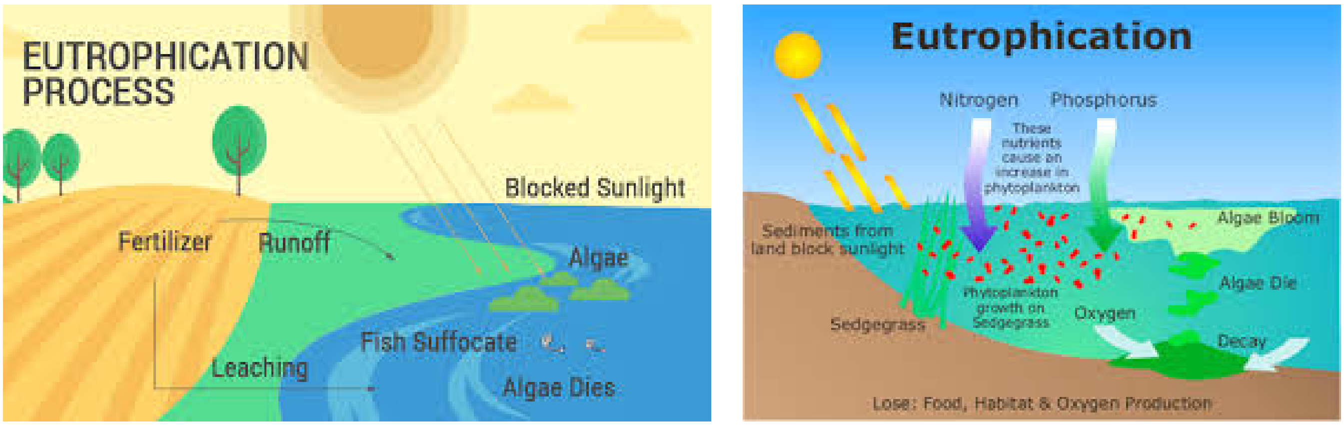


Figure 2: Eutrophication process overview

Consequences of Eutrophication:

After the exponential growth phase, the phase comes when there are not sufficient nutrients for the survival of the Algae. Then the algae dies and continues to deposit on the seabed. Bacteria starts to decompose the dead algae, and consumes oxygen for respiration during the biodegradation process, which subsequently causes oxygen scarcity in that zone. Sometimes the oxygen level drops to such a level (also termed as hypoxia) that no fish and animal could survive and create a dead zone. In the case of Harmful Algal Bloom, HABs, toxins could be created which will lead to mass mortality.

Indicators of Eutrophication:

There are multiple indicators for eutrophication. Among them **Chlorophyll-a**, total nitrogen, total phosphorus, biological or chemical oxygen demand and secchi depth are most commonly used indicators by the researchers and the evaluating communities.

Chlorophyll-a Concentration as an indicator of Eutrophication:

Photosynthesis in the plants and algae is facilitated by chlorophyll, and **chlorophyll a** is the predominant types of chlorophyll found in the most green plants and algae. The concentration of Chl a indicates the amount of algae in the water. High concentration Chl a suggests high amount of algae(Indicators: Chlorophyll a | US EPA, 2021).

Chlorophyll a measuring techniques:

There are various techniques to measure chlorophyll, including spectrophotometry, high performance liquid chromatography (HPLC), and fluorometry. All of these methods are published in Standard Methods for the Examination of Water and Wastewater.

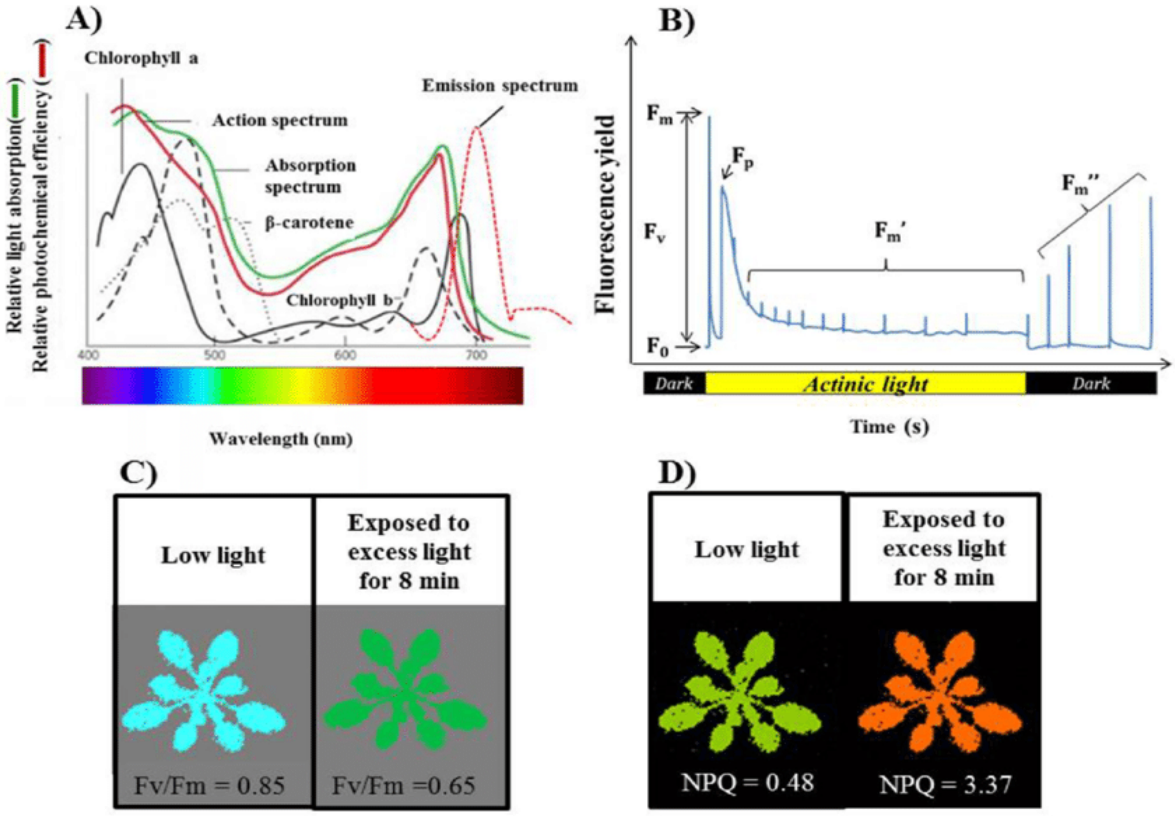
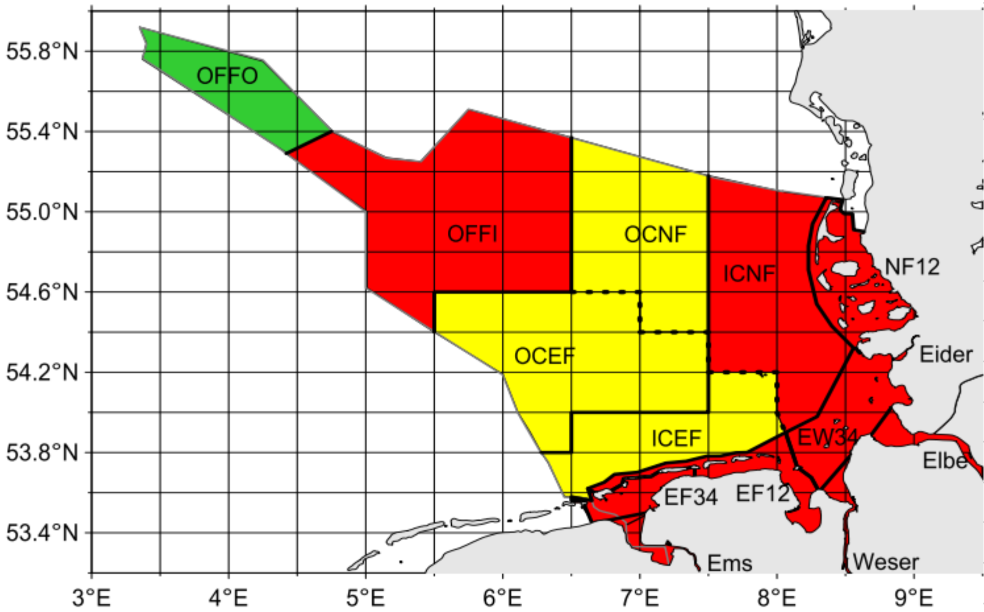


Figure 3: Chlorophyll-a Measuring techniques.(The principles of Chlorophyll fluorescence)

Area of Interest: Germany has 43098 km² of EEZ in the North sea also called as German Bight (Deuschen Bucht in German). As per the OSPAR Comprehensive Procedure German Bight is divided into **10** Bewertungsgebieten and, three river estuaries, Elbe, Ems, and Weser as follows-

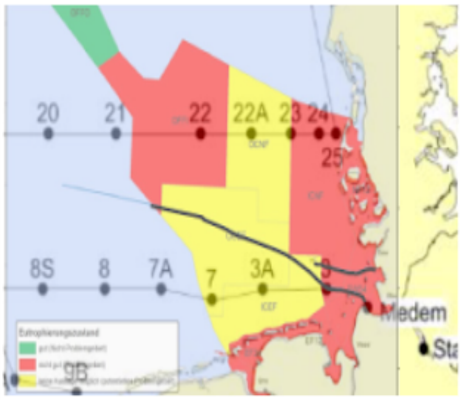


Abbreviation code for subarea	Number of squares	Area km²
OFFO	17.5	2542
OFFI	67	9730
OCNF	38.5	5591
OCEF	50.5	7334
ICNF	48	6971
ICEF	26.5	3849
NF1,2	15.5	2251
EF1,2	8.5	1234
EW3,4	14	2033
EF3,4	5	726
Elbe		327
Weser		182
Ems		327
All Estuaries		
	291	43098

Figure 4: German Bight and OSPAR Assessment areas.

For this study I only considered two Bewertungsgebieten **OECF** and **EW34** for which I have ferrbox data. I also had to extract the sampling points from the Das Bundesamt für Seeschifffahrt und Hydrographie, BSH ships report that are closest to my ship's track and the fixed station as follows-

Few BSH sample stations which are close to our Ferry Boxes' route	Latitude	Longitude	Estimated chl-a value
MEDEM	53.86685278	8.716716667	8.4
3 (GN003 ELBE1)	54.00003611	8.100113889	7.5
3A (GN003A)	54.00003056	7.166747222	2.1
7 (GN007)	53.91683056	6.416791667	2.2
22A (GN022A)	54.983575	7.000019444	1.9



Own estimation based on
- Report of the Chief Scientist R/V Celtic Explorer 18019 August 28th – September 13th, 2018 &
- Die Bundesregierung,Zustand der deutschen Nordseegewässer 2018

Figure 5: BSH ship sampling stations and COSYNA ship tracks.

Problem Definition:

Sensor fitted with a COSYNA Ferrybox can measure Chlorophyll concentration real time, every after 20 seconds, and stores the value in the local memory. The data is sent to the central database in Helmholtz Zentrum Geesthacht when the ship is connected to the internet. As we can see from the marine traffic images (*Fig 7*), there are numerous ships including cargo ships, bulk-carrier, container, and many more types, that regularly use german water during their passages. A ferrybox fitted onboard the ship will facilitate automatic acquisition of chl-a measurements with significantly less effort, and cost than traditional research vessel trips.

Now, there raises a question, if the measurement sampled by the ferrybox sensor is similar to the in situ sampling by research vessels like the BSH ship trips. If we can evaluate the ferrybox data, and come to an inference about the similarity in them, policy makers and government bodies could use these readily available data for better monitoring and making policies which are required by the legislative frameworks discussed in the section Legislative Frameworks.

Briefly, our problem can be defined by the following diagram.

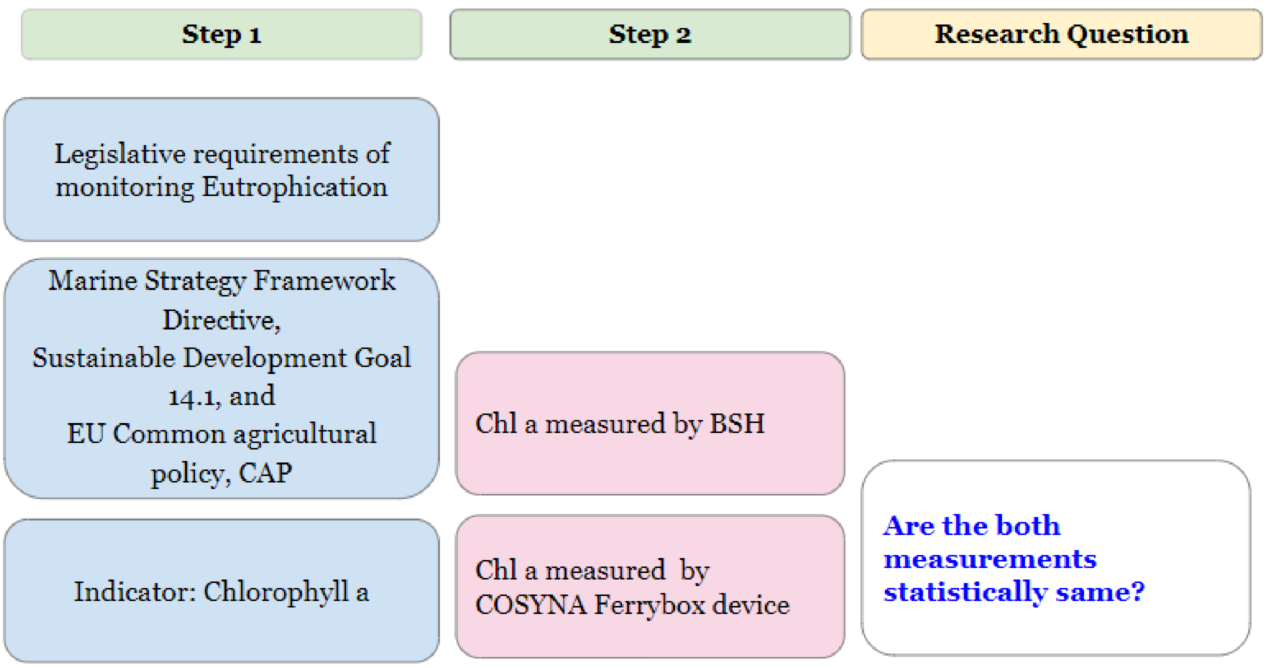


Figure 6: Summary of problem definition

As per the legislative instruments by different conventions(MSFD, CAP, SDG, and) and authorities (Federal Water Act (WHG)), it is a mandatory requirement to monitor the GES (Good

Environmental Status) indicators regularly. Germany has 70000 square kilometers in the north sea and in the baltic sea. It is implemented by the use various marine observation systems like-

a. regular monitoring cruises with help of research vessels,
b. by the fixed mooring stations ,
c. by free floating buoys at the sea
d. remote sensing from satellites

But in situ measurement technique is still considered to be the best, and less prone to error. The main problem with in situ measuring is that it requires lots of resources and efforts, and that is the reason why BSH ships conduct 1 or 2 measurement trips in the German waters both in Baltic Sea and German Bight in the North Sea. In the following pictures from a marine traffic website we can see numerous different types of ships are traversing through our area of interest. It would be a huge advantage if we could have a device or instrument fitted with specific sensors, and that device is installed on board the ships, and get regular readings in specific time intervals.

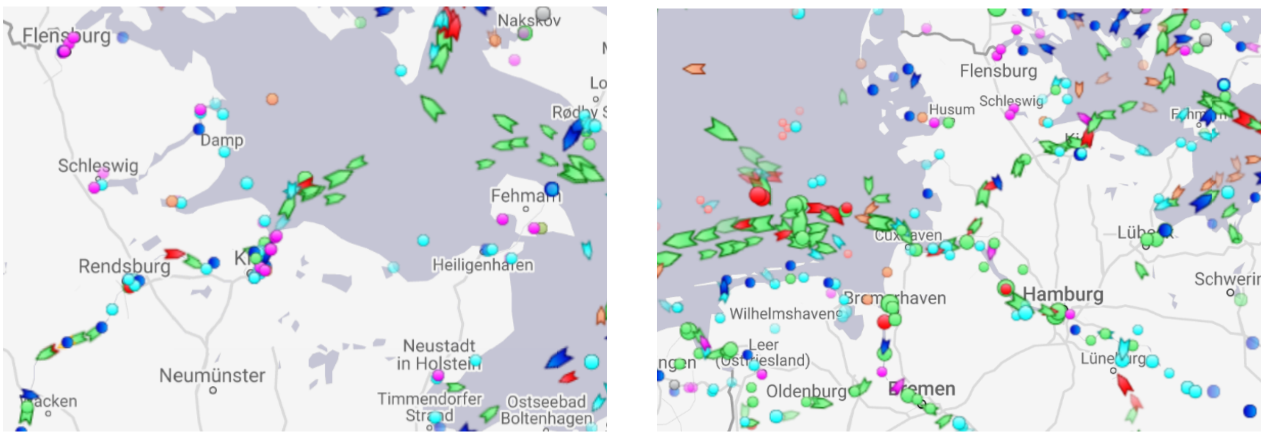


Fig 7 : Images of ship traffic in the german water (left in Baltic and right: North Sea). Source: (MarineTraffic: Global Ship Tracking Intelligence | AIS Marine Traffic, 2021)

Cosyna Ferrybox and it's working principle:

Ferrybox is a measurement system that can automatically measure the parameters (physical, chemical, and biological) of the water surface of certain depth depending on the ship's draft on which it is installed, and the inlet depth in the water in case of installed on a fixed object like, Cuxhaven, Spitsbergen and the research platform FINO3. This device can also be on any mounting facilities like fixed stations, in short we have to provide the samples to the inlets to carry out the operations.

Figure 8: Typical Ferrybox set

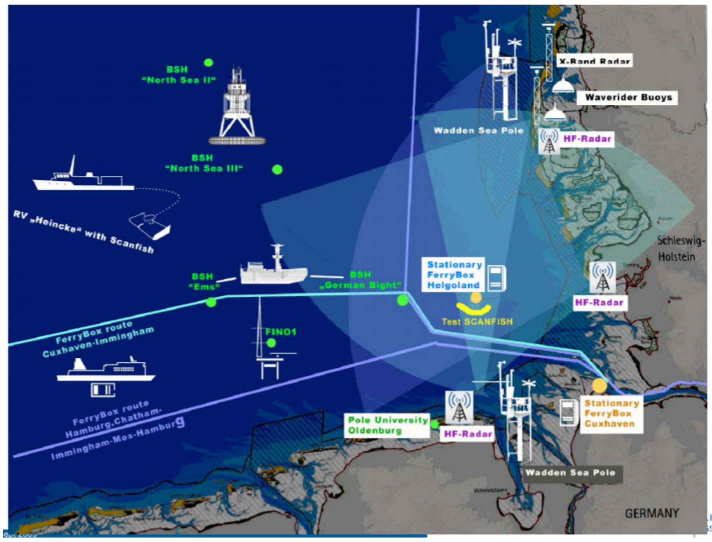


Figure 9: Ships that carry ferryboxes

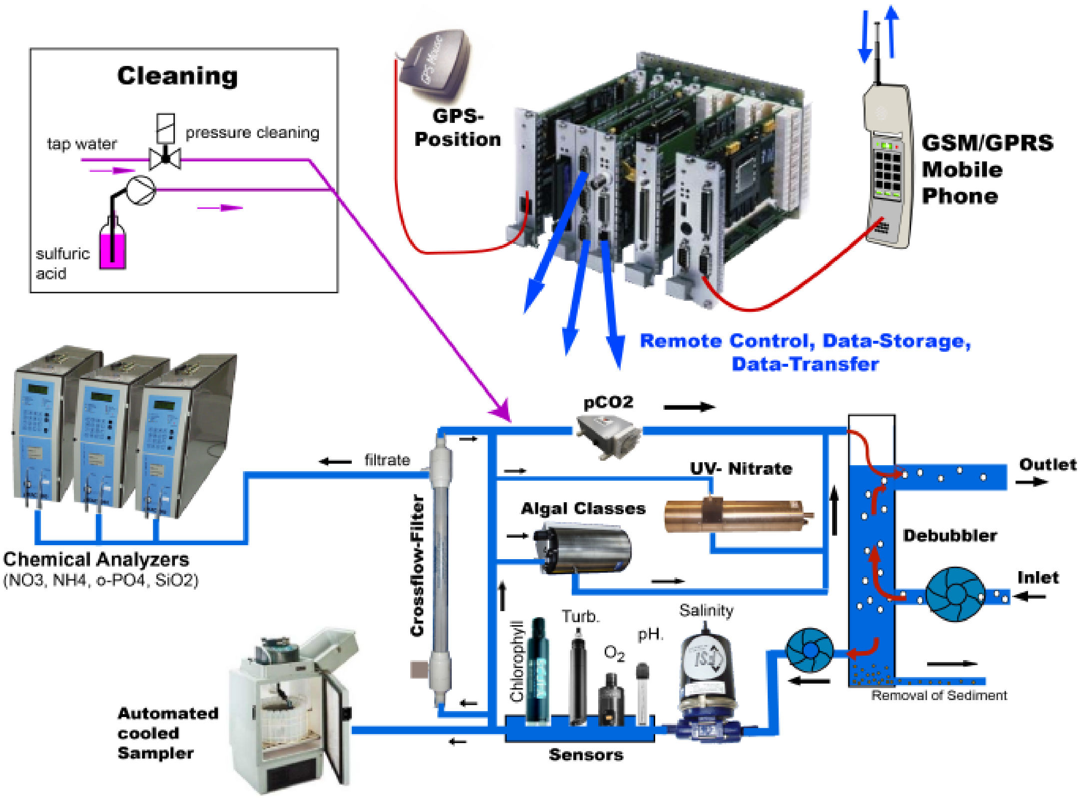
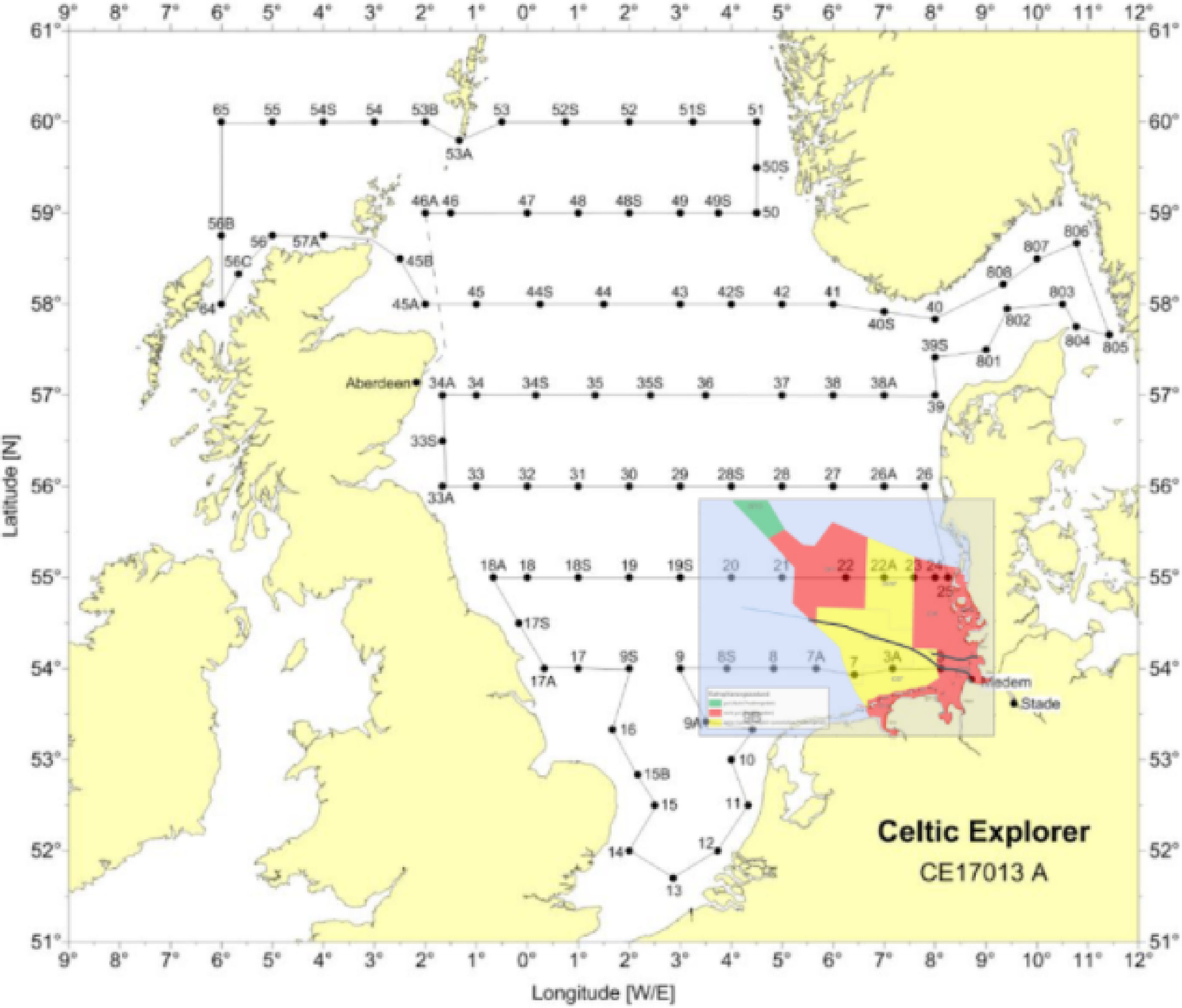


Figure 10: Working principles different sensors in Ferrybox

Methods and data collection:

Ferrybox data was collected from the COSYNA database for two ships, one is tourist streamer MS Funny Girl (conducts regular voyages between Helgoland and Büsum), another is MS Hafnia (conducts voyages between Cuxhaven and Immingham, England) and one fixed station in Cuxhaven between 2017 - 2018.

BSH data was collected from the survey report from the Celtic explorer report and extrapolated for the ships route as the ferrybox ship's route and the BSH sampling stations were not identical, has distances latitudinally.



Ship's track and sampling stations

Figure 11: Celtic Explorer, BSH ships track and sampling stations in 2017

Cuxhaven data Validation:

Ferrybox at Cuxhaven mounted on a cargo container near geographical coordinates of 53°52'37.2"N 8°42'17.4"E which is very close to the coastal water. Water is pumped into the device inlet continuously, and measured. Being close to the coast, this area is heavily fluctuated by the tidal effects, and the measurements show random changes due to dynamic characteristics of the coast. to validate the data extracted from the cuxhaven fixed station, we need to consider the dynamic character of the coast and consider accepting high grade of fluctuation in the measures.

Description of ferrybox data:

Chlorophyll-a comes along with other features such as, timestamp, geographical coordinates (latitude and longitude), depth of water,and a quality flag. In the below picture we can see an initial overview of the raw dataset.

time	latitude	longitude	depth [meter]	Chl-a_Fluor_Wetlabs_ECO_FLNTU [?g/l]	quality flag
2017-08-02T02:32:00Z	53,619721	-0,119008	2	0,341053	2
2017-08-02T02:32:20Z	53,619124	-0,116876	2	0,344842	2
2017-08-02T02:32:40Z	53,618523	-0,114719	2	0,351284	2
2017-08-02T02:33:00Z	53,617937	-0,11254	2	0,358	2
2017-08-02T02:33:20Z	53,617344	-0,110358	2	0,361137	2
2017-08-02T02:33:40Z	53,616743	-0,108183	2	0,367958	2
2017-08-02T02:34:00Z	53,616133	-0,106033	2	0,3652	2
2017-08-02T02:34:20Z	53,615538	-0,103845	2	0,365305	2
2017-08-02T02:34:40Z	53,614952	-0,101678	2	0,361137	2

Figure 12: Overview of raw dataset

Data Processing:

Primarily, the dataset had 166,000 observations. Few observations were excluded due inconsistent gps coordinates (may be from a gps device malfunction during the observation). The BSH ship's data are only available for the months of August, and September of 2017(figure ...). For this reason, the observations only for the mentioned months from the ferrybox data were considered to make a similar temporal comparison. The final dataset consists of approximately 19,000 observations.

survey period	research vessel and cruise id	nominal distance [nm]	marine physics, oxygen, pH-value	nutrients, chlorophyll	organic contaminants	trace metals	artificial radio nuclides	air chemistry
24.06.1998 – 16.07.1998	R/V Gauss 317	~ 2600	●	●				
02.07.1999 – 22.07.1999	R/V Gauss 335	~ 2600	●	●				
09.08.2000 – 23.08.2000	R/V Gauss 353	~ 2600	●	●				
11.07.2001 – 02.08.2001	R/V Gauss 370	~ 2600	●	●				
16.07.2002 – 31.07.2002	R/V Gauss 385	~ 2600	●	●	●			
28.07.2003 – 13.08.2003	R/V Gauss 405	~ 2600	●	●	●			
05.08.2004 – 20.08.2004	R/V Gauss 425	~ 2600	●	●		●		
10.08.2005 – 29.08.2005	R/V Gauss 446	~ 2600	●	●	●		●	
02.08.2006 – 20.08.2006	R/V Gauss 463	~ 2600	●	●		●		
03.08.2007 – 17.08.2007	R/V Pelagia 273	~ 2600	●	●	●			
21.07.2008 – 05.08.2008	R/V Pelagia 293	2715	●	●		●		
20.08.2009 – 09.09.2009	R/V Pelagia 311	3610	●	●	●		●	
04.08.2010 – 22.08.2010	R/V Pelagia 323	3310	●	●		●	●	
08.08.2011 – 28.08.2011	R/V Celtic Explorer 11010	3220	●	●	●		●	
07.08.2012 – 30.08.2012	R/V Celtic Explorer 12011	3500	●	●		●	●	
10.08.2013 – 04.09.2013	R/V Celtic Explorer 13012	4090	●	●	●		●	
01.08.2014 – 25.08.2014	R/V Celtic Explorer 14012	3470	●	●		●	●	●
07.08.2015 – 30.08.2015	R/V Celtic Explorer 15013	3580	●	●			●	●
03.08.2016 – 26.08.2016	R/V Celtic Explorer 16011	4000	●	●	●		●	●
11.08.2017 – 03.09.2017	R/V Celtic Explorer 17013	3600	●	●	(●)	●	●	●

Figure 13: In situ sampling at North Sea from 1998 to 2017

Result:

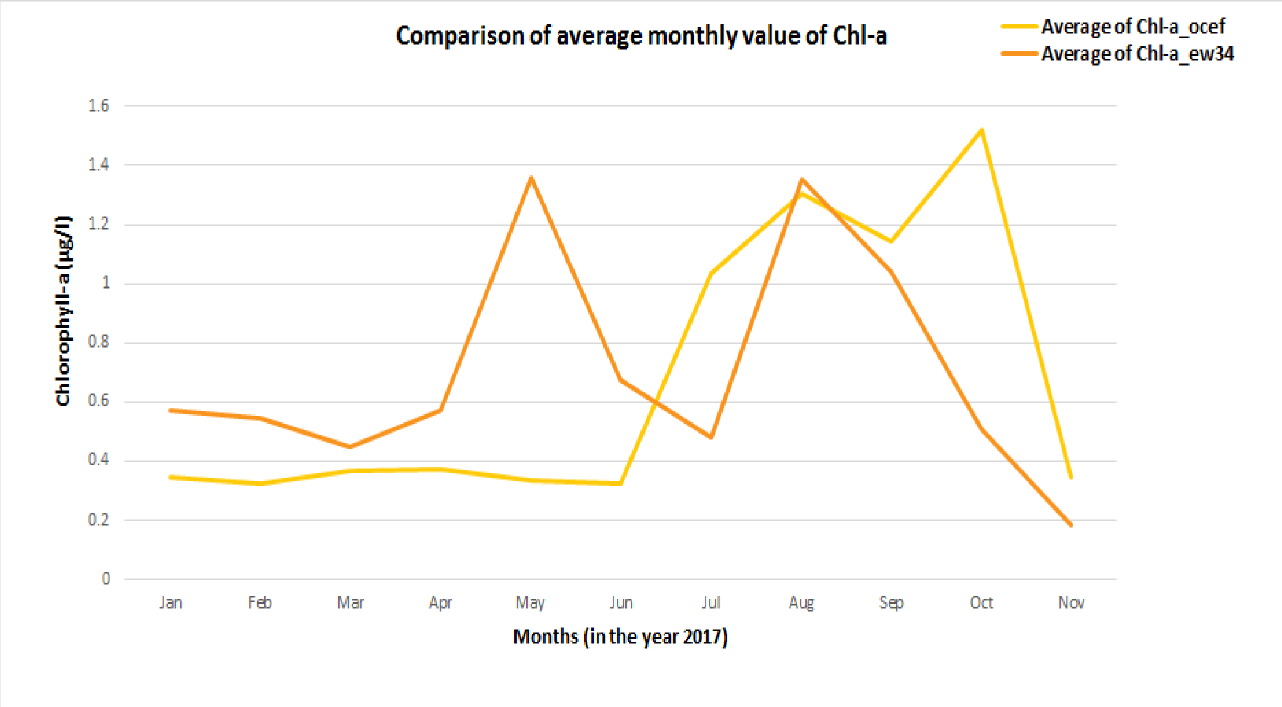


Figure 14: Average monthly Chl-a value in assessment area OCEF and EW34 area.

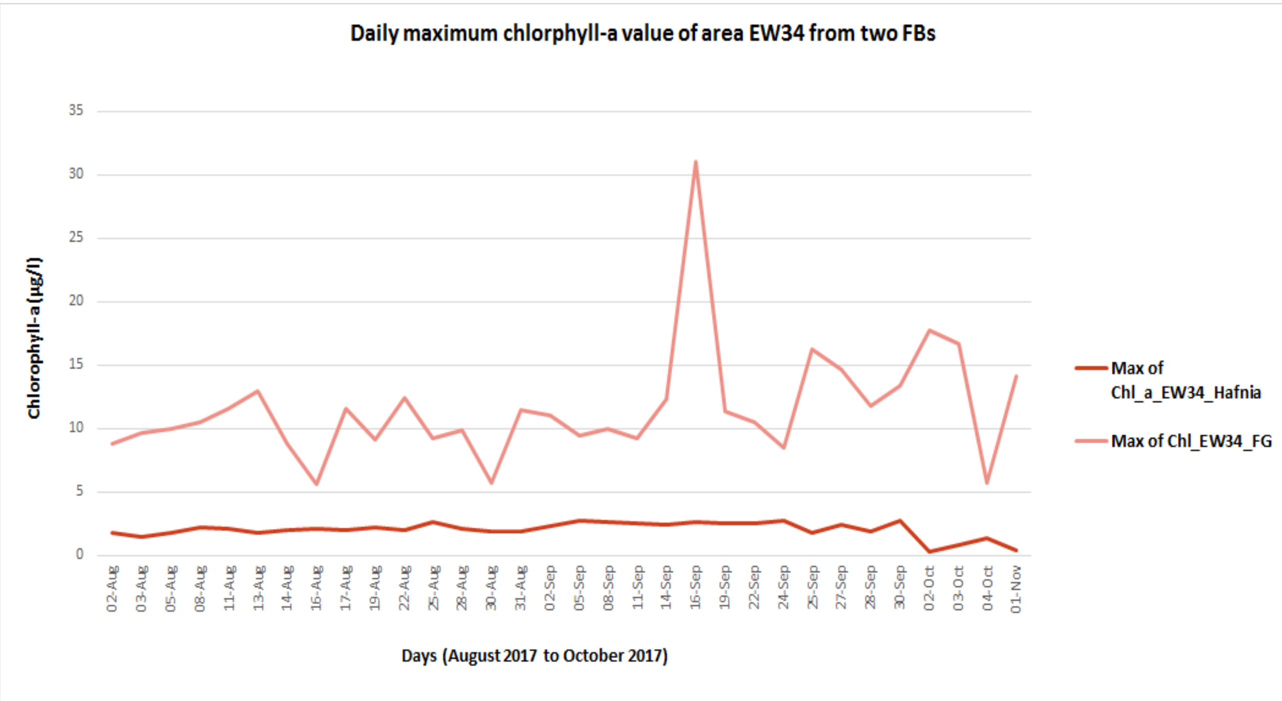


Figure 15: Daily Maximum values captured two different ships

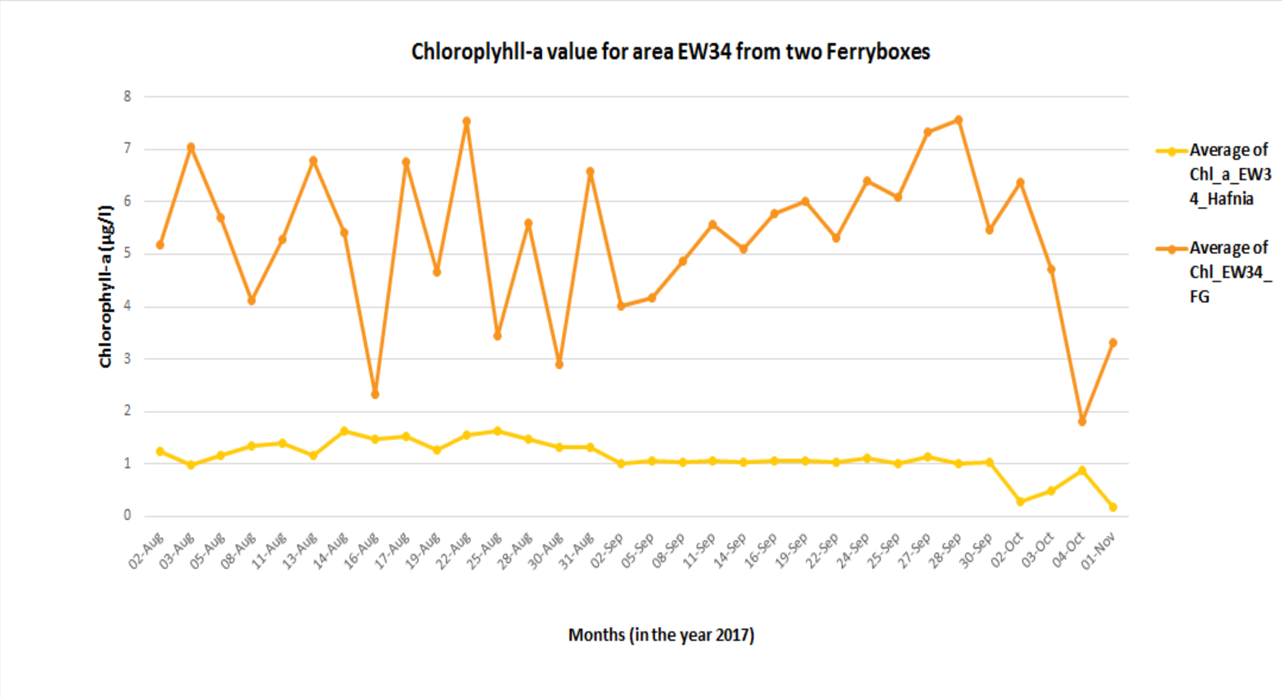


Figure 16: Daily Average Chl-a value in EW34 area by two different ships

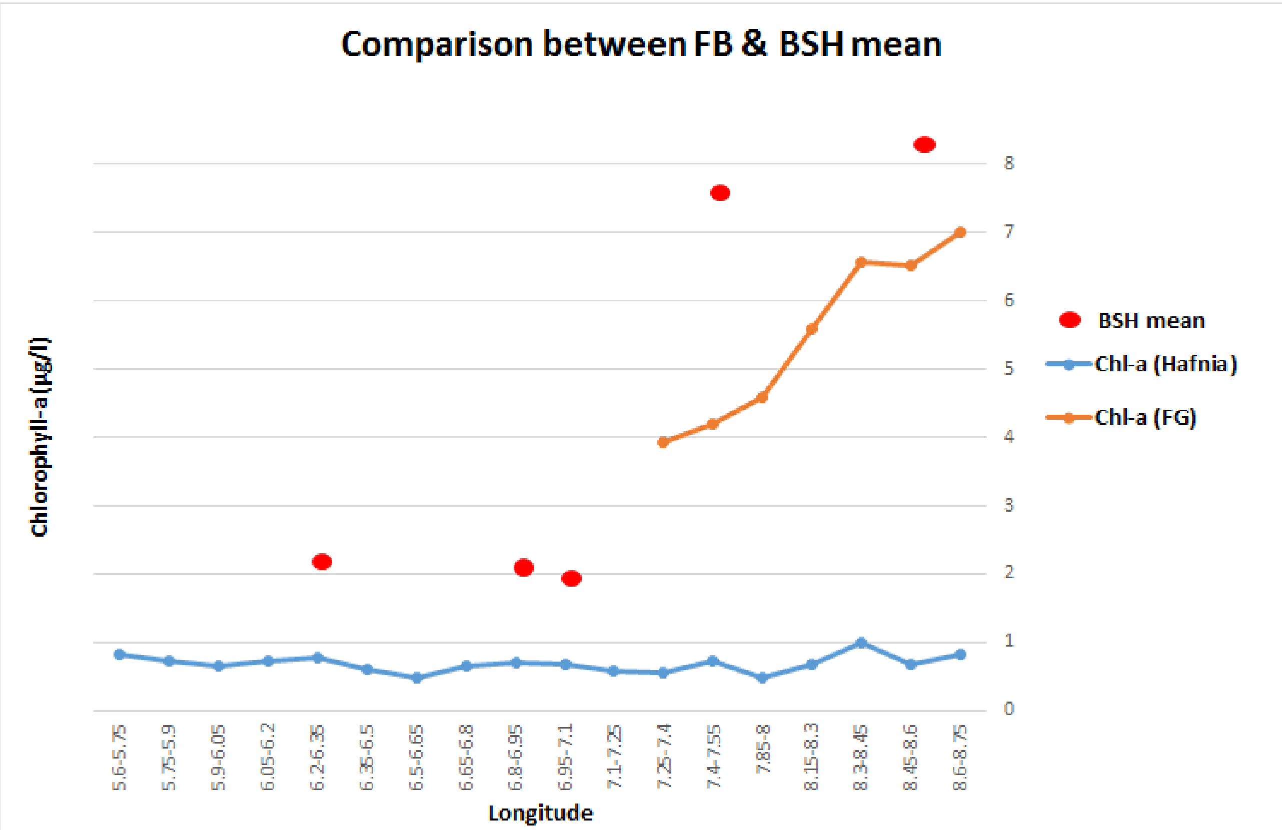


Figure 17: Comparison of Ferrybox measurements and BSH ship measurements.

Discussion:

The OCEF area is more deeper and far from the shore, and shows less values of Chl-a and shows less fluctuations compared to the EW34. This ship MS Hafnia is a bigger Cargo ship and normally makes passages through deeper water than the small ferry ship Funny Girl. Range and fluctuations of Chl-a value form MS Hafnia are characterised by the deeper water whereas for the Funny Girl mostly characterised by the shallow water.

Case 1: Both Ships in the same square, in the OCEF assessment area:

Figure 14: Shows the monthly average value of Chl-a in two selected Bewertungsgebieten OCEF and EW34 based on the all observations from both ships for the year 2017. For the EW34 area, the values fluctuate around the year, whereas for the OCEF area, Chl-a values fluctuate for June to November. Washed out rainwater from fertilised agricultural land could be a reason.

Case 2: Both ships in different area:

Figure 2: Now both ships' values are in the same Bewertungsgebieten but not in the same geographical coordinates. Hafnia travels through deeper water than Funny Girl, and we can see clearly that the daily maximum values from the Funny Girl are more fluctuating and dynamic than Hafnia.

Case 3: Yearly averages of the both area

This figure compares the daily average value of their two ships in the same Bearbeitungsgebiet EW34. We can see the trend is als most identical to that of in figure 2, more dynamic and fluctuating in the shallow water that the deeper water.

Case 4: Comparison with the BSH mean and the ships measures

Fig 4: This Figure shows the BSH ship mean (collected in the table .. from celtic explorer sampling stations in the figure given in Figure 17) compared to the values from the both ships. The values are not exactly matching. The reason behind this is that the sample stations are not exactly the same as the ship's tracks. But one thing is clear from the graph that our ferry box data follow the same trend as the BSH ships data. If we could get more precise BSH ship data that corresponds to the ferrybox ships tracks, we could come to an specific inference about the similarity. In that case we could do multiple statistical tests, ANOVA for example.

Advantages of using COSYNA database:

COSYNA database can provide various services in the monitoring of coastal and deep seas, but not limited to-

a. It provides temporal measurements for the same area (water sampling, Ferryboxes (20s frequency), satellite, ship survey, and from fixed points.)
b. Spatial differences on a same time frame
c. Ferry Boxes have the possibility to be used in large scale due to their lightweight (considering Pocket Ferry Box, which is more compact and easy transferable), simple and comprehensive operation. For example, if fitted on a fishing fleet, can provide data for a complete fishing ground

Conclusion:

Due to the less amount of BSH ship data, I could not conduct a specific statistical test. But, I hope with a considerable amount of observations from BSH samples and other sources of data, for example from satellite observation it is possible to infer a positive conclusion about similarity between Ferrybox data and BSH in situ sampling data, which will subsequently provide robust data sources for policy makers, and reduce the cost and recourse for monitoring the Eutrophication in near future.

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