A GEOCHEMICAL BASELINE STUDY OF GIANT KELP (*MACROCYSTIS PYRIFERA*) AT THE KELP BLUE FARM TO ASSESS CARBON SEQUESTRATION POTENTIAL

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ABSTRACT

The raised levels of carbon dioxide (CO_2) in the earth's atmosphere have contributed to global climate change, which has adversely affected a wide range of individuals, communities, and organizations. One of the ways to mitigate climate change is to grow a huge amount of kelp forests that can absorb carbon dioxide from the atmosphere and sequester it in the deep ocean. To grow these forests, the right biogeochemical conditions (temperature, nutrients, oxygen, salinity, pH, trace metals and ions) within the ocean is vital to assess the sequestration potential and the impacts on the ocean health. This study aimed at monitoring the biogeochemical changes at the proposed Kelp Blue farm and surrounding areas further away from the farm. This study also aims to create a baseline of the chemical composition of the farm and Lüderitz areas, which has not been done before. Using the results obtained from the study, the potential of the cultivated giant kelp to sequester CO_2 will be evaluated. This study measured the geochemical parameters using both in-situ probes and laboratory analyses at 10 different locations in Lüderitz (both offshore and coastal): offshore (within the Kelp Blue Pilot project farm, upstream of the farm in the Dumfudgeon rocks, downstream of the farm at Boot Bay and further south of Lüderitz at the Halifax island) and the coastal areas which are adjacent to the offshore study areas including at coastal site of Guano Bay which is about 17 km and the coastal area of Grossebucht which is about 20 km south the town of Lüderitz as another control site. This study also collected sediment samples at these offshore sites including further north of Walvis Bay at the different latitudinal transects. The sediments were analysed for trace metals by using a portable XRF and for carbon content by LOI (Loss on Ignition) method. Another geochemical analysis done was the titrimetric method to CO_2 determination of seawater by using NaOH as a titrant the end points were determined. The concentrations of nutrients (phosphates and nitrites) in seawater samples were determined by adding them to a 10 mL cuvette, which had been zeroed first. A specific nutrient reagent was then introduced, and using prescribed sample preparation techniques, a spectrophotometer was employed to measure the concentrations of the nutrients in µg/L and mg/L. The geochemical parameters changed in relation to the seasonality and geographical positioning. In a season when the upwelling system was strong, the concentration of nutrients, acidity and the value of the pH, salinity, other geochemical parameters increased more, compared to other seasons and the further southern sampling sites resembled to that of the Southern Benguela Upwelling System (SBUS). Higher concentrations of phosphates (614 µg/L) were found in areas close to the islands. This is due to the presence of guanos. These remarkable long duration geochemical measuring results shows that the cultivated kelp can co-exist with other natural existing kelp beds in this ecosystem, and they can thrive more predominantly in season of great influx of nutrients during the season of strong winds. With a dynamic Benguela upwelling eastern boundary, these kelp forests have an enormous potential to grow more and will function as carbon absorber and eventually sequester more carbon when cultivated at larger scale. To quantify the carbon sequestration potential of these giant kelps, there are other areas to be investigated such as developing a sediment carbon baseline using isotopic analyses, lipid biomarkers, identifying sediment hotspots where the kelp will be deposited, developing a carbon dioxide removal model and geochemical dispersion models. All these other areas will be developed from the baseline being developed by this study. This study recommends that a continuous and rigorous monitoring of the water and sediment geochemical changes be done as the kelp forest grows and as the scale of operation expands.

LIST OF PUBLICATIONS AND CONFERENCES

1. Mutjida P. S. (2022) 'Geochemical study of the nBUS in relation to Carbon Sequestration potential'. 7th Regional Graduate Network in Oceanography (RGNO). Swakopmund, Namibia. May 2022. (Oral and Poster)
2. Mutjida, P., S, Daniel, L., S, Rahman, A, Turchyn, A., S & Rangers, S., D. (2022). 'A geochemical baseline study of giant kelp (*Macrocystis pyrifera*) at the kelp blue farm to assess carbon sequestration potential' [OHP-MRC 34 – ENERGY]. 1st Multidisciplinary Research Conference: University of Namibia Oshakati & HP Campuses. Oshakati (OHP), Namibia. October 2022
3. P.S. Mutjida, L.S. Daniel, A. Rahman, A.S. Turchyn, and S.D Rangers. (2022). 'A geochemical baseline study of giant kelp (*Macrocystis pyrifera*) at the kelp blue farm to assess carbon sequestration potential.' National Research Symposium: National Commission on Research, Science and Technology (NCRST). Windhoek, Namibia. November 2022.
4. P.S. Mutjida, L.S. Daniel, A. Rahman, and S.D Rangers. (2023). 'A geochemical baseline study of giant kelp forest farm in the Lüderitz area to assess carbon sequestration potential.' The 29th Colloquium of African Geology (CAG29). Windhoek, Namibia. September 2023 (Abstract accepted July 2023).

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LIST OF ABBREVIATIONS AND ACRONYMS

µg/L	micrograms per litre
µM	Micromoles
BUS	Benguela upwelling system
C	Carbon
CDR	Carbon Dioxide Removal
CEO	Chief Executive Officer
CH_3COOH	Ethanoic acid
cm	centimetres
CO_2	Carbon dioxide
CO_2SYS	CO_2 SYSTEM
CRM	Certified Reference Material
Cu	Copper
DF Rocks	Dumfudgeon Rocks
DIW	De-Ionized Water
DO	Dissolved Oxygen
EC	Electrical Conductivity
ED-XRF	Energy-Dispersive X-ray Fluorescence
EIA	Environmental Impact Assessment
Fe	Iron
GPS	Global Positioning System
H_3BO_4	Boric acid
H_3PO_4	Phosphoric acid
HCl	Hydrochloric acid
ICP-OES	Inductive coupled plasma optical emission spectroscopy

IGCP	International Geoscience Programme
ISE	Ion Selective Electrode
$K_2S_2O_7$	Potassium disulfate
KB	Kelp Blue
KBP	Kelp Blue Pilot
KFF	Kelp Forest Foundation
LOI	Loss on Ignition
M.pyrifera	Macrocystis pyrifera
MME	Ministry of Mines and Energy
MSc	Masters of Science
N	Nitrogen
NaOH	Sodium Hydroxide
NatMIRC	National Marine Information and Research Centre
nBus	Northern Benguela upwelling system
NCRST	National Commission on Research, Science and Technology
NH_3:	Ammonia
Ni:	Nickel
$NO_3{}^-$	Nitrate
NO_2^-:	Nitrite
OHP:	Oshakati Hifikepunye Pohamba
P:	Phosphorus
Pg	Petagram
pH:	Potential of Hydrogen
$PO_4{}^{3-}$	Phosphate
RGNO	Regional Graduate Network in Oceanography

RV	Research Vessel
sBUS	Southern Benguela Upwelling System
SCOR	Scientific Committee on Oceanic Research
SST	sea-surface temperature
TA	Total Alkalinity
TDS	Total Dissolved Solids
ULR	Ultra Low Range
UNAM	University of Namibia
UNESCO	United Nations Educational, Scientific and Cultural Organization
XRF	X-ray Fluorescence

ACKNOWLEDGEMENTS

He giveth power to the faint; and to them that have no might He increases strength. Even the youths shall faint and be weary, and the young men shall utterly fall: But they that wait upon the Lord shall renew their strength; they shall mount up with wings as eagles; they shall run, and not be weary; and they shall walk, and not faint. Isaiah 40:29-31 (King James Version).

It has been the joy of the Lord which has been my strength, Firstly I would like to thank my Father through my Lord Jesus Christ with the guidance of the Holy Spirit that I got this privilege for a second chance to finish this thesis. Thank you, Lord, for connecting and sending people in my life. Whatever happens from now on I am forever grateful to You!

To the wife of my youth (Jane Mutjida), I thank God for you, you are the best gift God has given me, I love you! I would like to thank my father and mother (Protasius Mutjida and Paulina Muwema) for their continuous guidance and support in all my decisions.

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DEDICATION

I would like to dedicate this thesis to Daniel E Hooft the CEO and founder of Kelp Blue, he saw potential in me and gave me a chance to go back to UNAM and finish the thesis. Daniel here is the thesis for the baseline, more to come by the grace of God.

I would also like to dedicate this study to my sister Augusta who passed away in January 2023 and to my classmate Gift who was doing an MSc in algae but could not finish as she passed away during her studies.

My Family

My wonderful congregation: Lüderitz Potter's House Christian Fellowship Church

My wife in whom I am well blessed, Jane Mutjida

DECLARATION

I, PROTASIUS SHIKUSHO MUTJIDA declare hereby that this study is a true reflection of my own research, and that this work, or part thereof has not been submitted for a degree in any other institution of higher education.

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CHAPTER ONE: INTRODUCTION

The raised levels of Carbon dioxide (CO_2) in the earth's atmosphere have contributed to global climate change (Duarte et al., 2013), which has adversely affected a wide range of the individuals, communities, and ecosystems. As such, many world leaders have called for significant changes to the emission of greenhouse gases, especially CO_2 (Krause-Jensen et al., 2018). A wide range of mitigation strategies have been suggested globally and many leading nations have made a tremendous improvement towards mitigating the emission of CO_2. One of the mitigation options to combat climate change is by growing and restoring huge amount of kelp forests that can absorb carbon dioxide from the atmosphere and sequester it in the deep ocean and deep sediments (Duarte et al., 2017, 2021; Sondak et al., 2017; Thompson et al., 2017).

Ocean absorbs the atmospheric CO_2 and in the presence of seawater it forms carbonic acid which dissociates into bicarbonate ions and further into carbonate ions. As this happens, the pH (Potential Hydrogen) reduces thus increasing the seawater alkalinity (Thompson et al., 2017). The increase or decrease in pH affects other biogeochemical parameters like salinity, oxygen concentrations, Electrical Conductivity (EC), nutrients concentration, total dissolved solids (TDS), and the ions (major and minor).

Equation 1

$$CO_{2(g)} + H_2O_{(aq)} \rightarrow H_2CO_{3(aq)} \rightarrow H^+{}_{(aq)} + HCO_{3^-(aq)} \rightarrow H^+{}_{(aq)} + CO_3{}^{2-}{}_{(aq)}$$

Equation 1 describes the dissociation reactions of the interaction between the ocean and the atmosphere, where one of the atmospheric gases (CO_2) dissociates in the ocean.

The ocean covers more than 70% of the earth's surface and holds approximately 97% of all the waters in the entire continent sum together. Due to this vastness of the ocean, it plays major role as a frontline mitigator of climate change. The ocean plays a major role as a reservoir for carbon storage (Duarte et al., 2013; Field et al., 1998; Smale et al., 2020) where photosynthetic organism uses carbon for photosynthesis to bring about an equilibrium balance (Yoshiyama et al., 2009). Some of the vast distributed photosynthetic organisms are kelp forests, which provide important ecosystem services, such as habitat and food for a wide variety of marine animals, protecting coastlines from erosion, and helping to regulate the Earth's climate by absorbing carbon dioxide through photosynthesis (Chung et al., 2011).

Kelp Blue is a Dutch based start-up company that is on a mission to build artificial marine kelp forests around the globe to restore the health of the oceans and lock away vast amounts of CO_2. Kelp Blue is currently carrying out its first ever pilot project plan in Namibia off the coast of Lüderitz in the world’s most productive and consistent ocean upwelling system (the Benguela Current) which is situated in the South Atlantic Ocean (Figure 1.1).

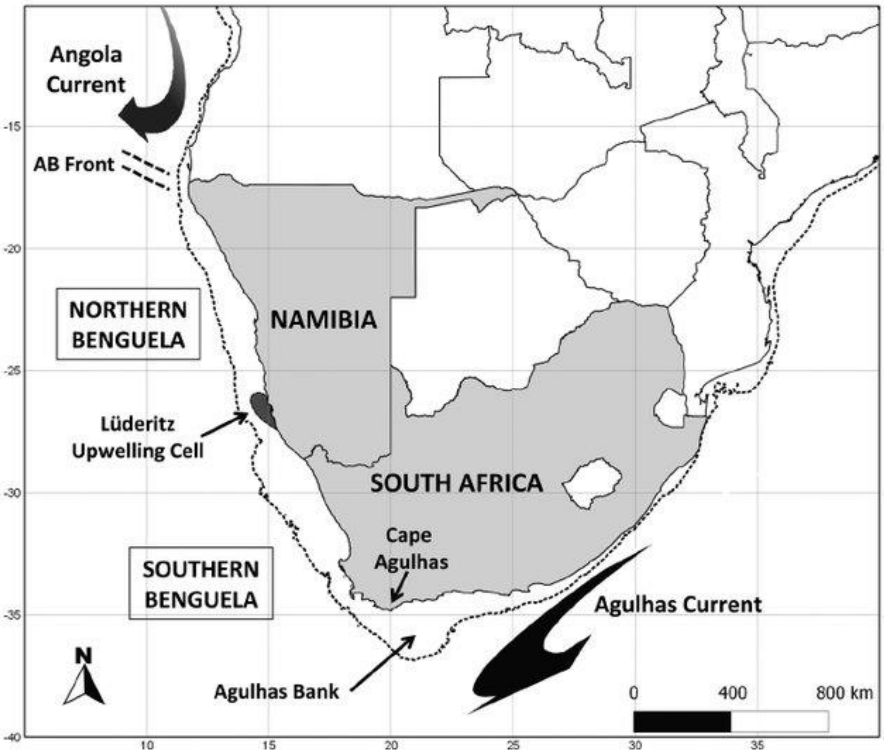

Figure 1.1 shows Map of the Benguela Current region bordering Namibia and South Africa, showing the 500-m depth contour (dashed line) and the approximate locations of the Angola Current, the Angola/Benguela (AB) Front, the Lüderitz upwelling cell (which separates the northern and southern Benguela subsystems), and the Agulhas Current (Pulfrich et al., 2020; Roux et al., 2013).

To develop a geochemical baseline for the Southern Atlantic Ocean, scientists would need to collect and analyse many samples from various locations in the region, considering the factors that influence the ocean's chemistry. The data collected will be compared to samples from nearby, undisturbed areas to determine the natural variability of the ocean's chemistry and identify any changes that may have occurred because of human activities in this case the cultivation of the kelp forest farm.

1.2 Statement of the problem

There is currently no available published or researched data on water geochemistry of the kelp forest farm within areas of Lüderitz (Pulfrich et al., 2020). If the kelp farm triggers calcification and changes in pH; major ions and other geochemical parameters are expected to occur.

To quantify the impact kelp forests can bring in capturing carbon, a baseline needs to be established prior to growing these forests. The study will develop a reference point that will show the geochemical parameters of the ocean within the areas of study which will then be benchmarked to evaluate how the Kelp Blue kelp forests have affected what was in the baseline and assess those impacts to carbon sequestration potential.

1.3. AIM

To develop a comprehensive geochemical baseline for the giant kelp at the Kelp Blue farm and to assess its potential to sequester carbon dioxide.

1.4. Objectives of the study

The research aimed to accomplish the following objectives:

- To monitor the changes in the ocean geochemistry around the kelp forest farm (Pilot)
- To compare the geochemical parameters of the Pilot from the other sites.
- To develop a biogeochemical baseline.

- To assess the carbon dioxide (CO_2) sequestration potential of the farm.

1.5. Hypothesis of the study

Is there a significant difference in the water geochemistry at the pilot, adjacent sites and control site compared to the seasonality? The presence of the artificial kelp forest will bring changes in the ocean geochemistry.

1.6. Significance of the study

This study will fill the knowledge gap in ocean chemistry and develop a geochemical baseline that is open to the public and academia. There is currently a development of a biogeochemical model that will show the carbon pathways within the kelp farm and this research will aid to bring this model to completion. The study will also create a positive environmental impact by enhancing ocean sensitivity and propose the benefit of drawing down a sizeable amount of CO_2 through solutions (Blue Economy).

1.7. Limitation of the study

The changes in the weather windows (including atmospheric temperature, wave patterns, swells, and the wind intensities) determined the timeline for data collection.

1.8. Delimitation of the study

There was a large amount of data collected which could create opportunities for follow-on studies to be conducted and using more statistical models will condense the data into a meaningful way. This study will only focus on water geochemistry due to the span of the study timeline.

CHAPTER TWO: LITERATURE REVIEW

2.1. Macrocystis Pyrifera (Giant Kelp)

Kelps are members of a group of brown seaweeds which includes the largest of the seaweeds, many of which form large kelp forests in shallow water (mostly <20 m depth) on rocky seashores around the world. In the Benguela upwelling system (BUS) on the west coast of Namibia and South Africa there are four species of kelp present: *Ecklonia maxima* ('sea bamboo'), *Ecklonia radiata*, *Laminaria pallida* and *Macrocystis pyrifera* (which is dominant in South African kelp forests and becomes less prominent northwards) (Fleischman et al., 2020).

Macrocystis pyrifera (M. pyrifera) is the largest seaweed in the world, known in some places as 'giant kelp'. It can grow up to 70 m in ideal conditions and given that the environment is conducive for it to do so. It is one of the most widespread marine species globally and forms the basis of large kelp forests in many regions. More also, *M. pyrifera* is one of the fastest growing kelp in the world, with growth rates of 50 cm per day reported in optimal conditions (Schiel & Foster, 2015). *Ecklonia maxima* (*E. maxima*) and *M. pyrifera* are not abundant in southern Namibia. *E.maxima* is only present in the more in the south and few have been spotted in the north of Lüderitz whereas *Laminaria pallida* is widely distributed in the Namibian marine waters (Eagledow & Bolton, 1994; Fleischman et al., 2021).

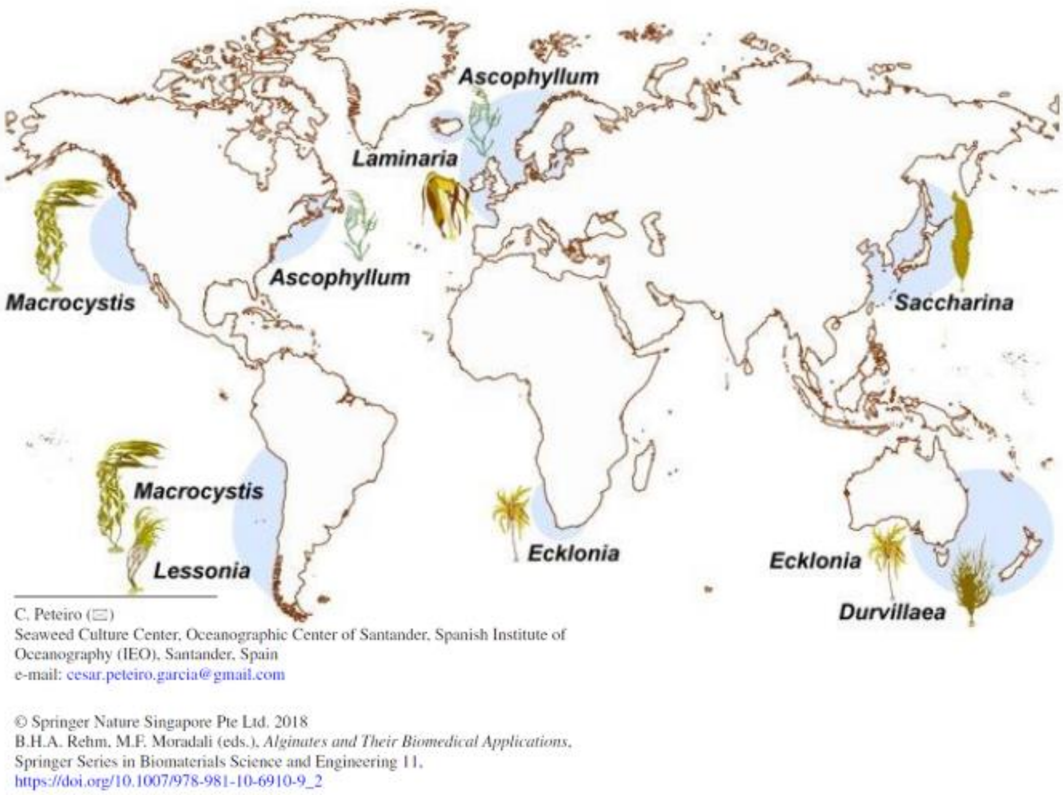

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Figure 2.1 shows the global distribution of different kelps. Though some M.Pyrifera is found in the Cape Town area it is not as dominant as Ecklonia Maxima (Peteiro, 2018).

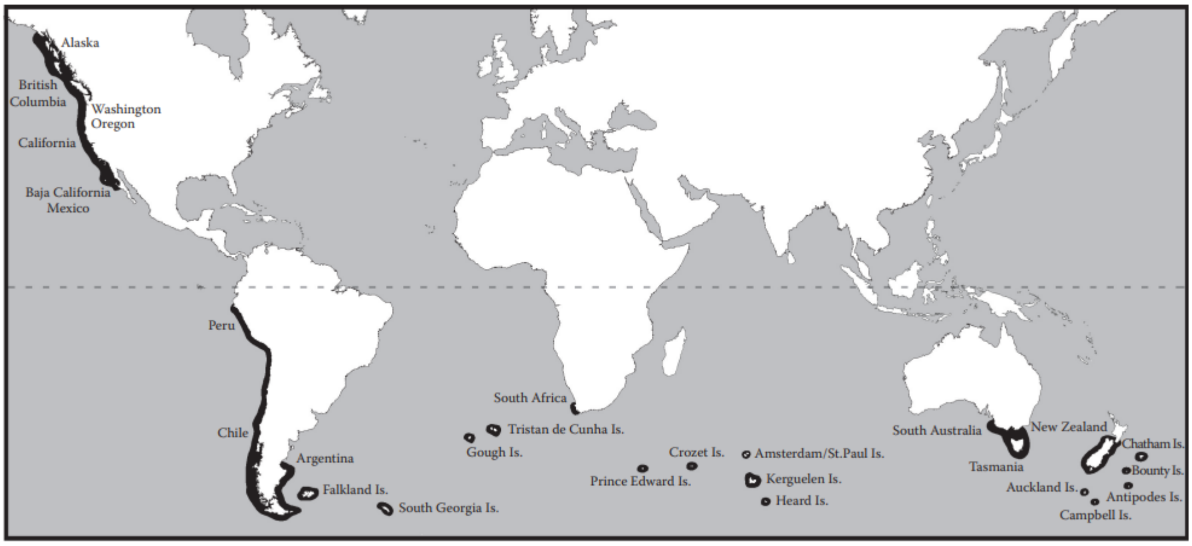

Figure 2.2 shows the global distribution of M.pyrifera source: https://gorcc.files.wordpress.com/2011/03/kelp-distribution.jpg after (Graham et al., 2007).

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2.2. Chemistry of the Namibian Waters

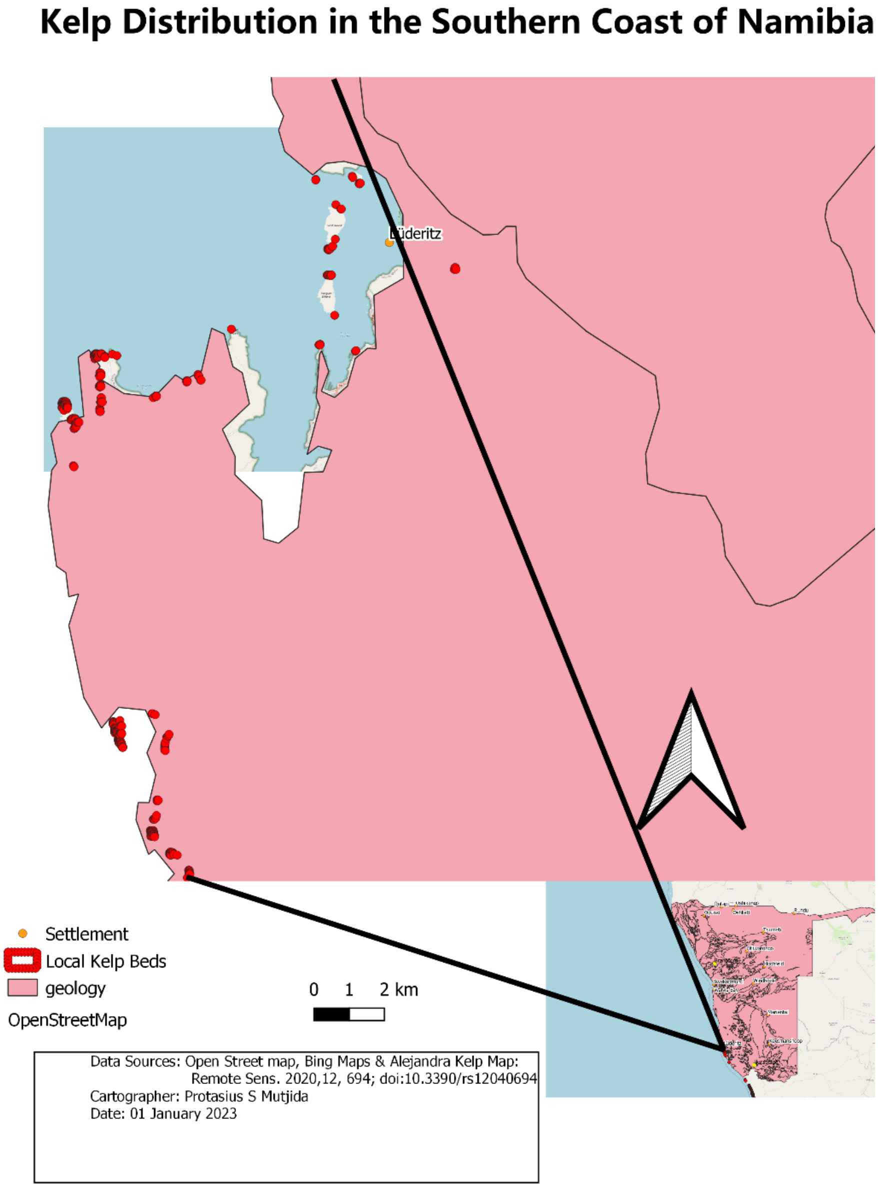
Namibia's marine environment is considered "relatively pristine" (Le Mézo et al., 2021; Sakko, 1998). This marine environment belongs to the Benguela System, which is an eastern boundary current upwelling system in the South-eastern Atlantic Ocean. The upwelling of nutrient-rich water causes the oceanographic condition in that particular environment to change into the surface zone (Flynn et al., 2020). These environmental changes include changes in the ocean health, nutrients uptake by the plankton communities, remineralization of nutrients, sediment carbon content and the rate at which dissolved carbon is sequestered and stored (Duarte et al., 2018; Flynn et al., 2020; Pitcher et al., 2021; Thompson et al., 2017; Van Der Plas et al., 2007). In these marine waters, some irregular anomalies are observed in temperature, oxygen concentration and salinity especially in the shelf waters (Eagledow & Bolton, 1994). The Benguela System is believed to be responsible for nitrogen loss in the oxygen-minimum Zone (OMZ) waters of one of the most productive regions of the world ocean as the upwelling waters are generally more oxygenated (>200 µM O_2) whereas the bottom waters can severely be depleted to about <10 µM O_2 (Bristow et al., 2017; Flynn et al., 2020). The massive nitrogen loss from the Benguela upwelling system is through anaerobic ammonium oxidation. Studies show that the anammox bacteria is linked to the removal of fixed inorganic nitrogen (FIN) in the OMZ water of open-ocean setting (Bristow et al., 2017; Kuypers et al., 2005). Gruber and Sarmiento, 1997 argued that the decrease in the ratio of FIN to phosphorus (P) in the bottom waters has been attributed to denitrification, process where nitrate (NO_3^-) is reduced to produce molecular nitrogen (N_2) through a series of intermediate gaseous nitrogen oxide products (Sarmiento & Gruber, 1997).

Studies have shown that most oceanic waters are depleted in inorganic nitrogen, phosphorus, Iron which are the nutrients that limit primary production in the ocean (Kuypers et al., 2005). Human activities at local scale have shown to be contributors to the chemical distributions in most ocean waters. An example of this is the nutrient enrichment in the New York Bight and Chesapeake Bay which has led to anoxia in the water column and has caused an impact on marine resources (Officer et al., 1984).

Phytoplankton is responsible for half global CO_2 fixation (~ 50 Pg (Petagram) of carbon per year). Phytoplankton take up nutrients at a ratio that varies considerably between different species and environmental conditions, but on average occurs at about 106 C : 16 N : 1 P : 0.0075 Fe (carbon : nitrogen : phosphorus : iron) throughout the ocean, which is commonly referred to as the Redfield ratio (Heaney & Droop, 1985; Hutchins et al., 2009; Redfield, 1960). The sea water, apart from nutrients, also contains major ions (Na^+, K^+, Mg^{2+},Ca^{2+},Cl^-, SO_4^{2-} ,HCO_3^-) and other trace elements such (Ni, Cu, Fe, S and Co) which require a sample to be concentrated before analysis (James et al., 2021; Steiner et al., 2018).

2.3 Macroalgae and the ocean biogeochemistry

Macroalgae or seaweeds, are large, multicellular algae that are found in the oceans around the world including the coastlines of Namibia (Figure 2.3). When they reach maturity growth level they form canopies on the surface of the waters that can be spotted from a distance or through aerial photography (Bryson et al., 2013; Schiel & Foster, 2015).



Data Sources: Open Street map, Bing Maps & Alejandra Kelp Map: Remote Sens. 2020,12, 694; doi:10.3390/rs12040694
Cartographer: Protasius S Mutjida
Date: 01 January 2023

Figure 2.3 shows the spatial distribution of natural kelp beds in Southern Coast of Namibia.

These macroalgae play a number of important roles in the ocean environment, including serving as a source of food and habitat for a variety of marine organisms and influencing the geochemistry of the oceans (Wheeler et al., 2022).

One of the keyways in which macroalgae influence ocean geochemistry is through their role in primary productivity as many species of macroalgae, particularly those in the brown and green algae groups, can photosynthesize and produce oxygen. This process, known as oxygenic photosynthesis, results in the production of organic matter and the removal of carbon dioxide from the water column (Chung et al., 2011; Fleischman et al., 2020). This can have significant impacts on the local and global carbon cycle, as well as on the pH and other chemical properties of the oceans (Smale et al., 2020; Wheeler et al., 2022).

Macroalgae can also influence ocean geochemistry through their role in nutrient cycling by absorbing and sequestering nutrients such as nitrogen and phosphorus from the water column, which can be returned to the water through decomposition or herbivory (Bullen et al., 2021; Le Mézo et al., 2021). This process can help to regulate nutrient availability in the ocean and support primary productivity in marine ecosystems. In addition to their role in primary productivity and nutrient cycling, macroalgae can also influence the geochemistry of the oceans through their physical presence.

The structures of macroalgal communities, such as kelp forests and coral reefs, can create complex physical environments that affect the exchange of gases, heat, and nutrients between the ocean and the atmosphere (White et al., 2021). They can also provide shelter and habitat for a variety of marine organisms, which can influence the distribution and diversity of species in an area (Kim et al., 2017). However, kelp forests are vulnerable to a variety of human impacts, such as pollution, overfishing, and climate change, which can damage or destroy these ecosystems and harm the animals and plants that depend on them (Williams et al., 2022).

There is evidence that kelp forest help reduce ocean acidification in surrounding waters (Hirsh et al., 2020; Hoshijima & Hofmann, 2019; Steiner et al., 2018). Ocean acidification is caused by the increase of carbon dioxide in the ocean, can make ocean water more acidic. This can make it harder for other organisms to form shells and skeletons, thereby negatively impacting on their growth and reproduction.

2.4 Geochemical Baseline

A geochemical baseline can be defined as a reference point that represents the natural levels of chemical elements and compounds in a specific environment, such as soil, water, or air. According to “The Blue Book” (Darnley et al., 1995), a geochemical baseline is used as a benchmark for evaluating the impact of human activities on the environment, such as mining, industrial operations, and waste disposal, by comparing the levels of these chemicals in the affected area to the baseline.

The term geochemical baseline was used in the late 1980s and it was officially introduced in 1993 at the IGCP (International Geoscience Programme) which has served as a knowledge hub of UNESCO (United Nations Educational, Scientific and Cultural Organization) to facilitate international scientific cooperation in the geosciences (*International Geosciences Programme - IGCP 2021 Annual Report*, 2021). Determining a geochemical baseline typically involves collecting and analysing samples from the area of interest and comparing them to samples from nearby, undisturbed areas (Darnley et al., 1995; Hua et al., 2020).

The early scholars had challenges when it came to defining geochemical baseline due to the regional changes of the geology in the different areas, the sample material collected, grain sizes and chances of sample contamination. As a result of these challenges the baselines were always be verified by having other sites than the focused site (Salminen, 1997).

Developing a geochemical baseline is important for several reasons:

a) **Environmental Impact Assessment (EIA):** A geochemical baseline can be used to identify and evaluate the potential impacts of human activities on the environment. By comparing the levels of chemicals in an affected area to the baseline, it is possible to identify any changes that may have occurred because of these activities.

b) **Resource Exploration and Management**: A geochemical baseline can also be used to identify and locate natural resources, such as minerals and oil. It can also be used to monitor the depletion of these resources over time.

c) **Compliance with Regulations**: Many countries have regulations in place to protect the environment and human health. A geochemical baseline can be used to ensure that human activities follow these regulations by measuring the levels of chemicals in the environment and comparing them to the baseline.

d) **Improved understanding of natural processes**: A geochemical baseline can provide a snapshot of the natural conditions of an area, which can help scientists understand the natural processes that occur in the environment and how they may be affected by human activities (Gustavsson et al., 1997).

e) **Risk Management**: A geochemical baseline can be used to identify potential risks to human health and the environment and to develop strategies to mitigate or manage those risks (Hua et al., 2020).

Overall, a geochemical baseline is an essential tool for understanding the impacts of human activities on the environment and for protecting the health and well-being of people and the planet. According to the "BLUE BOOK" geochemical baselines differ from country to country and many countries do not have. For the countries that has the geochemical baseline data, the data is either incomplete or inconsistent throughout, thus obtaining a global geochemical baseline is essential, hence, national and regional geochemical surveys should be tied together to a global geochemical database (Darnley et al., 1995).

In Fuxin city, China, a geochemical baseline study of heavy metals in the topsoil showed that the urban topsoil was slightly contaminated, howbeit, the main contamination came from the mining sites (Hua et al., 2020). Another study done in the Namibian marine coastline looked at level of copper on the coastline using ICP-OES (Inductive coupled plasma optical emission spectroscopy). The result showed that the level of copper were higher in both mussels, sediments and water column of the coastline of the Walvis Bay harbour (Edosa et al., 2019).

2.5 The geochemical properties of sediments in Lüderitz

Marine sediments are formed through a variety of processes, including the weathering and erosion of rocks on land, the precipitation of minerals from seawater, and the accumulation of organic material from marine organisms. One of the major sources of marine sediment is the erosion of continental rocks and soils, which is transported to the ocean by rivers and streams. This sediment is then transported by ocean currents, such as the longshore drift and the ocean gyres, and deposited in areas such as deltas, beaches, and the continental shelf. Another important source of marine sediment is the precipitation of minerals from seawater. This process, known as authigenesis (Figure 2.4), occurs when dissolved minerals in seawater crystallize and settle to the ocean floor. Common authigenic minerals include calcite, aragonite, and silica.

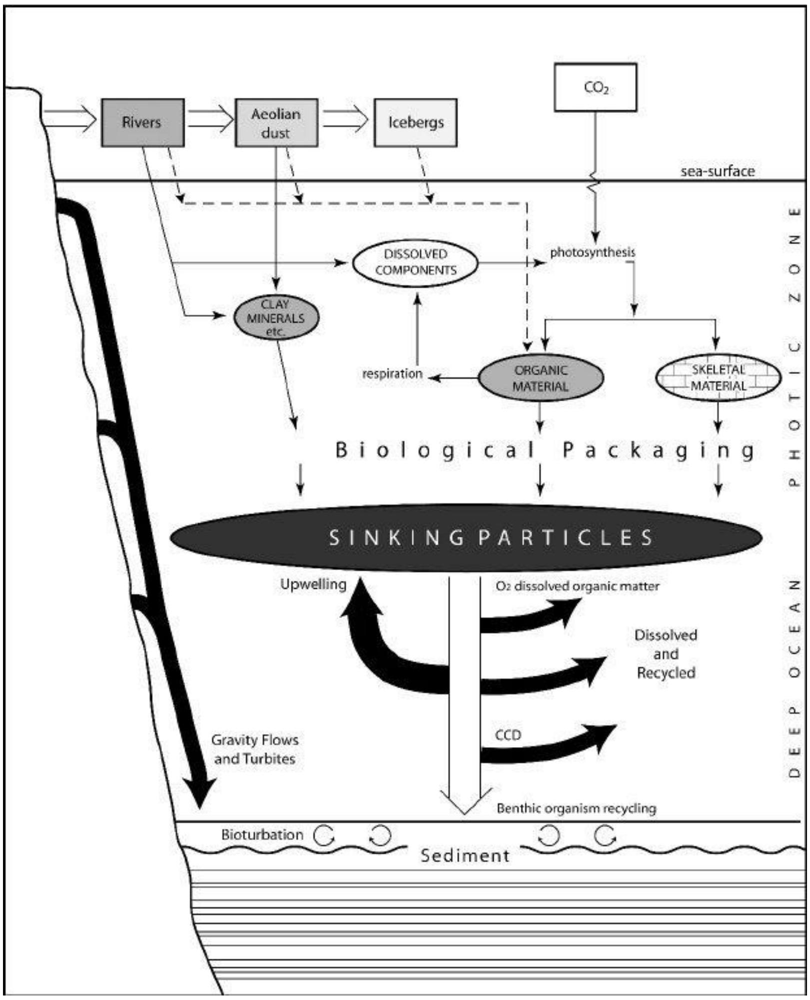


Figure 2.4 shows the formation of marine sediments and the depositional pathways (adapted from (MASLIN & SWANN, 2006).

The accumulation of organic material from marine organisms is also a major source of marine sediment. Organic material, such as the remains of plankton and shells, can accumulate on the ocean floor and form sediments such as diatom ooze and calcareous ooze.

The Namibian coastline is characterized by its long stretches of sandy beaches and towering sand dunes. The geology of the area is dominated by sedimentary rocks, including sandstones, conglomerates, and shales, that have been weathered and eroded over time to form the dunes and beaches. The areas around the Namibian coastlines are also characterized by the presence of ancient river channels and estuaries, which have left behind deposits of silt and clay. The geology of the Namibian coastline is influenced by the action of waves, winds, and the movement of sand dunes (Ribas et al., 2013). The area is also known for its rich mineral resources, including diamonds, copper, and zinc (Abshire et al., 2020). The Namibian coastline and continental shelf are characterized by a narrow shelf and a steep continental slope (Figure 2.5). The shelf is narrow because of the combined effects of tectonic activity and erosion. The area has a history of tectonic activity, including rifting and uplift, which has led to the formation of a narrow shelf (Brown et al., 2014). The shelf is also affected by erosion, which has been carved away at the coastline and continental shelf (Figure 2.6), leaving behind a narrow strip of land (Dingle, 1992).

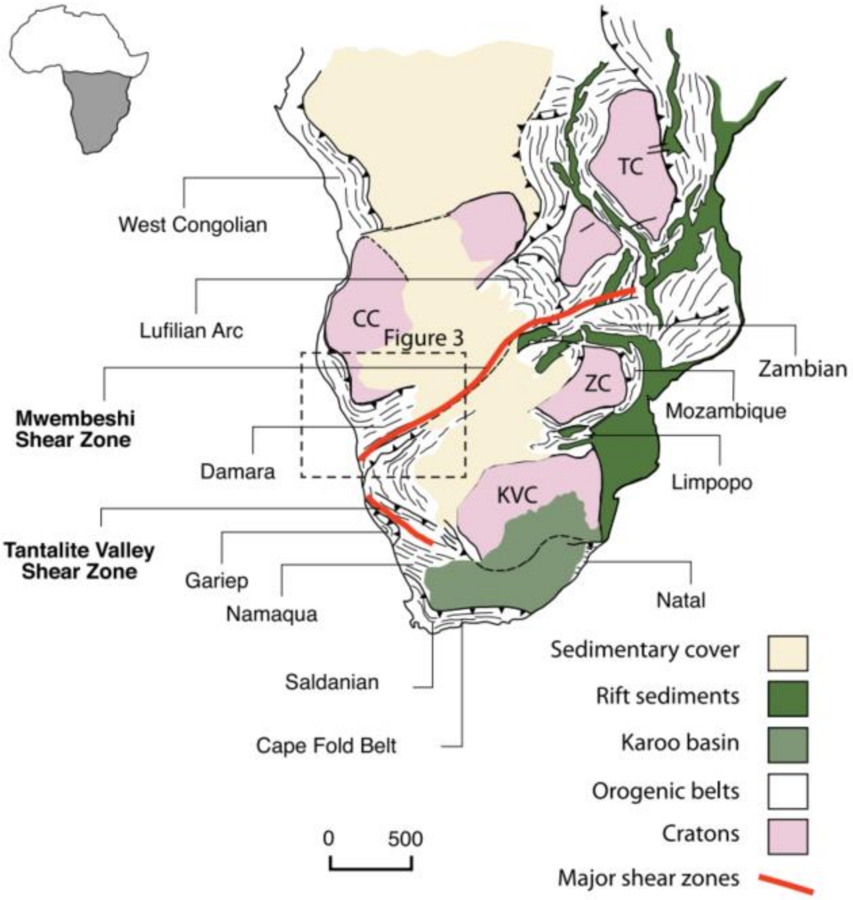


Figure 2.5 shows the simplified map illustrating the basement tectonic framework of Southern Africa, where KVC is Kaapvaal Craton, CC is Congo Craton, TC is Tanzanian Craton, ZC is Zimbabwe Craton. Image obtained from:(Brown et al., 2014).

Sediments play a major role in the ocean when it comes to carbon storage, cycling of major metals and ions. Studies have shown that most of the organic and inorganic carbon are stored in marine sediments, and they are buried in making it difficult for these carbon stocks to escape back into the water column and earth surface (Figure 2.6). Marine sediments plays a bigger role in mitigating the effects of climate change through carbon capturing (Atwood et al., 2020; Aumont et al., 2016; Krause-Jensen et al., 2018). Sediments also play a vital role in the cycling of major metal ions and polyatomic anions in the ocean. Heavy metal ions such as copper, zinc, and lead, as well as major anions such as nitrate ($NO_3{}^{-}$) and phosphate ($PO_4{}^{3-}$), are often found in sediment (Flynn et al., 2020; Tyrrell & Lucas, 2002).

These metal ions and polyatomic anions can be transported by ocean currents and deposited in sediment, where they are and protected from the water column. This process helps to regulate the concentrations of these elements in the ocean and prevents them from becoming too concentrated and potentially harmful.

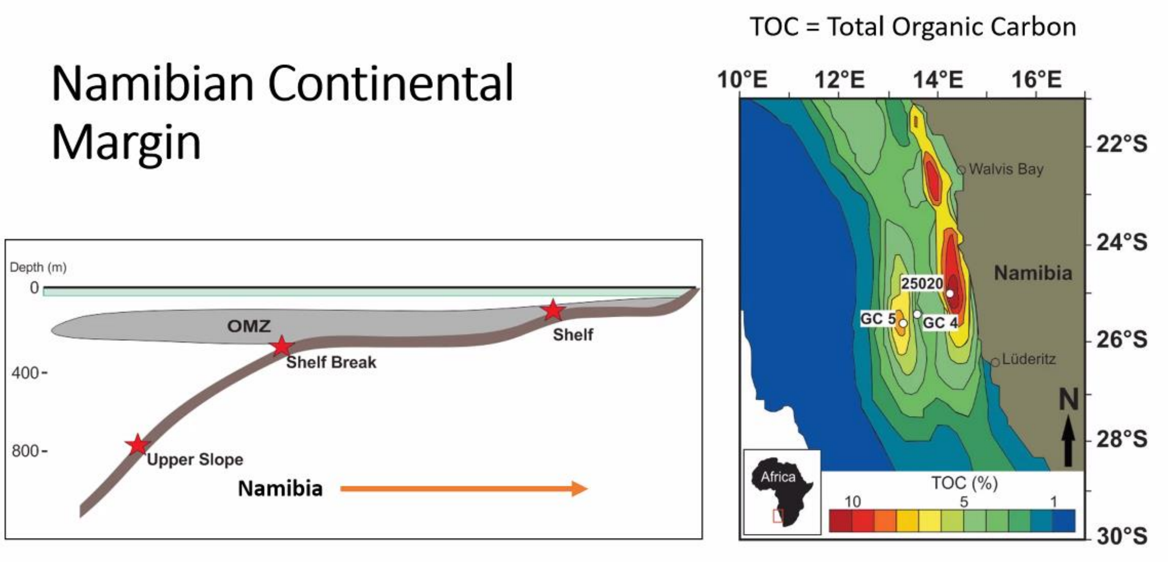


Figure 2.6 shows the Namibian continental margin and the Oxygen minimum zones (OMZ), Shelf break and shelf taken from (Abshire et al., 2020).

Additionally, sedimentary rocks and minerals are important for the formation of many important resources such as oil, gas, and mineral deposits. The sediment also acts as a sink for pollutants and can be used to monitor the environmental changes and human impact on coastal and marine areas.

CHAPTER THREE: RESEARCH METHODS AND MATERIALS

3.1. Research design

Before installation and deployment of the array, as per the recommendations of the Kelp Blue Environmental Impact Assessment (EIA) (Pulfrich et al., 2020), an extensive and thorough water quality monitoring was required. Due to the EIA requirement, adequate time was allotted to develop the research study, which included a rigorous methodology of sample collecting that was safe, ecologically friendly, and replicable, as well as a control location on both the coast and offshore to describe all parameters required.

Using dispersion models, the downstream and upstream impacted areas from the pilot farm were identified as shown in the Figures 3.1-3.3.

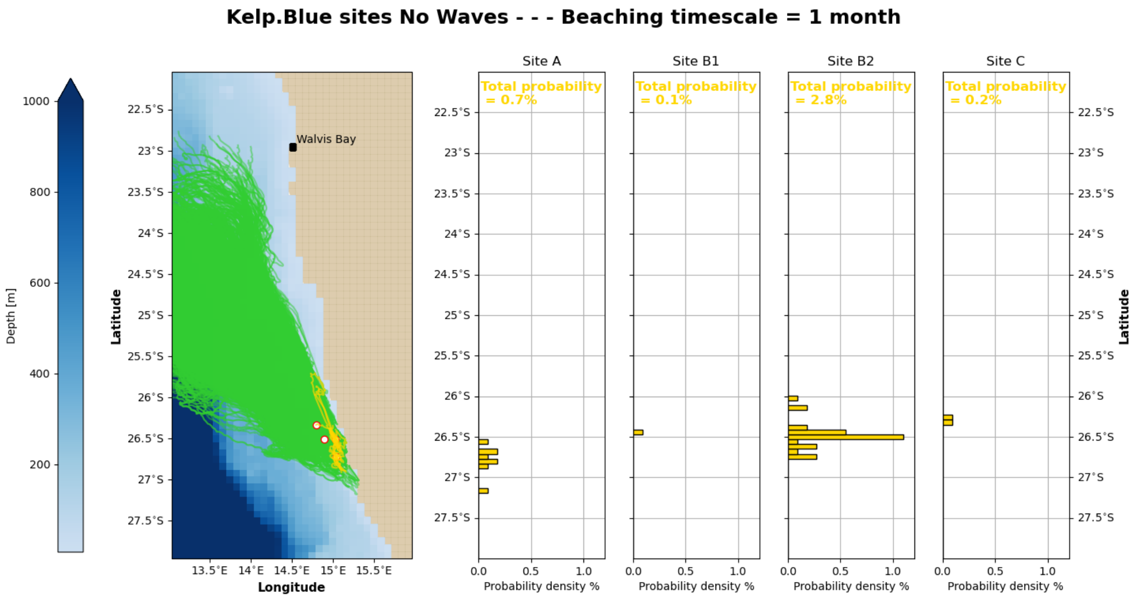


Figure 3.1 shows the monthly simulation dispersion with no waves of the kelp from the different proposed site before commencement of the Kelp Blue project with Site B2 being the favourable site which is the research study area.

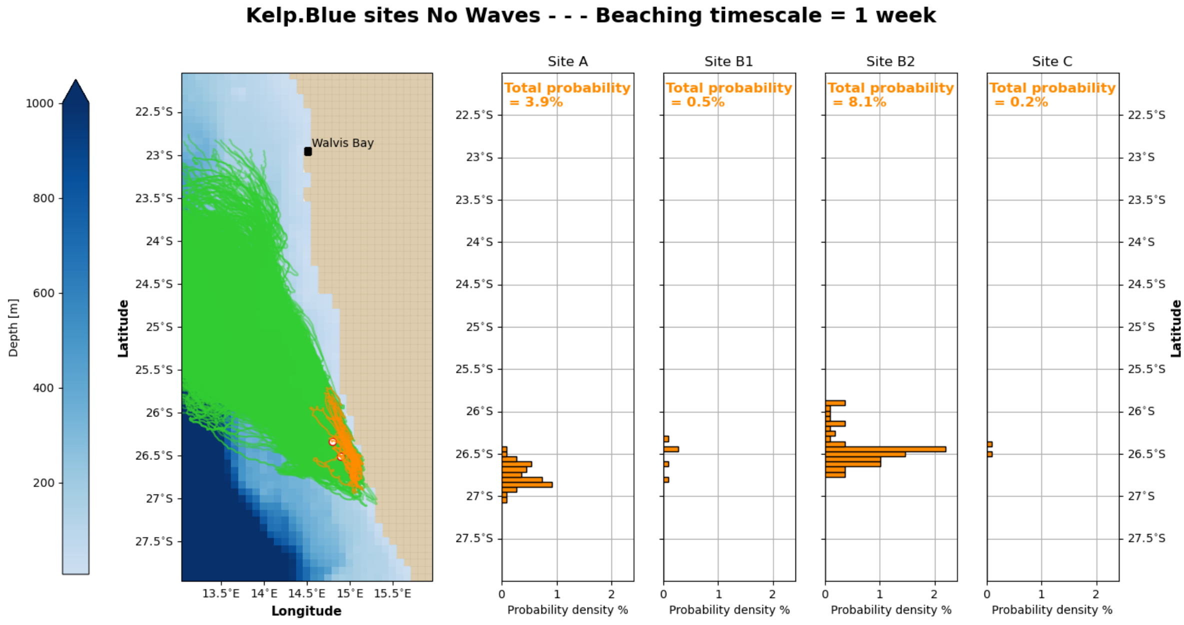


Figure 3.2 shows the weekly simulation dispersion with no waves of the kelp from the different proposed site before commencement of the Kelp Blue project with Site B2 being the favourable site which is the research study area.

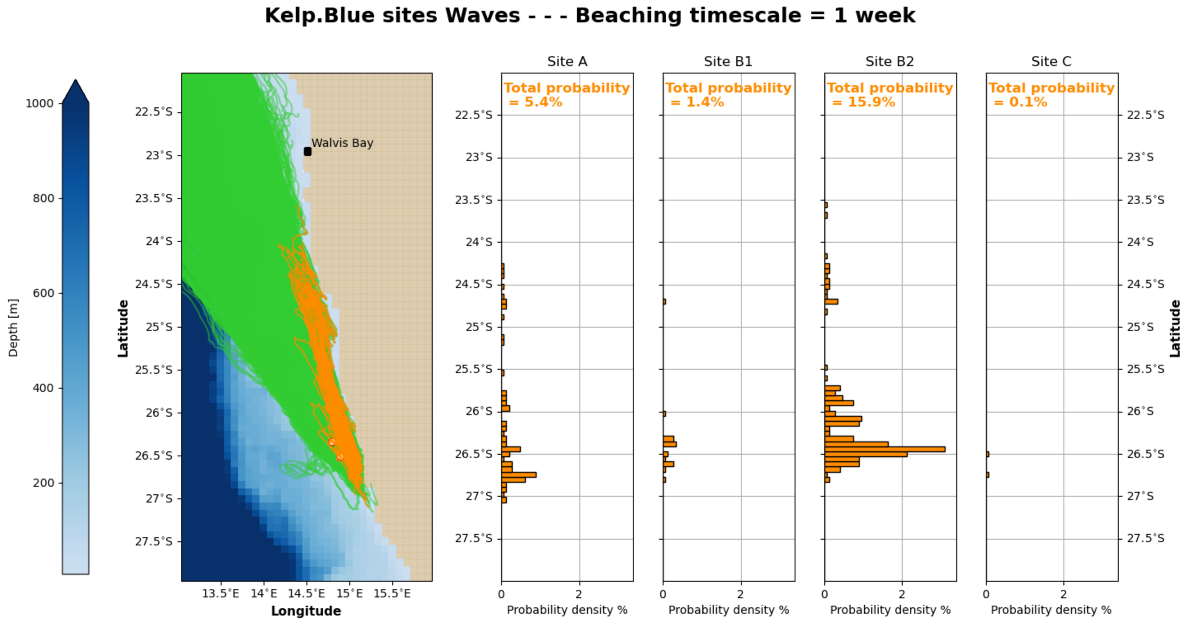


Figure 3.3 shows the weekly simulation dispersion with waves of the kelp from the different proposed site before commencement of the Kelp Blue project with Site B2 being the favourable site which is the research study area.

To Accomplish all the milestones necessary to develop a baseline, the study design is described in the flow chart below (Figure 3.4):

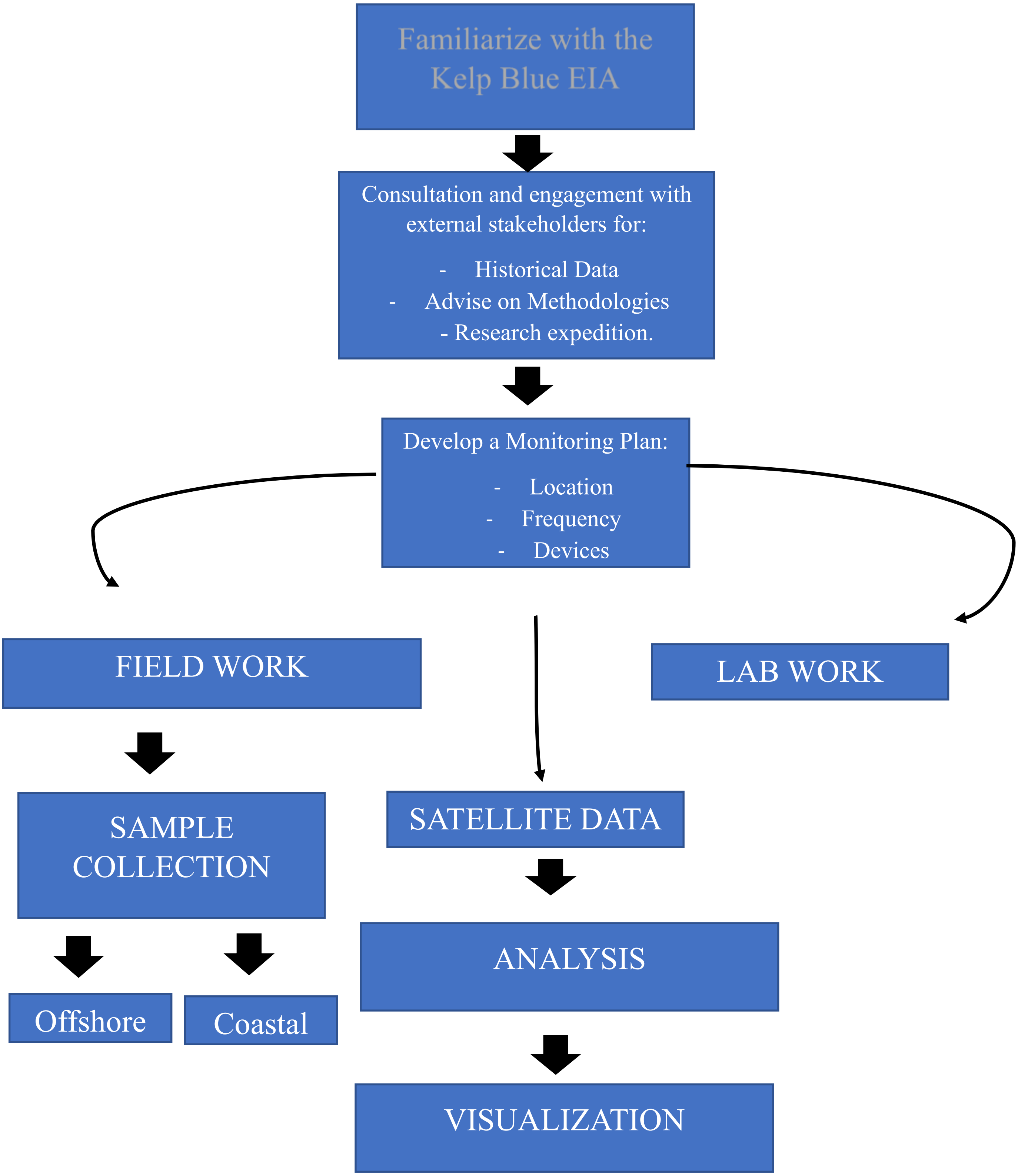


Figure 3.4 study design flowchart

Based on the data obtained through analyses and visualisation a geochemical baseline was developed following the steps indicated in the flowchart above (Steiner et al., 2018).

3.2 Sampling sites

The sampling sites were Halifax Island, Guano Bay and Grossebucht (which served as control sites), Kelp Blue pilot plot (main study area), Boat Bay (downstream site) and Dumfudgeon rocks (upstream site). From these sites both coastal and offshore sampling was conducted.

3.3. Apparatus, chemicals, and reagents

All chemicals used were of industrial and laboratory grade. These are listed in table 3.1 along with their physical features and analytical methods in which they are used.

Table 3.1 The different chemicals and reagents used in the study.

Reagent name	**Chemical Grade**	**Reagent state**	**Colour**	**Molecular Formula**	**Method of analysis**	**Parameter to analyse**
Potassium disulfate	Industrial	Solid	White	$K_2S_2O_7$	Diazotation Method	Nutrients
Sodium Hydroxide	Laboratory	Liquid	Clear	NaOH	Colorimetric	Titration (CO_2 determination)
Ammonia	Laboratory	Liquid	Clear	NH_3	Colorimetric	Titration (TA)
Phosphoric acid	Laboratory	Liquid	Clear	H_3PO_4	Colorimetric	Titration (TA)
Boric acid	Laboratory	Solid	White	H_3BO_4	Colorimetric	Titration (TA)

Hydrochloric acid	Laboratory	Liquid	Clear	HCl	Colorimetric	Titration (TA)
Ethanoic acid	Laboratory	Liquid	Clear	CH_3COOH	Colorimetric	Titration (TA)
Methylene Blue	Laboratory	Liquid	Blue	$C_{37}H_{27}N_3Na_2O_9S_3$	Indicator	Titration
Methyl red	Laboratory	Solid	Red	$C_{15}H_{15}N_3O_2$	Indicator	Titration
Phenolphthalein	Laboratory	Liquid	Clear	$C_{20}H_{14}O_4$	Indicator	Titration

Various devices were employed to measure, collect, and trace the various parameters, samples, and locations during the study, as shown in Table 3.2. The measurement devices were calibrated every three months or whenever they were serviced.

Table 3.2 The different apparatus used in the study and their purpose for use.

Apparatus	Purpose for use
Multiparameter Sonde	Measure water geochemistry parameters
Photometers	Measure water quality and nutrients
Nutrient sensor	Measure nutrients
CO_2 sensor	Measure the carbonate concentration
Titration kits	Conduct titration for acidity and alkalinity
Sample bottles	Water collection and storage
Buckets	Water collection
Niskin Bottles	Water collection
GPS (Garmin e-trex 10)	Location identification
Sediment Grab	Sediment collection

3.4. Instrumentation and Methodology

3.4.1 Water collection

The water collection during the monitoring were done at the coastal and offshore sites. Dispersal models were used to advise the prioritisation of the coastal monitoring. The adopted principle was to identify control sites and impact sites. Impact sites are areas where changes were anticipated to first occur. The control sites were chosen because they were conveniently accessible and could be researched more regularly than areas further away from Lüderitz, which might constitute a risk.

Water geochemistry parameters measurements at the coast were conducted within the quadrants set up in different locations, along the shore and intertidal zones where the water was deep enough to deploy the monitoring devices. When the weather on certain days was too rough (boisterous winds, high tides, and high waves) to deploy the device a bucket was used to draw out water samples for measurements and small 125 mL sampling bottles were used to collect water for laboratory analysis such as nutrients analysis and titrimetric analysis. For the offshore monitoring, Niskin Bottles were used to collect water from various depths.

Prior to the water collection, the Niskin bottles were sterilized by rinsing the bottles with the same sample. The Niskin bottle is equipped with two taps which were closed during the collection unless when the water was decanted (Figure 3.5). The Niskin bottle is equipped with two stoppers which are connected by an elastic cord, and a release mechanism connected to a metered rope that is used to lower the bottle to the desired depth. Using a messenger (or weight) which is clipped into the rope and lowered once the Niskin bottle has reached the desired depth, when the messenger meets the trigger, the release mechanism is triggered when the messenger meets the trigger, and this cause the stoppers to be released to the closed position and water at the desired depth is locked in the bottle. This was done at the different offshore stations (Halifax, Dumfudgeon Rocks, Kelp Blue pilot farm and Boot Bay).

When the Niskin bottles were brought up with water sample of desired depth, different water samples were collected (Figure 3.5). The first water samples were separated for laboratory analysis on land and then the rest of the water samples were transferred to a bucket where measuring devices were deployed to take measurements. This was done for different depth profiles (15 metres, 20 metres and 30 metres) except for the surface (about 10 cm below sea surface level) since the devices could easily be dropped down for measuring and water scooped from the surface with a bucket. Once the water samples were collected, the GPS (Global Positioning System) coordinates were taken either with a Garmin e-trex 10 or with a mobile phone (Table 3.3)

Table 3.3 The sampling location points with their various GPS coordinates.

Sampling locations	Latitude	Longitude
Grossebucht	26°44'29.0"S	15°05'41.0"E
Guano Bay	26°39'21.0"S	15°04'55.0"E
Halifax	26°38'56.0"S	15°04'52.0"E
Dumfudgeon Rocks	26°30'04.0"S	15°07'06.0"E
Boot Bay	26°27'00.0"S	15°05'54.0"E
Pilot Site	26°29'11.86"S	15°03'51.86"E
Shearwater Bay (Formerly BTP)	26°37'59.55"S	15°06'25.87"E
Dumfudgeon rocks coastal	26°29'60.0"S	15°08'19.0"E
Pilot Coastal	26°27'49.0"S	15°06'53.0"E
Boot Bay Coastal	26°27'27.0"S	15°07'04.0"E

Using a Quantum Geographic Information System (QGIS) software, the sample location points were overlayed on both street map layer and using a geology shape file a study area map was generated as seen in (Figure 3.5-3.6).

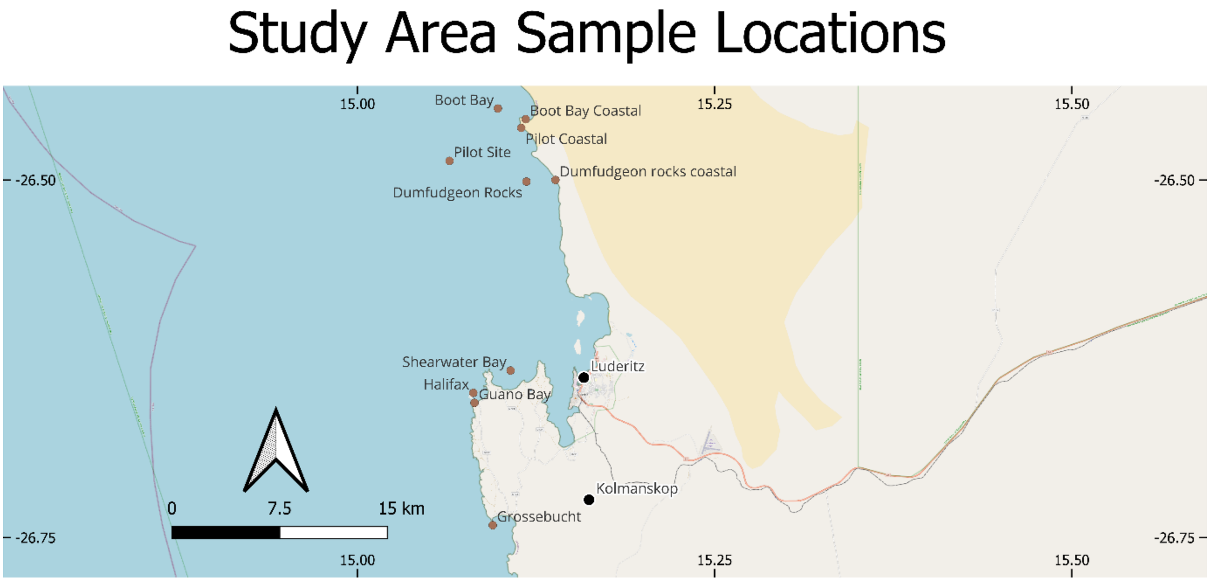


Figure 3.5 shows the study area sample locations plotted on QGIS using open street map.

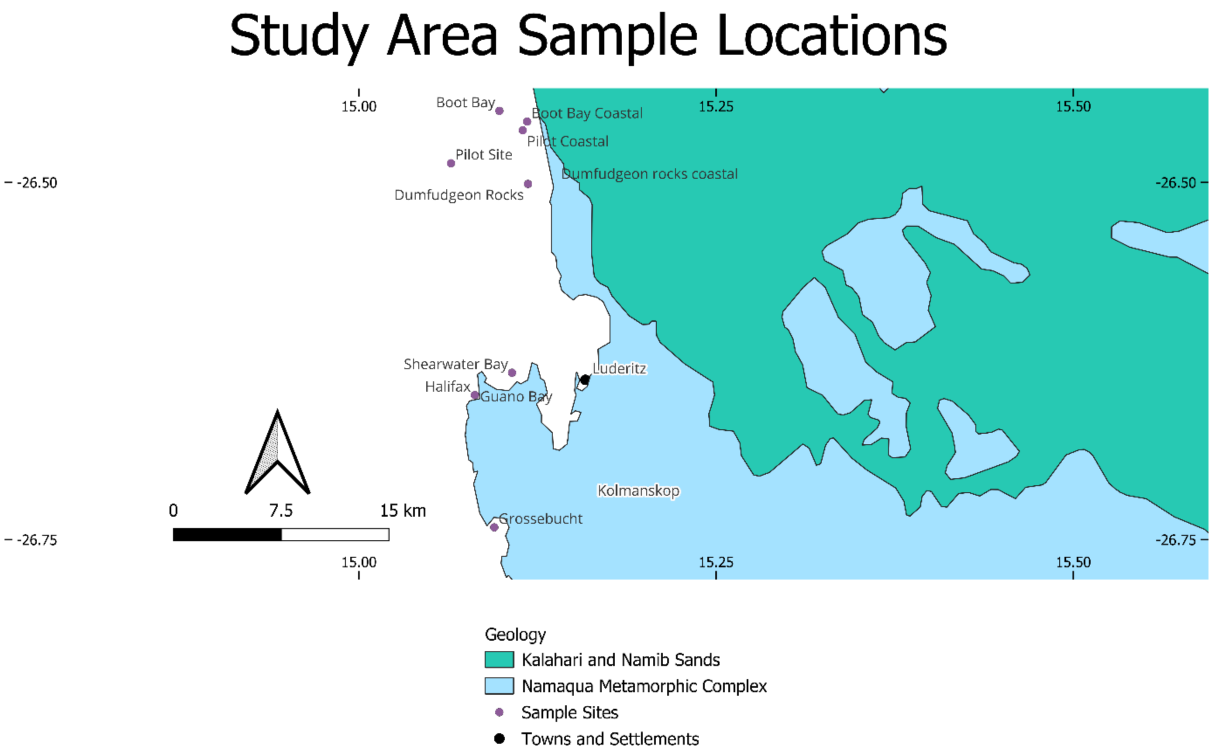


Figure 3.6 shows the study area sample locations plotted on QGIS using the Namibian geology shapefile as a layer.

Figure 3.7 shows the Kelp Blue team (from left to right: Loyiso Dunga and Iriya Jona) holding and reassembling the open Niskin bottle.

The collected samples from both coastal and offshore monitoring were stored in sample bottles in a refrigerator or cooler box with ice, for further laboratory analysis.

3.4.2 Multiparameter Sonde (geochemistry measurements)

A HI9829 multiparameter meter (sonde) (Figure 3.7) was mainly used during the study to measure the different geochemistry water parameters. The meter is connected to a probe that has four main electrodes that measure different parameters of interest including as pH, temperature, conductivity, salinity, dissolved oxygen, TDS, and turbidity.

Figure 3.8 show the connection of the probe cord (the metallic part) to the meter.

The probe cord was then attached to the meter and the cover was tightly screwed in before switching on the meter, as show in Figure 3.8.

Once the probe was confirmed to be safely connected to the meter and beaker of the probe covering the electrode was replaced with another (probe shield) that can be used for deploying and exposing the electrodes to the water sample (Figures 3.9-3.11).

Figure 3.9 shows the probe with electrodes.

Figure 3.10 shows the probe with the protective shield.

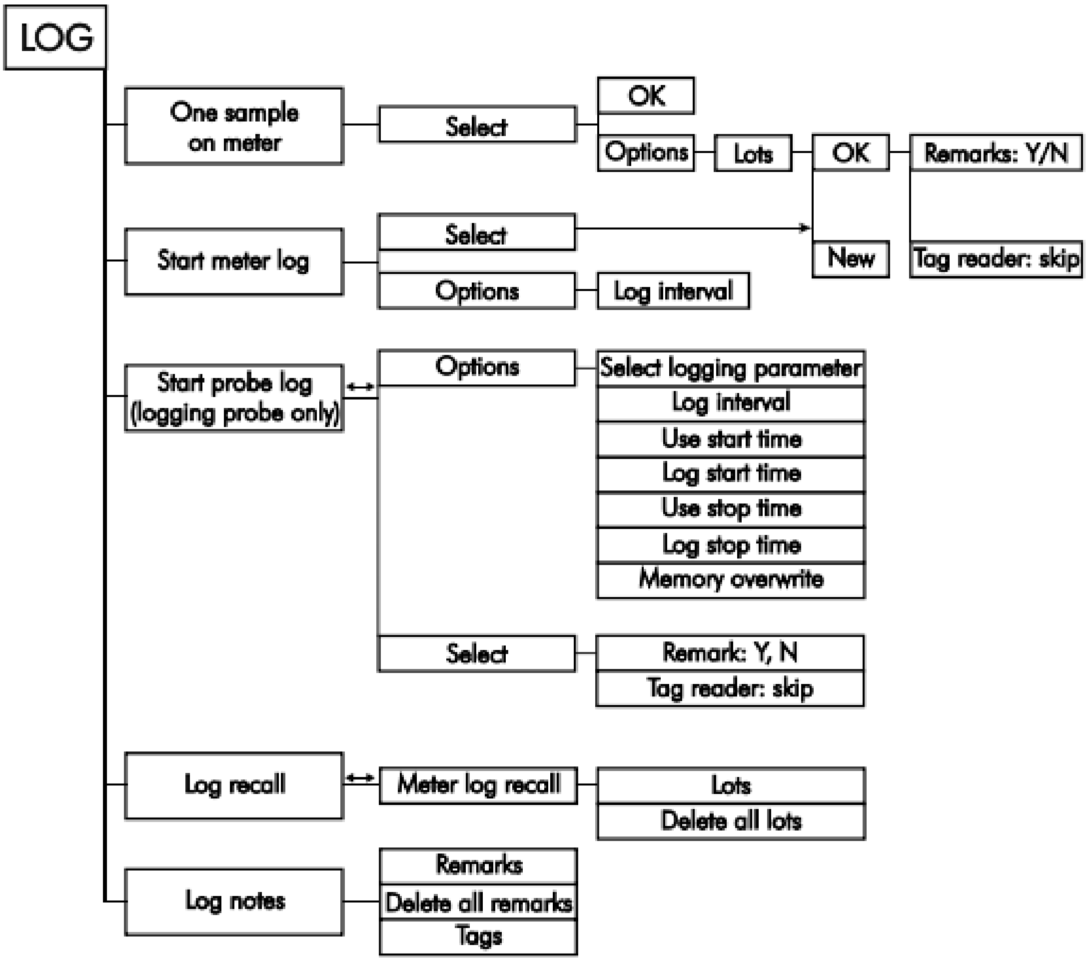
Figure 3.11 shows long shield cover for probes used when deploying the probe in the water.

The yellow and red electrode is an ISE (Ion Selective Electrode) which measures pH, the big black electrode measures EC and turbidity, the small olive, black and white electrode measures DO and the last thin metal electrode measures temperature.

Once connected, the meter present can be switched as shown in Figure 3.12 and following the steps in Figure 3.12 the data measurements are recorded as shown in Figure 3.13.

Figure 3.12 shows how to switch the ON button indicated by the red.

From measurement mode, press <Log> to access the log menu.



- The data logged on the meter are organized by lots. Up to 44,000 complete records can be stored in up to 100 lots. Each lot can store log-on-demand records and/or continuous records with different parameter configurations.

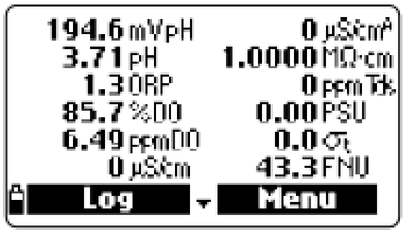


Figure 3.13 shows the mode procedures to log the data.

Figure 3.14 shows Loyiso with Iriya from Kelp Blue using the multiparameter sonde to take the water geochemistry reading at the coastal area.

After every two (2) months the sonde (Figure 3.12) was calibrated, and all the data was then transferred using a software into the local disk for storage and later visualization.

3.4.3 Spectrophotometer (nutrients measurements)

The water samples nutrients (NO_2^- and PO_4^{3-}) measurements were performed using the HANNA HI83303 multiparameter photometer which is a spectrophotometry instrument. The spectrophotometry analysis was based on specific chemical reactions between a sample and a reagent in order to produce a light-absorbing compound (Arai et al., 2018; Prien, 2013).

The photometer has an optical system that enables it to measure the concentration of the substance using the Beer Lambert's Law:

$$-log\frac{I}{I_O} = \varepsilon_\lambda\, c\, d \qquad \text{Equation 2}$$

where I, is the intensity of the light beam, I_o is the intensity of the light beam after absorption, ε_λ is the molar extinction coefficient at wavelength λ, d is the optical path through the substance and c is the molar concentration of the substance (seawater sample).

$$-log\frac{I}{I_O} = A \qquad \text{Equation 3}$$

Where A is the absorbance, which then is:

$$A = \varepsilon_\lambda\, c\, d \qquad \text{Equation 4}$$

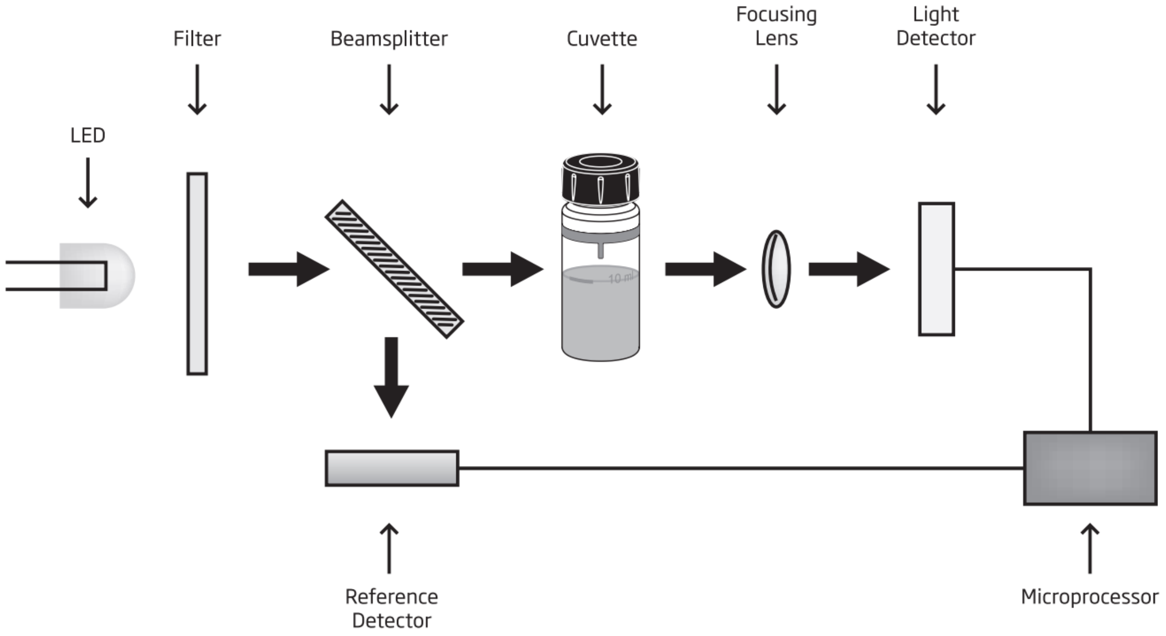


Figure 3.15 shows the HANNA instrument HI83303 block diagram, the reference detector (the internal reference system) does the compensation of any drifts caused by temperature changes by providing a stable light source for all blank and seawater sample measurements.

The optical system of the instrument works as shown in the block diagram above (Figure 3.15). Nutrient analyses were performed as follows with the guided steps of the HANNA HI83303 instruction manual:

The following method analysis were selected on the HANNA HI83303 photometer Nitrite Marine ULR (Ultra Low Range) and Phosphate Marine ULR were used as the key selection method display.

The water samples collected with the Niskin bottle and from the surface were stored in airtight water bottles. During the analysis the samples were analysed at 25°C room temperature and pressure (r.t.p).

A KANSO Certified Reference Material (CRM) (a framework of SCOR [Scientific Committee on Oceanic Research] WG147) was used to benchmark the accuracy of the seawater samples collected.

A 10 mL cuvette was filled with seawater sample collected at different monitoring station and different offshore depths was filled to the mark and placed in the HANNA HI83303 photometer to create a blank (meter was zeroed). A potassium disulfate reagent was added to the sample and a cuvette preparation methodology for each nutrient analysis was performed (for nitrite it was shook gently for about 15 seconds whereas for phosphate it was shook gently for about 2 minutes) (Figure 3.16-3.17).

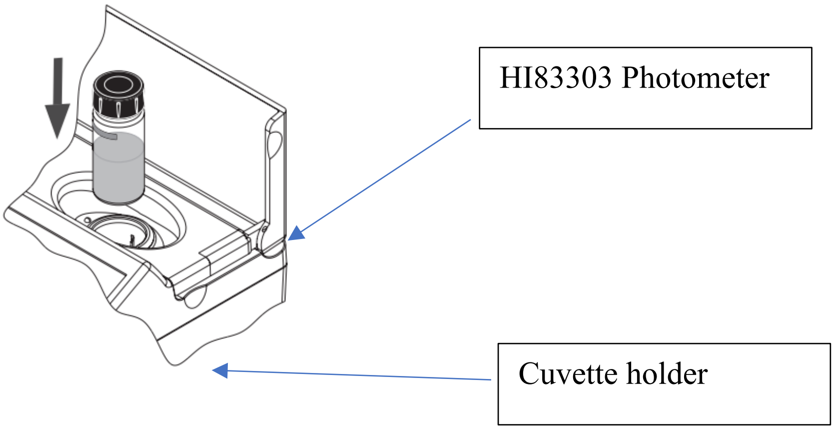


Figure 3.16 shows sample in a cuvette being placed in the photometer cuvette holder.

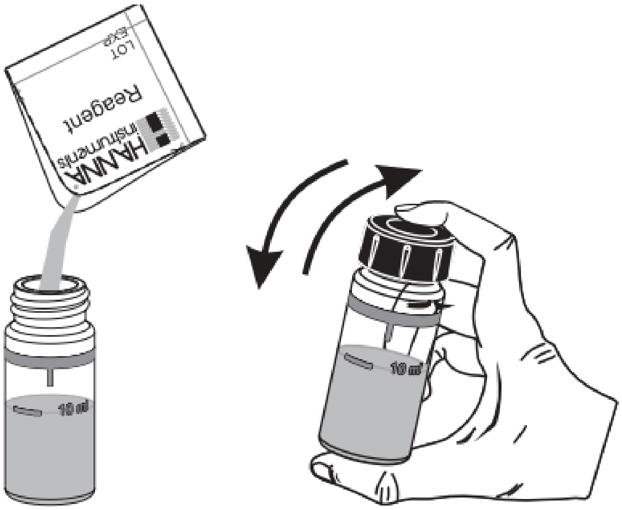


Figure 3.17 shows the nutrients reagents being added to the seawater sample and shaken to dissolve the reagents.

Once the powder reagents in the sample completely dissolved, the cuvette was placed in the photometer cuvette holder and the timer countdown gave the readings of the nutrient concentration (Figures 3.18-3.21). The photometer converted the results to µg/L of the nutrients (PO_4^{3-}) and (NO_2). .And these results were then converted to µM (mol/kg) as the unit widely used (Flynn et al., 2020; Panassa et al., 2018).

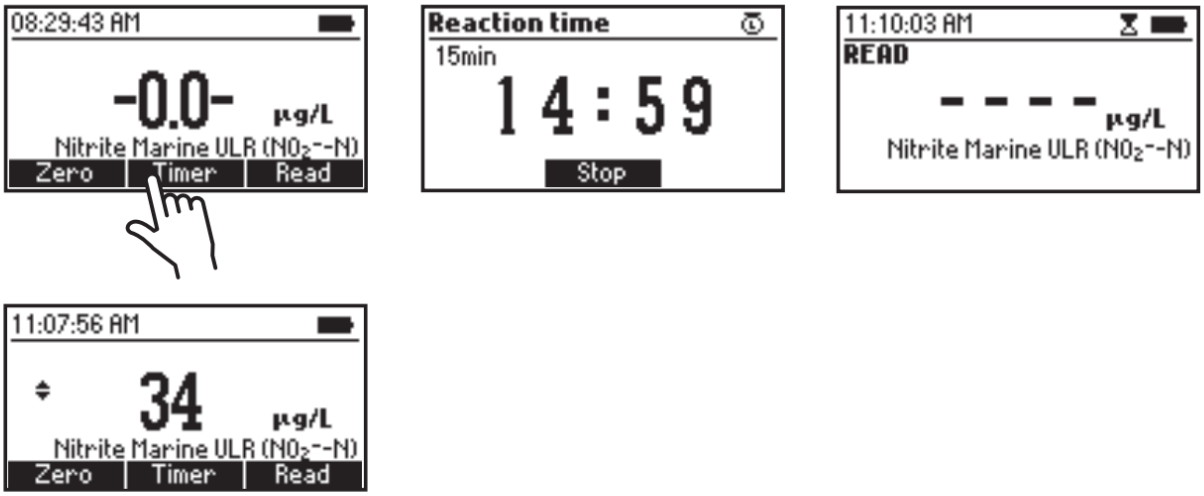


Figure 3.18 shows the countdown timer of the nitrite analysis with nitrite- nitrogen results.

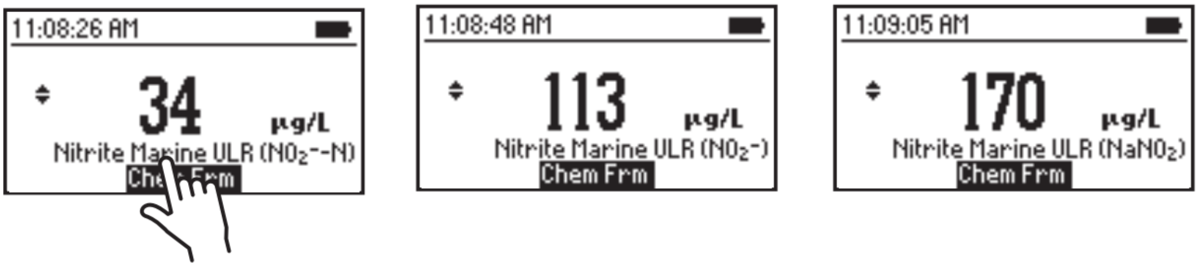


Figure 3.19 shows the conversion of the analysis with nitrate to nitrogen results to nitrate and Sodium nitrite ($NaNO_2$)

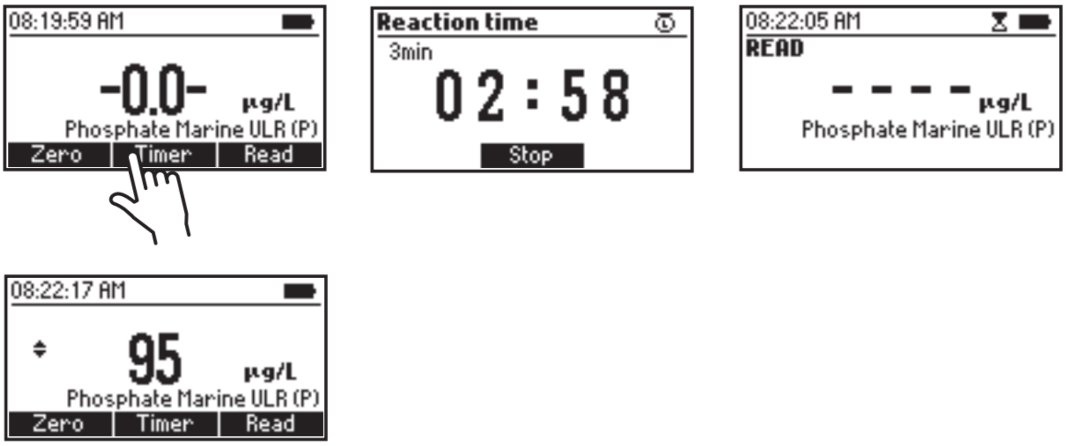


Figure 3.20 shows the countdown timer for phosphate analysis and the phosphorus results.

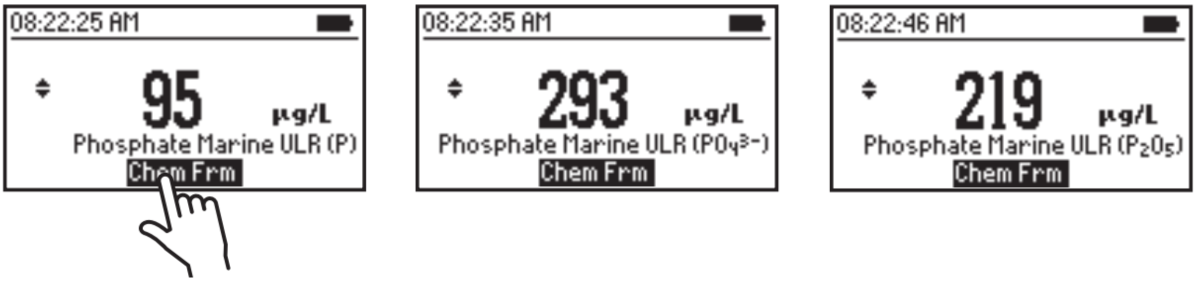


Figure 3.21 shows the conversion of Phosphorus (P) to Phosphate and Phosphorus pentoxide (P_2O_5).

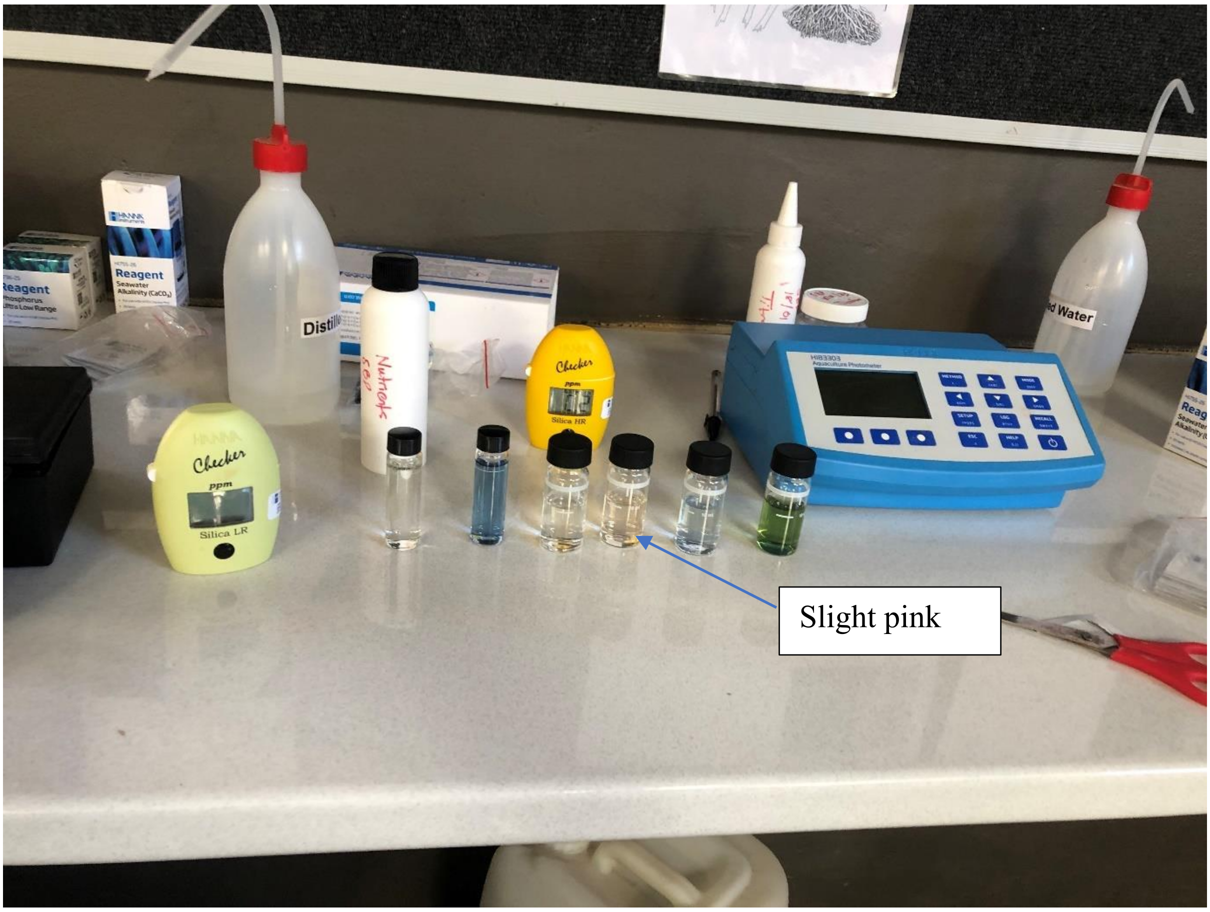


Figure 3.22 shows the samples in a cuvette after various nutrient analysis (from left to right): silica HR (High Range), silica LR (Low Range), Nitrate, Nitrite UL), Phosphate ULR

Silica HR (High Range), silica LR (Low Range), Nitrate, Nitrite ULR (the sample colour turned slightly pink after the reaction with the reagent), Phosphate ULR (the sample colour turned blue after the reaction with the reagent) (Figure 3.22).

3.4.4 CO_2 determination and Alkalinity Test by Titration

Two titration steps were followed, one was to determine the amount of CO_2 that has been consumed by the seawater sample (Hernández-Ayón et al., 1999) and the other titration step was for the alkalinity test (Saderne, Fusi, Thomson, Dunne, Mahmud, et al., 2020).

The CO_2 determination titration involved the gradual addition of basic titrant solution (NaOH) whereas the alkalinity test involved the gradual addition of acid titrants such as HCl, NH_3 (weak base), H_3BO_4, H_3PO_4 and CH_3COOH. The different indicators were prepared and diluted in the Kelp Blue and UNAM's laboratories.

3.4.4.1 Preparation of Indicators

a) Methyl red

A 0.25 g of Methyl red powder was weighed out on an analytical balance scale. The weighed methyl red was added to a clean 500 mL volumetric flask with ~ 238 mL of absolute ethanol (EtOH).

To find the amount of 95% alcohol that must be used for dissolving 0.1 grams:

$$0.05\ g_{methyl\ red} \times 2 = 50\ mL_{95\%\ ethanol} \times 2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$To\ use\ 0.1\ g\ of\ methyl\ red\ we\ needed\ to\ dissolve\ with\ 100\ mL\ of\ 95\%\ ethanol$$

$$To\ use\ 250\ mL\ of\ 95\%\ ethanol, 0.25\ g\ of\ methyl\ red\ was\ needed\ to\ be\ dissolved:$$

$$0.1\ g \times 250\ mL = x \times 100\ mL \leftrightarrow x = \frac{25\ g\ mL}{100mL} \leftrightarrow x = 0.25\ g \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$\therefore 0.25\ g\ was\ \ needed\ to\ dissolve\ the\ methyl\ red\ given\ increase\ in\ mass$$

We didn't have 95% alcohol but 99.9% (absolute ethanol) so we then did a balance reaction again: $250\ mL \times 95\% = x\ mL \times 99.9\% \ \rightarrow\ x \cong 238\ mL\ of\ absolute\ EtOH$ ………….. (7)

The mixture was then swirled and an ~ 8 mL of 0.1 M NaOH solution to was added to the volumetric flask. After the solution was effected, the de-ionized water (DIW) was added until the 500mL mark.

b) Methylene Blue

A saturated solution of methylene blue was prepared by adding 1.5 g of powdered methylene blue to 100 mL of 95% ethanol. The alcohol was slowly added to dissolve the powder. Subsequently, 30 mL of the saturated alcoholic solution of methylene blue was added to 100mL of distilled water along with 0.1 mL of 10 % potassium hydroxide.

c) Phenolphthalein

0.5 g of phenolphthalein powder was carefully weighed out on an analytical balance, while simultaneously preparing a 50 % ethanol (50 mL ethanol and 50 mL DIW) in a 125 mL volumetric flask. The 0.5 g of phenolphthalein powder was then dissolved in the 125 mL of the 50 % ethyl alcohol. Two drops of this mixed solution was then added to a sample contain seawater and slowly adding NaOH solution to it, a colour change from clear to pink confirmed the indicator test (Kiichi & Nobuyoshi, 2009).

3.4.4.2 Preparation of Titrants

The titrants used in the titrations for both CO_2 determination and alkalinity were 0.1 M solution. All the titrants used in the study had higher molar concentrations except for NaOH that was already 0.1 M. The rest of the titrants were diluted using the formula for calculating dilution, for example diluting of 32 % Ammonia (Perry et al., 1997):

Firstly, the molarity of 32% of ammonia needed to be identified:

where $\rho = density\ of\ NH_3 = \frac{0.907\ g}{cm^3}$, $17.03 \frac{g}{mol}\ molar\ mass\ of\ NH_3$

$$M_{32\%\,NH_3} = 0.32\ \left(\frac{g\ NH_3}{g\ aqeous\ solution}\right) \times \frac{0.907\ g}{cm^3} \times \frac{1000\frac{cm^3}{dm^3}}{\frac{17.03g}{mol}NH_3}\ \ldots\ldots\ldots\ (8)$$

$$\therefore M_{32\%\,NH_3} = 17.04\ M$$

To dilute 17.04 M of NH_3 to 0.1 M:

$C_1V_1 = C_2V_2,$ *where C is the concentration and V is the volume* ………….. (9)

$$17.04\ M \times V_1 = 0.1\ M \times 500\ mL$$

$$\Rightarrow V_1 = \frac{50\ M\ mL}{17.04\ M}$$

$$V_1 = 2.93\ mL$$

$$\approx 3.00\ mL\ of\ NH_3\ was\ used\ in\ a\ 500\ mL\ volumetric\ flask\ and\ the\ DIW\ was\ added\ to\ the\ mark$$

These preparation steps were done for other titrants as shown in Table 3.4 the table below:

Table 3.4 shows the titrant used for titration and the volume used to dilute to the titrant.

Titrant name	State before preparation	Molarity (M)	Volume flask used (mL)	Volume of titrant used for dilution (mL)
NH_3	Solution	17.0	500	3.00
HCl	Solution	1.0	500	50.00
H_3PO_4	Solution	14.6	500	3.40
H_3BO_4	Powder	1.1	250	23.00
CH_3COOH	Solution	1.0	500	50.00
NaOH	Solution and pellets	0.1	125	125.00

3.4.4.2 Titrations

The titration station with all the titrant solutions in the burette were prepared once the indicators and titrants were ready. Graduated cylinders were filled with known volume of the seawater sample (analyte) for each monitoring site and depths for the offshore sites (Figures 3.23-3.25). Two drops of the indicator were added to the analyte. Phenolphthalein was used as the indicator for NH_3 and NaOH, while methyl red and methyl blue were used as indicators for other titrants. The initial burette reading was taken, and the titrant was added dropwise to the sample until the solution turned slight pink to pink; and the final reading of the burette was then recorded. The endpoint of the titration was reached when the colour change of the sample using NaOH titrant became permanent and the solution turned from the acidic state to the alkaline state, this method is known as CO_2 determination (Goertzen et al., 2010; Schönherr et al., 2018).

Figure 3.23 shows the burette set up for titration in the UNAM organic chemistry lab with volumetric flask contain different prepared titrants.

Figure 3.24 shows the volumetric flask with prepared solution of titrants and indicators.

Figure 3.25 shows the endpoint reaction of the analyte (seawater sample) and titrants.

3.4.5 Sediment collection

Marine sediment collection is a critical process in marine science and environmental studies, aimed at studying the composition, properties, and environmental conditions of sediments on the seafloor. Proper collection methods are crucial for obtaining accurate data. During this study, two methods of sediment collection were employed; namely: sediment grab sampling and sediment coring.

a) Sediment grab sampling

This method involved deploying a grab sampler to collect surface sediment samples. At the offshore sites, sediment samples were collected using a Van Veen Grab (Sediment Grab) (Beukema, 1974; Wijsman et al., 2022).

The sediment grab was connected to a long rope that was used to launch the grab from the boat, when launching the grab, the hook was connected to a slit that made sure the grab jaws were open as shown in the (Figures 3.26-3.28):

Figure 3.26 shows the mechanism of how to open the sediment grab.

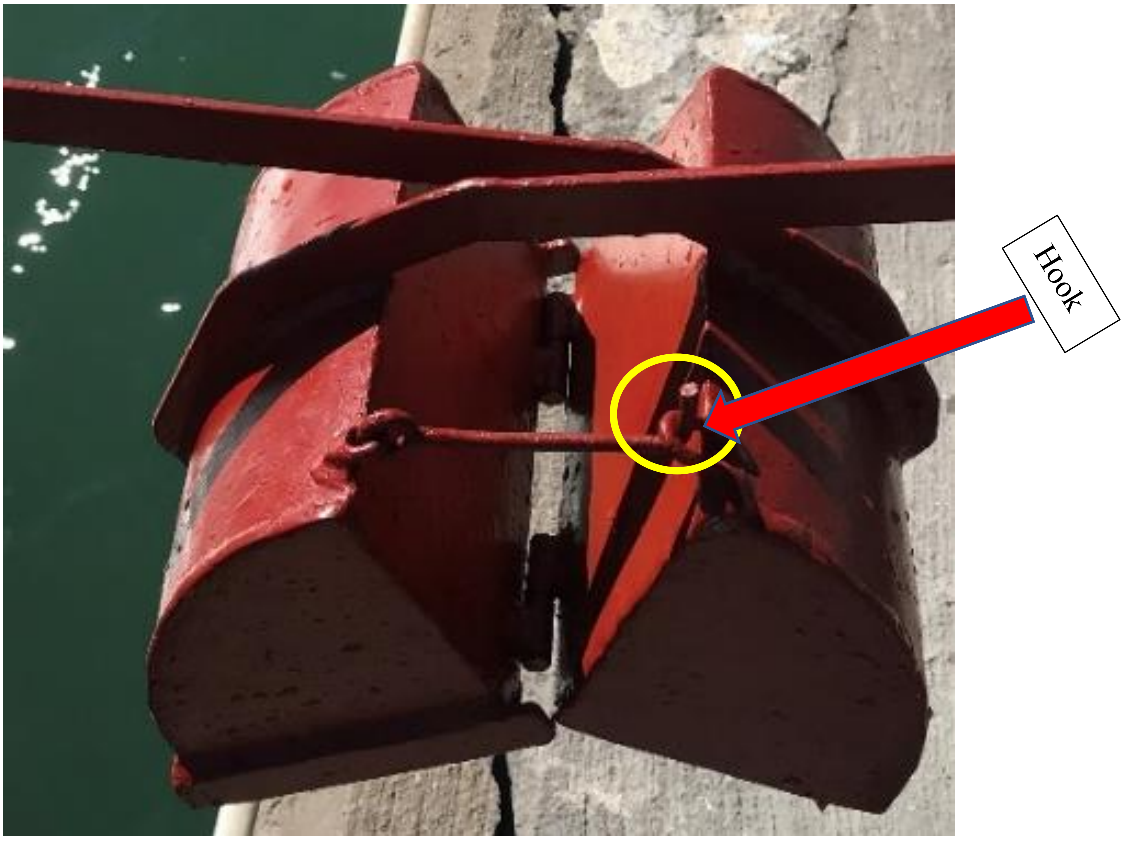


Figure 3.27 shows how to connect the hook to the open slit of the grab.

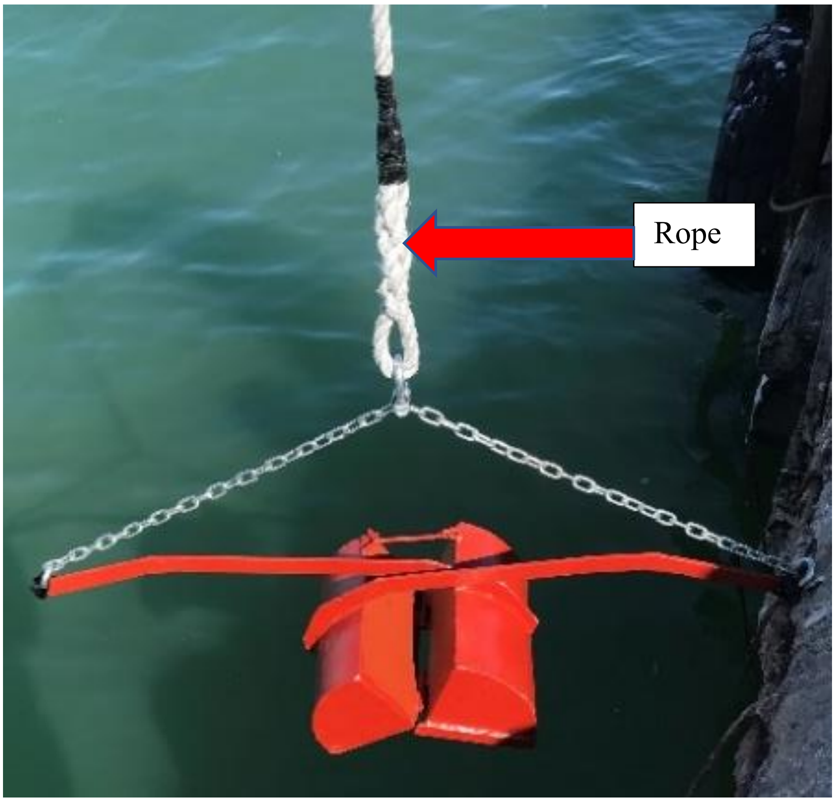


Figure 3.28 shows how to drop down the grab for sediment collection at the seafloor.

When the grab reached the seafloor, it collected the sediment, and the sediment was stored in zip-locke bag and stored in a deep freezer.

b) **Sediment coring**

. Using a multi-corer that was mounted on the RV (Research Vessel) Mirabilis, some sediments were collected during the study from Namibia's deep ocean and northern coastline. The multi-corer consisted of six (6) core tubes of about 60 centimetres (cm) in length that were coupled to it (Figure 3.29). Using the vessel winch the multi-corer was lower down into the ocean and when it reached the seafloor the core tubes were tightly closed with sediment and water intact. With a slack on the winch from the vessel the operator knew the multi-corer had hit the benthic floor.

Figure 3.29 shows Kurt Hanselmann (Emeritus Professor of biogeochemistry) pointing towards the multi-corer on the deck with the core tube.

Connected to the core tube is the spider-like arm hand that was on springs once the corer reached the floor it snapped and closed the core tube making the collected sediments intact and trapped.

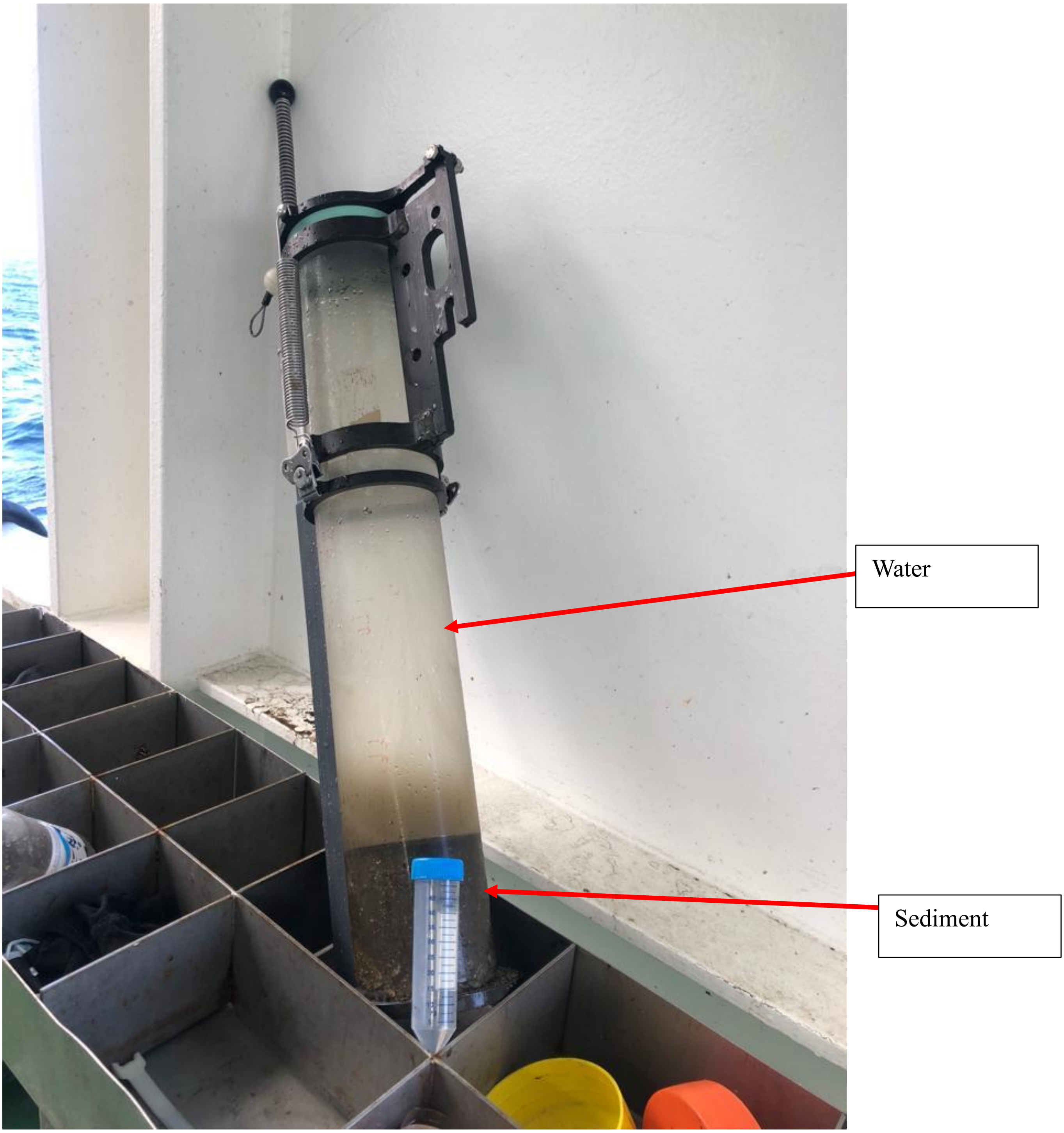


Figure 3.30 shows the successful coring with sediments and the bottom of the tube and falcon tube as a scale.

The sediment (Figure 3.30) collected with the multi-corer was stored in a freezer while on the vessel, once on land the sediment samples were stored in a -85°C freezer at NatMIRC. Five sediment samples from each of the sampling locations (3 study locations where 2 were from further north of Walvis Bay) were then sent to the geochemistry laboratory at the Department of the Geological Survey under the Ministry of Mines and Energy (MME) (Figures 3.31-3.32). The sediment was analysed using two different techniques: Loss on Ignition (LOI) and Energy-Dispersive X-ray Fluorescence (ED-XRF), which uses a handheld Niton XRF analyzer.

Figure 3.31 shows the frozen sediment from the coring done at the 20° latitude

Figure 3.32 shows the sediment in a freezer box were sent to the MME laboratory in Windhoek for sediment analysis for LOI and XRF.

Five samples were handed over to MME for XRF and LOI analysis. The samples were not crushed nor pulverized to maintain the state in which they were collected. The samples were analysed in the state they came (wet samples).

After XRF analysis, the empty crucibles and the five samples were dried separately for six (6) hours in a pre-heated oven at 1050 °C to remove any moisture content. The crucibles and the samples were allowed to cool in a desiccator for 30 minutes and afterward the mass of crucibles (n_1) was taken. About 1.70 g of each dried samples were added to the crucible and weighed (n_2). Thereafter, the crucibles with dried samples were placed in the furnace for an hour at 1050

°C. From the furnace the crucible with samples were allowed to cool in a desiccator for 30 minutes and subsequently weighed (n_3). Carbon content of each sample was then calculated.

Carbon content calculation:

LOI formula:

LOI (weight %)= $\frac{n_2-n_3}{n_2-n_1} \times 100$ or LOI (weight %)= $\frac{n_2-n_3}{(amount\ of\ sample\ weighed} \times 100$ ….(10)

$where\ n_1\ is\ the\ mass\ of\ the\ empty\ crucible, n_2\ the\ mass\ of\ the\ dried\ sample\ added\ to\ the\ crucible\ and\ n_3\ is\ the\ mass\ of\ the\ weight\ of\ the\ crucible\ containing\ sample\ after\ the\ furnance\ and\ placed\ in\ a\ desiccator\ to\ cool\ for\ 30\ minutes.$

CHAPTER FOUR: RESULTS AND DISCUSSION

The results gathered by this study comprised of the water geochemistry, nutrients found in the water samples, titrimetric analysis, and the sediment analysis.

The correlation between the results of water geochemistry, nutrients found in water samples, titrimetric analysis, and sediment analysis in the ocean plays a crucial role in understanding the complex interactions and processes occurring in marine ecosystems. These interconnected factors provide valuable insights into the health and dynamics of marine environments, helping researchers and scientists make informed decisions about conservation, pollution control, and the overall well-being of our oceans (Baird et al., 2021; Zhao et al., 2021).

Water geochemistry, a fundamental aspect of marine research, involves the analysis of chemical components in seawater. It offers a snapshot of the chemical makeup of the ocean, including the concentrations of various ions and compounds. This information is essential for understanding the physical and chemical properties of seawater, such as temperature, TDS, DO, pH, and alkalinity. Water geochemistry results can serve as a baseline against which other data can be compared, helping identify anomalies or trends that may impact marine life (STEMM-CCS D2.9, 2019; Sutton et al., 2022).

Nutrient analysis in water samples is a vital component of ocean research. Nutrients, such as nitrites, phosphates, and silicates, are essential for the growth of marine organisms. By measuring nutrient levels in water, scientists can assess the availability of these crucial substances for phytoplankton and other primary producers. The relationship between nutrient levels and biological productivity is a central aspect of oceanography, as it influences the entire food web, from microscopic plankton to large marine mammals (Basu & Mackey, 2018; Bristow et al., 2017; W. Li et al., 2023).

Titrimetric analysis is a method that determines the concentration of a specific chemical substance in a solution through a titration process. In the context of oceanography, titration is often used to measure parameters like alkalinity. Alkalinity is particularly important, as it reflects the ocean's buffering capacity against changes in pH, such as ocean acidification. By correlating titrimetric results with nutrient and geochemical data, researchers can gain a comprehensive understanding of the chemical and biological dynamics in a specific marine region (Mashoreng et al., 2019).

Furthermore, titrimetric analysis complements nutrient measurements by providing information on the buffering capacity of seawater. Changes in pH due to increased carbon dioxide in the atmosphere (ocean acidification) can affect the solubility of nutrients and the availability of carbonate ions for shell-forming organisms (James et al., 2021; Steiner et al., 2018). These effects are evident not only in water samples but also in the composition of marine sediments over time.

4.1 Geochemistry results

Geochemical parameters, including pH, temperature, salinity, turbidity, dissolved oxygen (DO), and total dissolved solids (TDS), play a crucial role in understanding the sequestration of carbon in various environmental systems. The variation in these parameters can significantly influence the processes that determine carbon sequestration. During the study all these parameter readings were taken at different study locations (Figure 4.1) over a period of 12 months and averaged (Table 4.1).

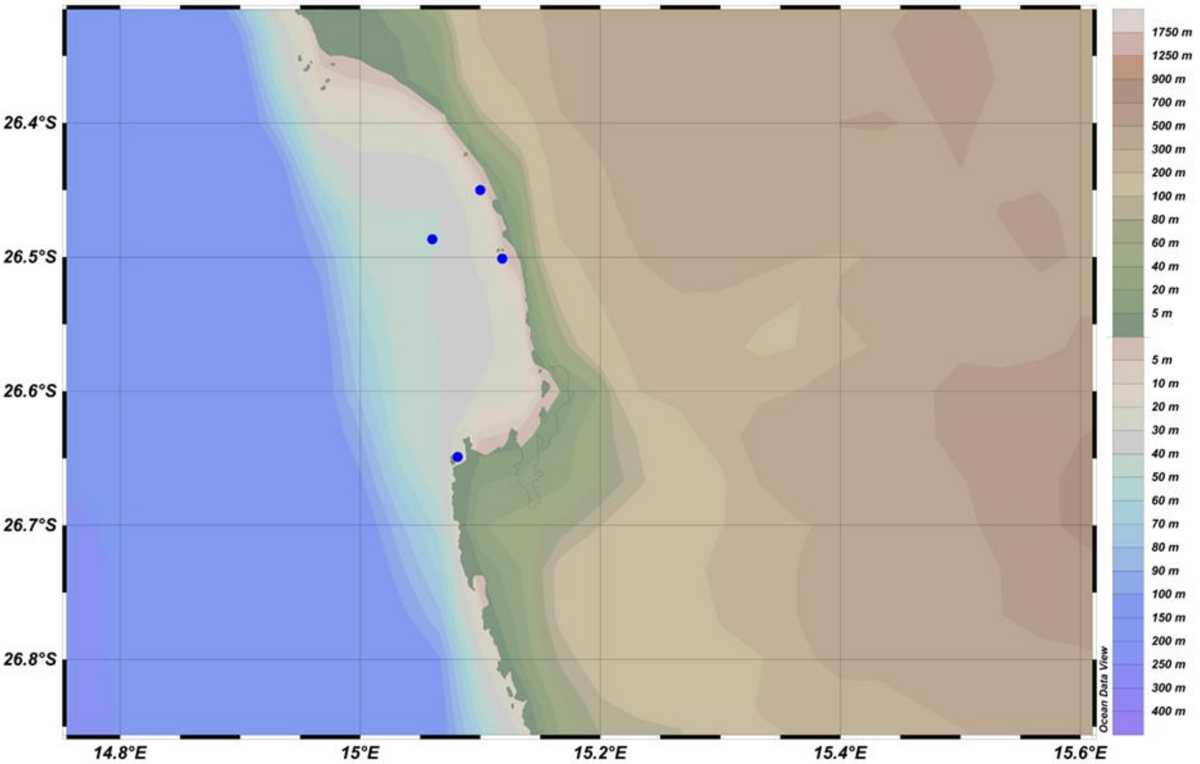
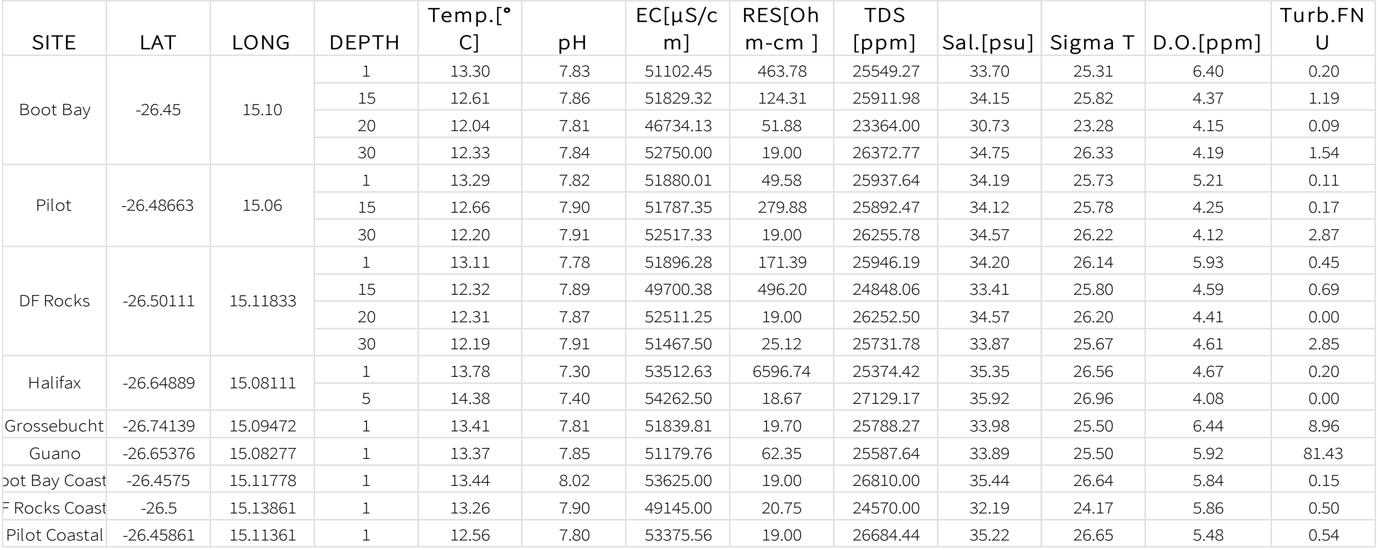


Figure 4.1 shows the offshore monitoring sites and the elevation above and below sea level. Map designed using Ocean Data View (ODV) software.

Table 4.1 shows the average the geochemistry results at all the sites of sampling during the study.



SITE	LAT	LONG	DEPTH	Temp.[°C]	pH	EC[µS/cm]	RES[Ohm-cm]	TDS [ppm]	Sal.[psu]	Sigma T	D.O.[ppm]	Turb.FNU
Boot Bay	-26.45	15.10	1	13.30	7.83	51102.45	463.78	25549.27	33.70	25.31	6.40	0.20
			15	12.61	7.86	51829.32	124.31	25911.98	34.15	25.82	4.37	1.19
			20	12.04	7.81	46734.13	51.88	23364.00	30.73	23.28	4.15	0.09
			30	12.33	7.84	52750.00	19.00	26372.77	34.75	26.33	4.19	1.54
Pilot	-26.48663	15.06	1	13.29	7.82	51880.01	49.58	25937.64	34.19	25.73	5.21	0.11
			15	12.66	7.90	51787.35	279.88	25892.47	34.12	25.78	4.25	0.17
			30	12.20	7.91	52517.33	19.00	26255.78	34.57	26.22	4.12	2.87
DF Rocks	-26.50111	15.11833	1	13.11	7.78	51896.28	171.39	25946.19	34.20	26.14	5.93	0.45
			15	12.32	7.89	49700.38	496.20	24848.06	33.41	25.80	4.59	0.69
			20	12.31	7.87	52511.25	19.00	26252.50	34.57	26.20	4.41	0.00
			30	12.19	7.91	51467.50	25.12	25731.78	33.87	25.67	4.61	2.85
Halifax	-26.64889	15.08111	1	13.78	7.30	53512.63	6596.74	25374.42	35.35	26.56	4.67	0.20
			5	14.38	7.40	54262.50	18.67	27129.17	35.92	26.96	4.08	0.00
Grossebucht	-26.74139	15.09472	1	13.41	7.81	51839.81	19.70	25788.27	33.98	25.50	6.44	8.96
Guano	-26.65376	15.08277	1	13.37	7.85	51179.76	62.35	25587.64	33.89	25.50	5.92	81.43
oot Bay Coast	-26.4575	15.11778	1	13.44	8.02	53625.00	19.00	26810.00	35.44	26.64	5.84	0.15
F Rocks Coast	-26.5	15.13861	1	13.26	7.90	49145.00	20.75	24570.00	32.19	24.17	5.86	0.50
Pilot Coastal	-26.45861	15.11361	1	12.56	7.80	53375.56	19.00	26684.44	35.22	26.65	5.48	0.54

Temperature variation:

Temperature is critical factor in geochemistry measurements. Warmer temperatures can enhance microbial activity, which may accelerate the decomposition of organic matter, releasing carbon into the atmosphere. On the other hand, colder temperatures can slow down decomposition processes, favouring the preservation of organic carbon in sediments and soils (García-Martín et al., 2019; Weinstock et al., 2022).

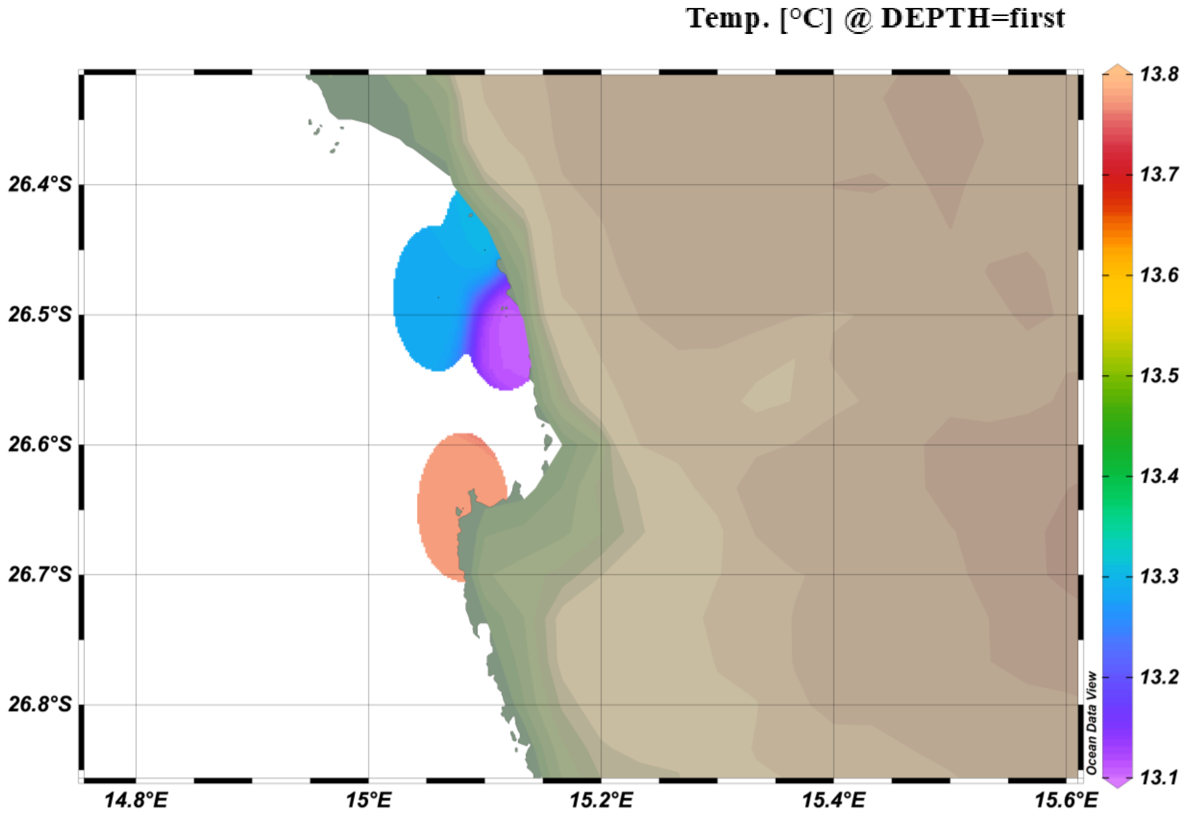


Figure 4.2 shows the temperature variations from the control (south) to the downstream of the farm (north) for the offshore areas. Maps and visualization of results were done on ODV software.

Halifax island had the higher temperatures amongst the offshore areas.

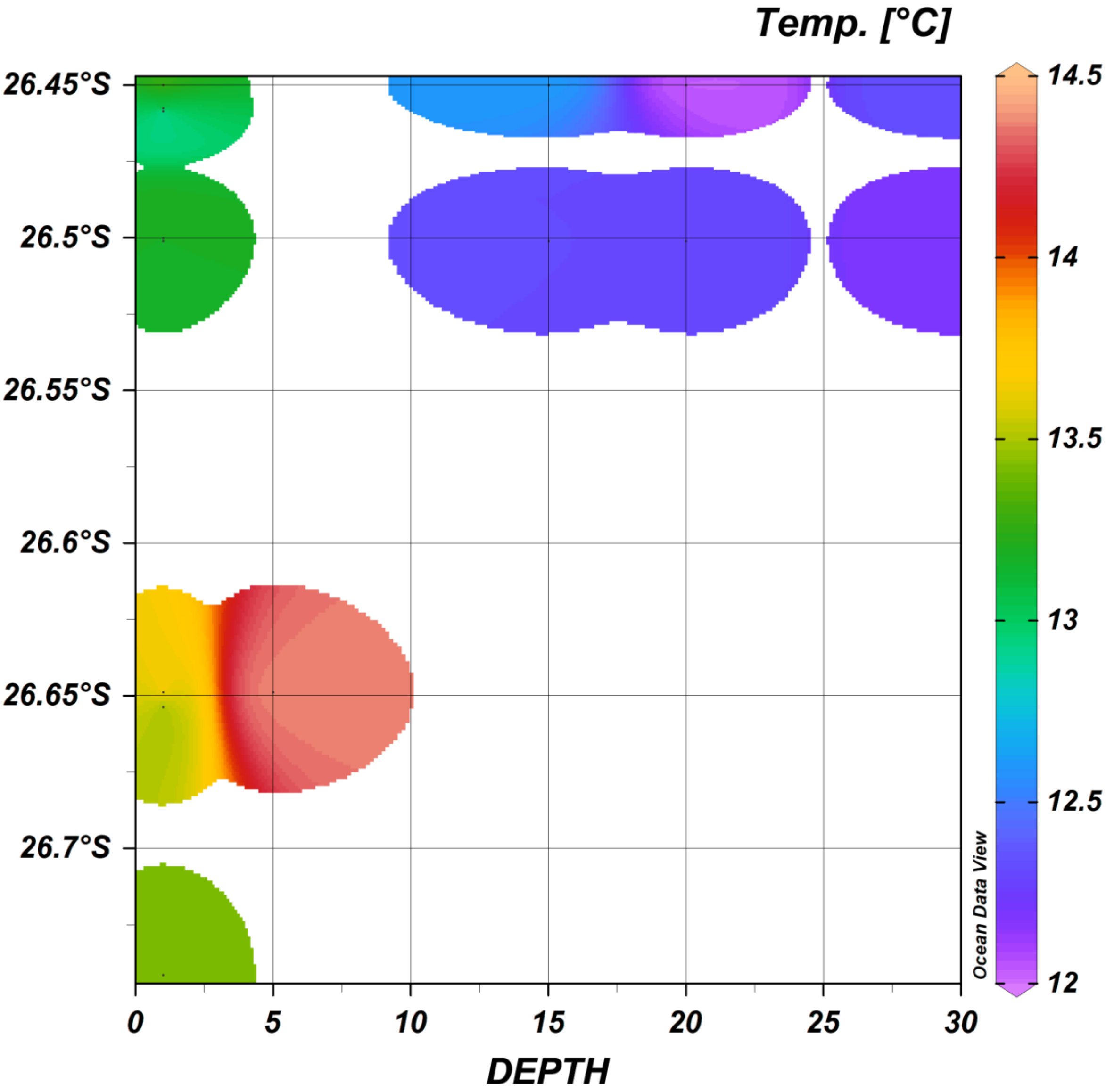


Figure 4.3 shows the temperature distribution at different depths during the study period.

Further offshore in deeper waters (DF Rocks, Pilot and Boot Bay) the temperature increased further north (Figure 4.4) as the study findings have shown that sea-surface temperature (SST) tend to be warmer at the north compared to the south, due to the distance towards the equator as well as the artic which influences the temperature of the southern ocean (Cole & Villacastin, 2000; Grémillet et al., 2008; Kirst et al., 1999).

The temperatures recorded at Halifax Island (Figure 4.4) compared to other site was mainly due to the SST as the depth was shallower compared to other offshore sites and that it was closer to the coastal areas where temperatures are from the continental margin influences the water masses in coastal areas (Narayanan et al., 2019; Venancio et al., 2014).

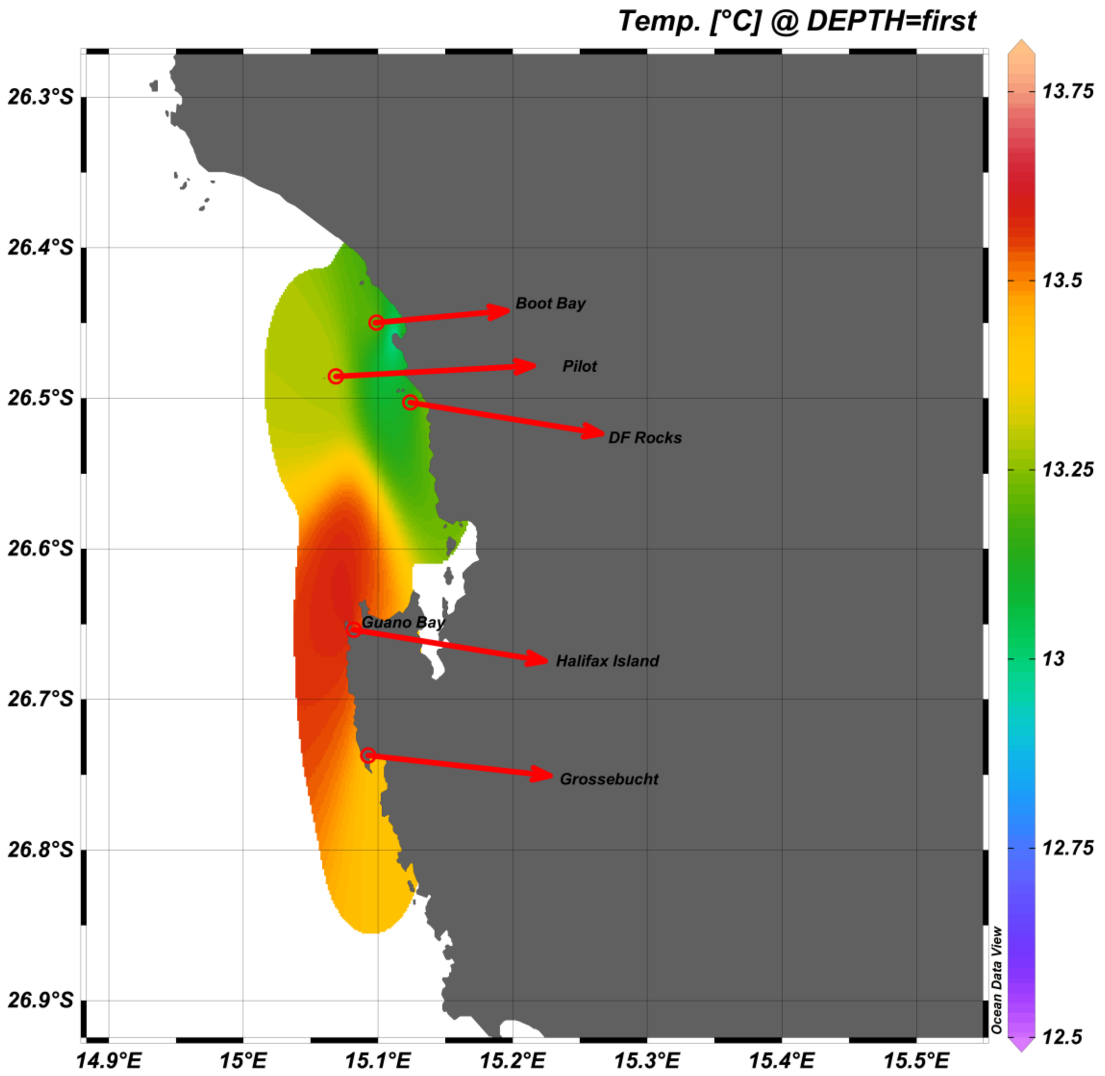


Figure 4.4 shows more temperature variability, with lower temperatures observed at offshore and nearshore sites.

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Lower temperatures were recorded the further below sea surface and this decreased with depth while SST was observed to be higher at Grossebucht, Guano Bay and Halifax Island (Figure 4.3). Various studies have attested to the low temperatures which are consistent with this study findings. This is because cold water exhibits higher density compared to warm water. As the water masses goes deeper (sink), it becomes colder due to the natural process of cold, saline ocean water sinking towards the ocean basins' bottom, displacing the less dense, warmer water found near the surface. This downward movement of cold, salty water, alongside the wind-driven movement of warm water on the surface, gives rise to a intricate system of ocean circulation known as the 'global conveyor belt' (Figure 4.5) (Henry et al., 2014; Scheen & Stocker, 2020).

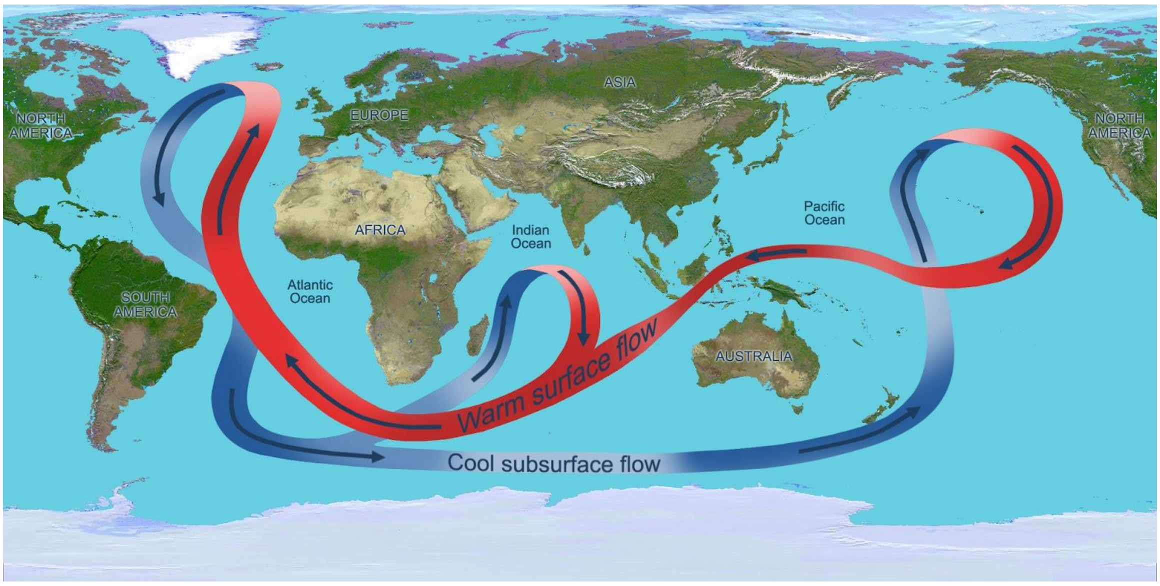


Figure 4.5 shows the global conveyor belt (https://sealevel.jpl.nasa.gov/images/ostm/newsroom/features/images/201004-1a.jpg, accessed on 25/04/2023)

The seasonal climate also played a role in temperature variation as higher temperatures were observed during the summer season compared to winter as per Figure 4.3 and Figure 4.4.

The temperature variation values obtained during this study favours the proliferation of *M. pyrifera,* hence *M. pyrifera* will thrive at the proposed pilot farm and further south of the farm due to the favourable temperate conditions, similar to the sites where kelp naturally grows.

The studies conducted in South America where *M. pyrifera* widely grows (especially from Peru to Cape Horn and Argentina), indicated considerable temperature gradient is from 9°C to 20°C, which is in the acceptable limits. Temperature values observed at the Pilot farm (Figure 4.4) and all the surrounding areas within the Lüderitz active cell were within the 9-20 °C range (Becheler et al., 2022; Körner et al., 2023; Le et al., 2022). More also, the temperate conditions of the pilot farm resembles that of the Southern Benguela upwelling cell (Fleischman et al., 2020; Grémillet et al., 2008).

pH Variation:

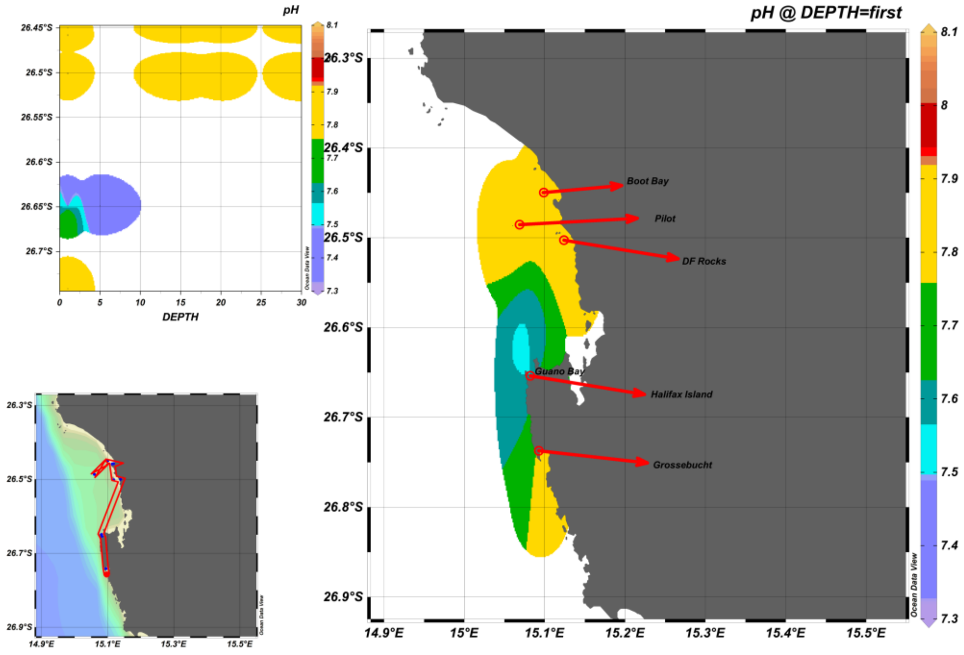


Figure 4.6 shows the pH variation at the different monitoring station offshore and coastal monitoring sites of the study.

The plot on the bottom left corner of Figure 4.6 shows the defined section (encompassing all the monitoring sites), the plot on the top left corner shows the variation of pH with depth and latitudinal location, whereas the plot on the left side of Figure 4.6 shows the pH distribution throughout the region of study. The result therefore revealed that the pH variation was almost evenly distributed throughout all the study areas, except at Halifax Island and Guano Bay which had low amount of 7.6 to 7.7 pH values (Figure 4.6).

The lower temperatures observed at these sites can be attributed to various anthropogenic activities as these sites are closer to the town of Lüderitz. Islands, especially those with high human population densities or industrial activities, may experience pollution from runoff, sewage discharge, and industrial waste. These contaminants can introduce acidic substances into the marine environment, thereby lowering the pH of the surrounding waters (Kye et al., 2023; Landrigan et al., 2020). The Halifax island and its adjacent bay (Guano Bay) have a rather tragic history where few centuries ago due to guano mining this lead to increased inputs of nutrients and organic matter as a result of guano mining, a few centuries ago,, resulted in algal blooms and the subsequent decomposition processes that consume oxygen and release CO_2, leading to acidification of marine waters (Griffith & Gobler, 2020; R. Li et al., 2022; Riebesell et al., 2018).

At some depths below the sea surface, there was a higher reading (7.9 to 8.1 pH values) were observed of pH compared to those results observed from the surface water (Figure4.7). The increased levels of pH in deeper water could be probably due to various subsea process including biological activities: where phytoplankton perform photosynthesis in the presence of sunlight; absorbing carbon dioxide from the water and converting it into organic matter. This uptake of CO_2 reduces the concentration of carbonic acid and increases pH (Basu & Mackey, 2018; Onyeaka et al., 2021; Sethi et al., 2020; Sun et al., 2022; Wang et al., 2023). Another process is called vertical mixing where below the sea surface, the waters are less exposed to the atmosphere and, therefore, experience less direct contact with carbon dioxide. This reduces the rate of carbon dioxide dissolution and helps maintain higher pH values in deeper waters (Barry et al., 2013; Chen et al., 2022; Fabry J. et al., 2019; Hurd et al., 2022; Parker, 2016; Saderne, Fusi, Thomson, Dunne, Pelembe, et al., 2020).

This was also observed at the offshore monitoring sites, where lower pH readings were observed at the Halifax Island both at the surface and at 5 meters below sea level as shown in Figure 4.7 below:

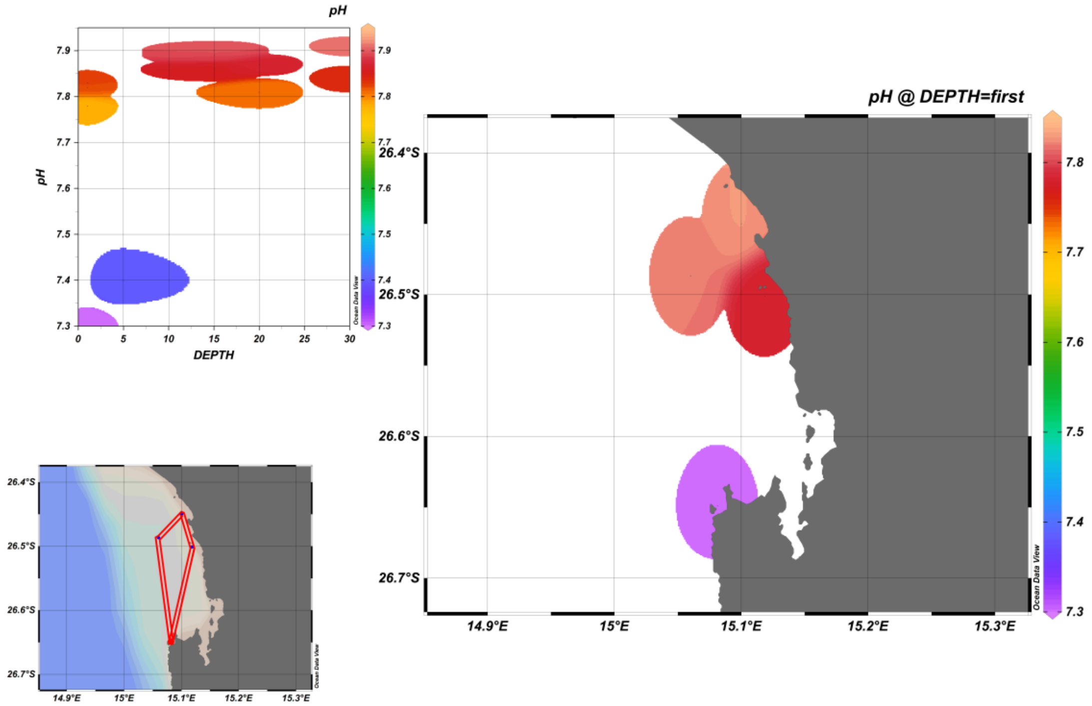


Figure 4.7 show the offshore pH values distributions, the left bottom corner shows the monitoring section, the top right corner shows the depth profiles of pH.

The ocean's capacity to sequester CO_2 depends on its pH levels. When carbon dioxide dissolves in seawater, it reacts with water molecules to form carbonic acid (H_2CO_3). Carbonic acid then dissociates into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-) (Figure 4.8). The increased concentration of hydrogen ions leads to a decrease in seawater pH, making it more acidic (Dickson, 2010; Hirsh et al., 2020; R. Li et al., 2022).

Lower pH values indicate higher acidity, and this hinder the ocean's ability to absorb and store CO_2. This is because high concentrations of hydrogen ions interfere with the formation and preservation of carbonate ions (CO_3^{2-}) in the ocean.

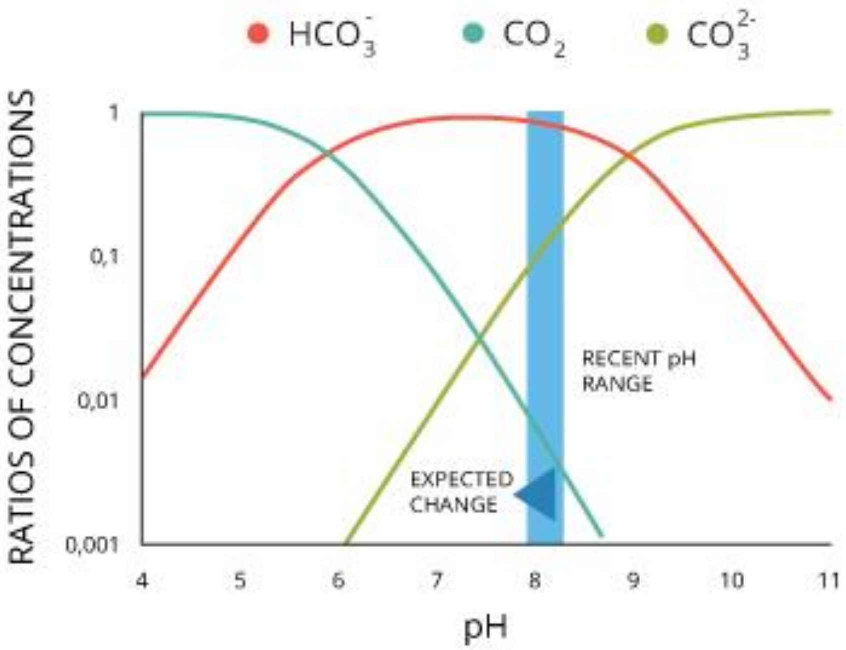


Figure 4.8 shows that an oceanic pH of 8.3, carbonate levels are high enough for coral building. As CO_2 increases and pH decreases, carbonate levels will quickly drop below optimum levels. https://www.fondriest.com/environmental-measurements/wp-content/uploads/2013/11/ph_ocean-carbonates.jpg *(accessed on 31072023).*

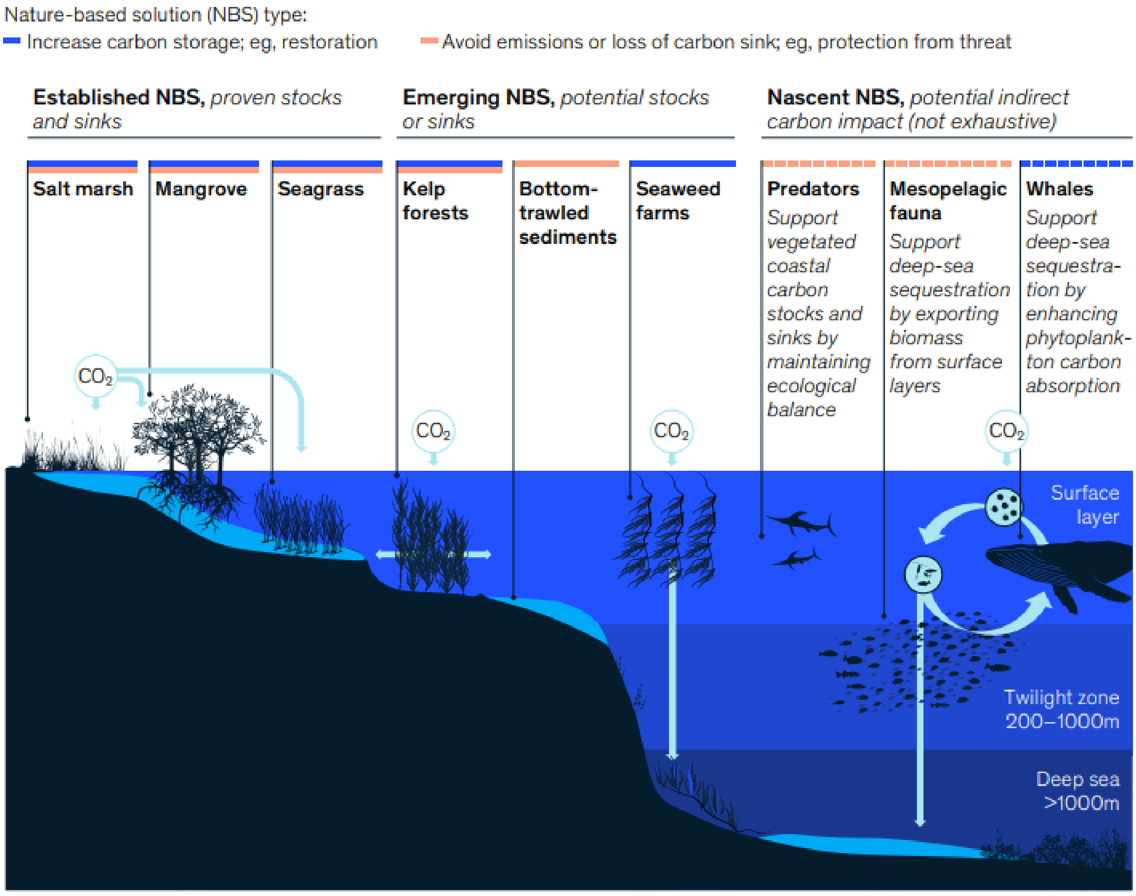
Carbonate ions play a crucial role in the carbonate system of the ocean, which includes the equilibrium between dissolved inorganic carbon species (Figure 4.8). Carbonate ions combine with calcium ions (Ca^{2+}) to form calcium carbonate ($CaCO_3$), which is the building block for marine organisms like corals, molluscs, and foraminifera. These organisms use calcium carbonate to construct their shells and skeletons (James et al., 2021; R. Li et al., 2022).

In more acidic conditions (>7.6 pH units), carbonate ions become less available. This reduced carbonate ion concentration limits the availability of carbonate minerals for marine organisms, hindering their ability to build and maintain their calcium carbonate structures. As a result, ocean acidification can negatively impact marine ecosystems, especially those reliant on calcium carbonate structures. The decrease in carbonate ion concentration also affects the dissolution of existing calcium carbonate sediments. More acidic conditions can lead to increased dissolution of calcium carbonate, releasing CO_2 back into the water and potentially the atmosphere. This process reduces the ocean's capacity to store carbon dioxide in the long term (Barry et al., 2013; James et al., 2021; Steiner et al., 2018).

The presence of the kelp forest at the pilot farm and surrounding sites in Lüderitz will help remediate ocean acidification through a process called "biological carbon sequestration." Kelp, which are large brown algae, have the ability to absorb and utilize CO_2 from seawater during photosynthesis (Chung et al., 2011; Hurd et al., 2022; Krause-Jensen et al., 2018; Macchiavello et al., 2010; Saderne, Fusi, Thomson, Dunne, Pelembe, et al., 2020; Sondak et al., 2017).

Kelp has rapid growth rates and high biomass production (Sondak et al., 2017). As kelp grows, it accumulates significant amounts of organic carbon (Figure 4.9). When kelp biomass sinks to the ocean floor or is harvested and utilized for various purposes, it sequesters carbon, effectively removing it from the atmosphere and the surface ocean for long periods (Bayley et al., 2017).

McKinsey company released an article (Figure 4.9) that showed the potential of kelp as a nature based solution due to the ability of the kelp to survive at the pH levels observed in this study and the ability of increasing the pH levels (Claes et al., 2022; Xiao et al., 2021).



Source: McKinsey analysis

Figure 4.9 shows the latest scientific research and leverages McKinsey analysis to estimate the potential for abatement or conservation by 2050. This report also includes deeper analysis of kelp reforestation and bottom trawling to show how economies of scale in these emerging solutions could help reduce prohibitive costs.(Claes et al., 2022)

Total Dissolve Solids (TDS) variation:

Total dissolved solids (TDS) encompass various ions, including carbonates and bicarbonates. The concentration of these ions can influence the buffering capacity of water, affecting the pH and the solubility of carbonates, ultimately influencing carbon sequestration processes.

During the study the TDS measurements were taken at all the study areas and more than 25000 ppm (Figure 4.10) of dissolved solids were recorded which were the acceptable values of the marine environment (Sugiarti et al., 2023).

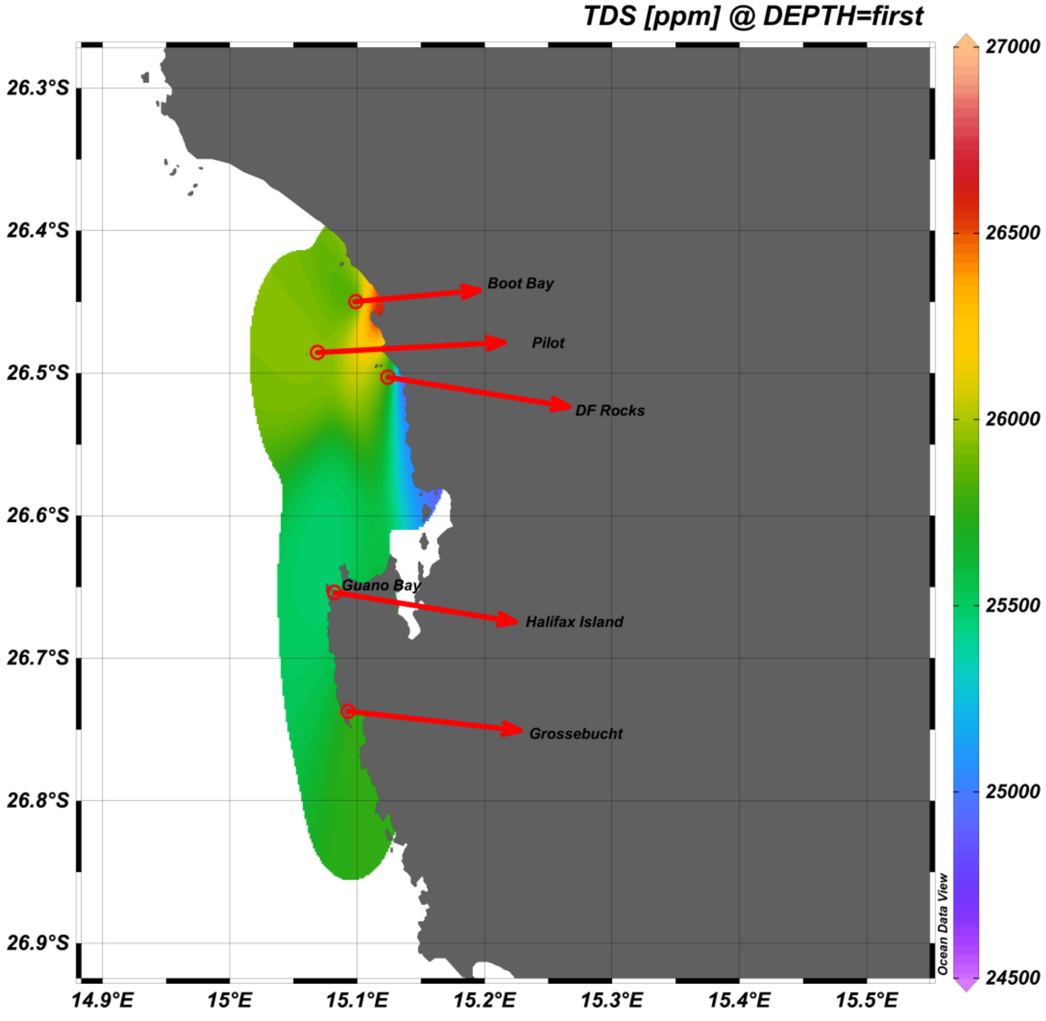


Figure 4.10 shows the TDS distribution and variability at the different monitoring sites (including both offshore and coastal).

From the map distribution (Figure 4.10), higher amounts (>27000 ppm) of TDS readings were observed further north and at the coastal areas of Boot Bay and Pilot Area. This is because the TDS distribution in the BUS is influenced by a combination of physical and biological processes that are characterized by strong coastal winds that drive the upwelling of nutrient-rich water from the ocean depths (Hutchings et al., 2009; Lima et al., 2019; Tyrrell & Lucas, 2002). The upwelling then brings dissolved minerals to the surface and leads to higher TDS levels near the coastal area especially at Boot Bay and Pilot areas (Rixen et al., 2021).

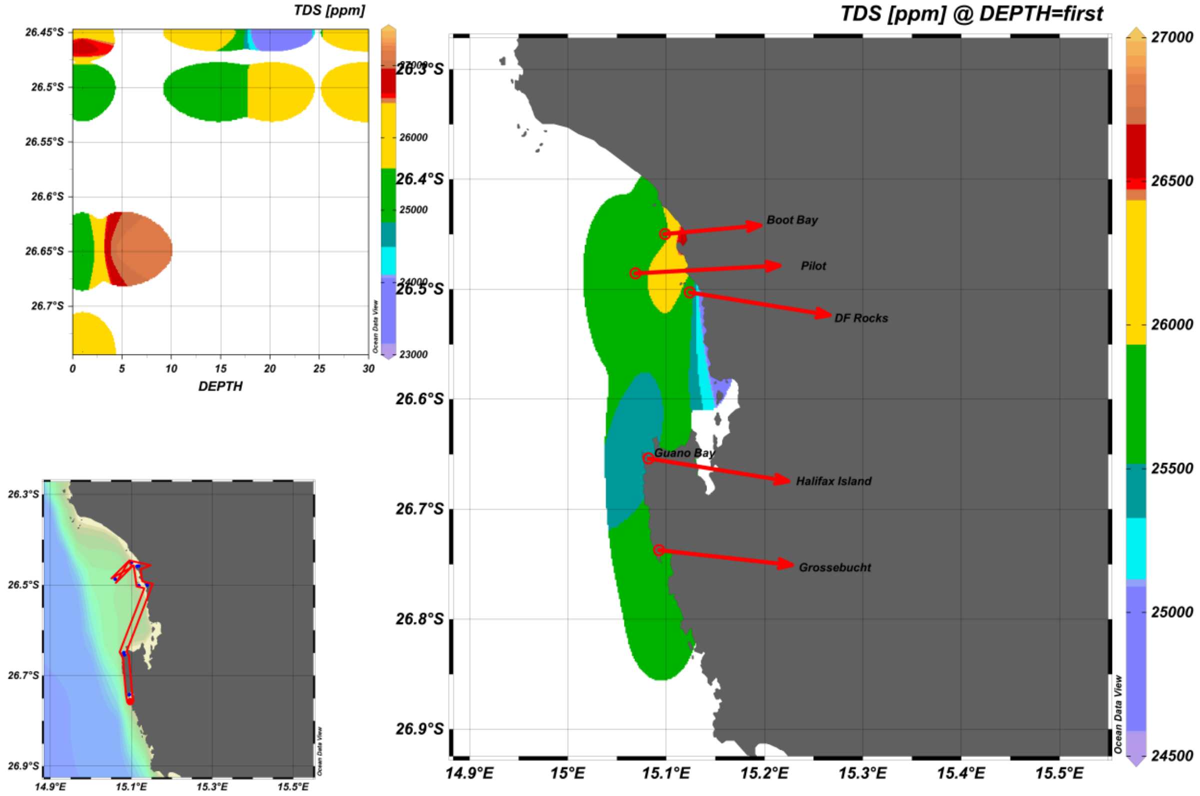


Figure 4.11 shows the variability of TDS at the different sites and depths.

Overall, the TDS levels in these areas were influenced by a combination of physical processes, such as upwelling and mixing of water masses, and biological processes, such as phytoplankton uptake of dissolved minerals (Aumont et al., 2016; Barlow et al., 2009).

Dissolved Oxygen (D.O) variation

Dissolved oxygen is the measurement of unbound, elemental oxygen in water or other liquids. It holds significant importance in evaluating water quality due to its impact on the aquatic organisms inhabiting a particular body of water (Facilities, 2016). Studies have shown that the amount of DO needed for marine organisms to thrive varies from creature to creature within the water bodies, for example kelp thrive ranges from 4 to 5 ppm. The measurements in this study showed that DO vary from 4.5 to 7 ppm at different locations (Figure 4.12). Table 4.1 showed the DO level values found at each study location.

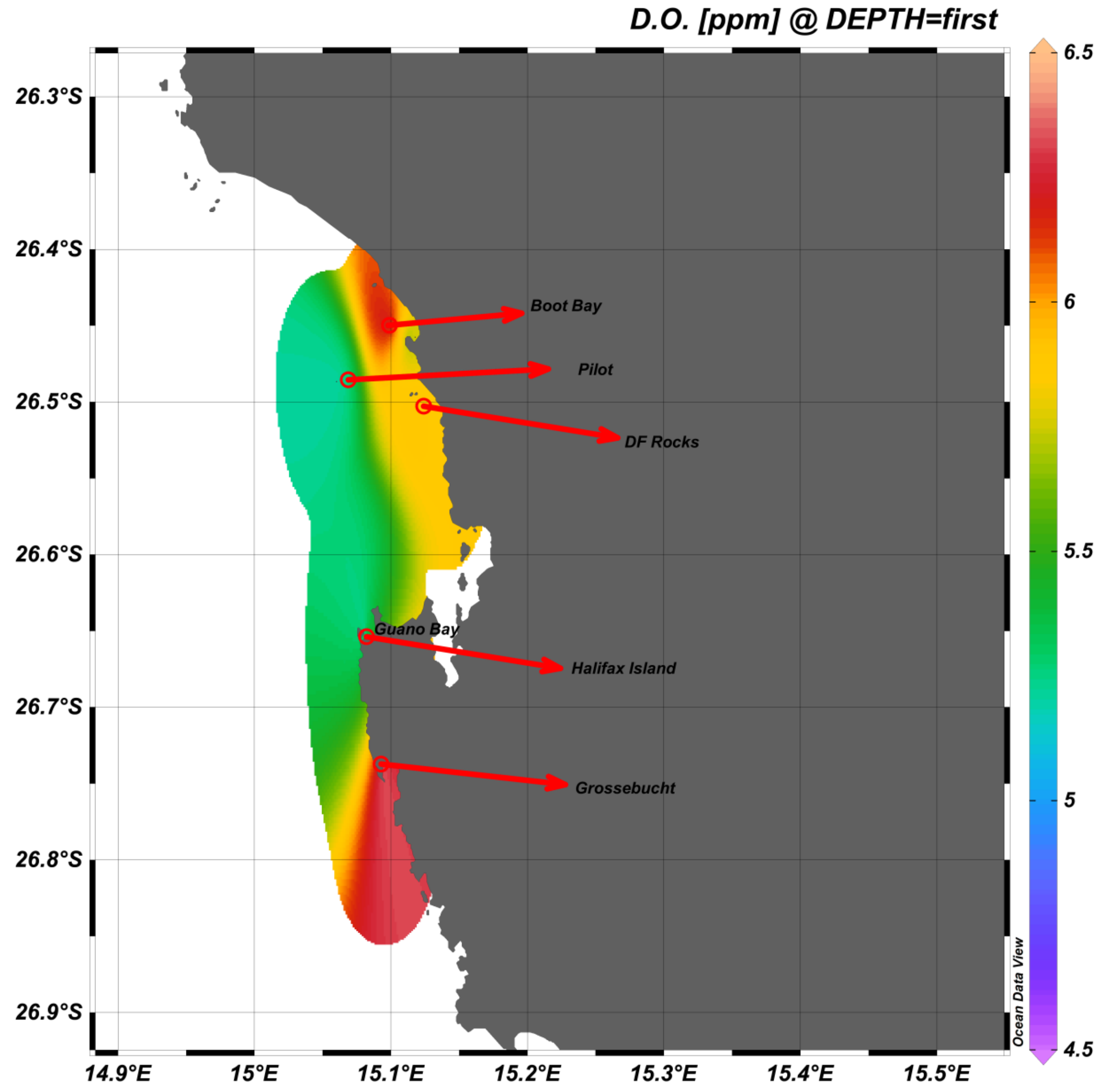


Figure 4.12 shows the dissolved oxygen in ppm variability and distribution.

Higher amounts of D.O was observed at the coastal areas compared to the offshore areas (Figure 4.12). The upwelling brings cold, oxygen-rich water to the surface, leading to higher DO levels near the coast (Hoshijima & Hofmann, 2019; Najjar et al., 2007).

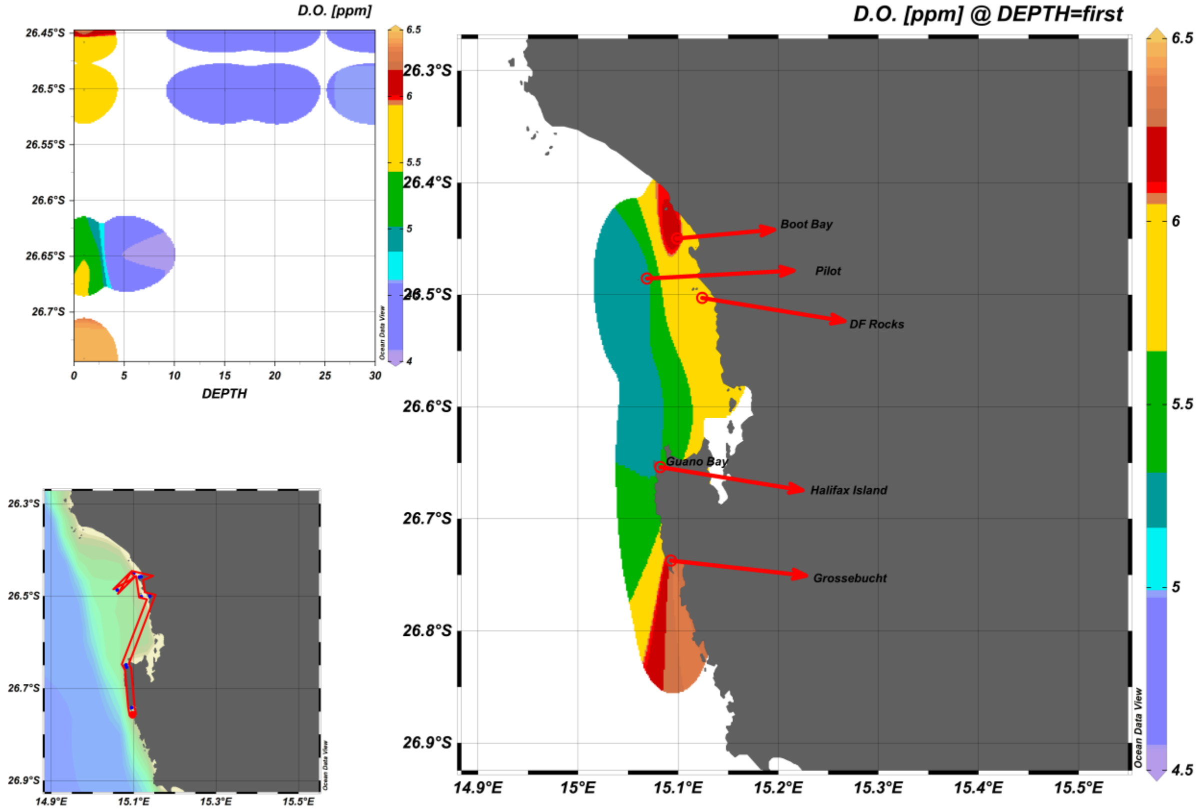


Figure 4.13 shows on the top left corner the variability of D.O at different depths.

Oxyclines were observed at higher depths. In set at the bottom left corner (Figure 4.13) shows the map of the different monitoring sites, while on the right-hand side figure show the D.O variation at different sites. Higher D.O values was observed at Boot Bay (6.40 ppm) and down at Grossebucht (6.44 ppm). The D.O and pH results of this study shows that all the study areas have the potential to accommodate the cultivated farm at large scale due to the amounts available and the continuous prevailing active upwelling cell.

More also, as a result of the higher productivity in the Benguela upwelling system (BUS), the phytoplankton respirations and temperature contributes to the lower oxygen levels in the open ocean when compared to the coastal areas (Pitcher et al., 2014).

Geochemistry seasonality

The geochemistry of all the sample area locations varied in relation to the seasonality. Changes were observed especially in major geochemistry parameters such as the pH and temperature. The pH varied between 6.80-8.20 and temperatures of 6.0-16.10 °C, over the study period (Figure 4.14).

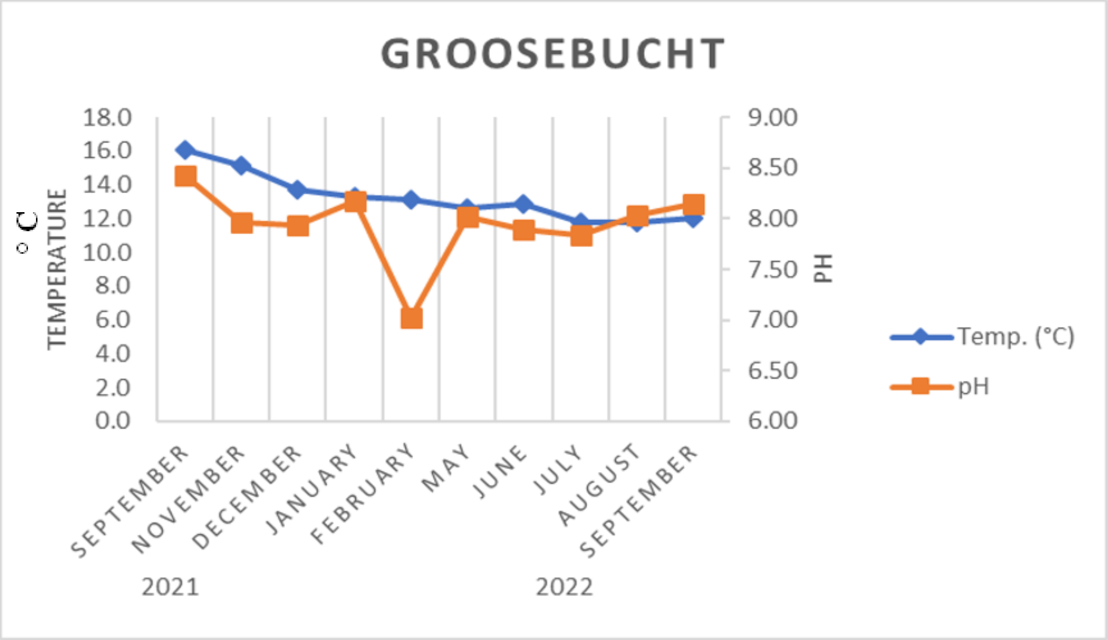


Figure 4.14 shows the seasonal variation of temperature and pH at Grossebucht control site.

Higher pH was observed during the peak season of the upwelling (September to January), and this has a direct relationship with temperature.

The monthly trends observed at Grossebucht area had higher pH and temperature values during the peak of an upwelling season. Due to the Lüderitz active upwelling cell, the dominance of high pH was observed to be throughout the year with slight increase during the peak season compared with the Northern Benguela Upwelling system (n-BUS) (Flynn et al., 2020; Hutchings et al., 2009; Lima et al., 2019).

Similar seasonal pattern was also observed at Guano Bay as shown in Figure 4.15 below:

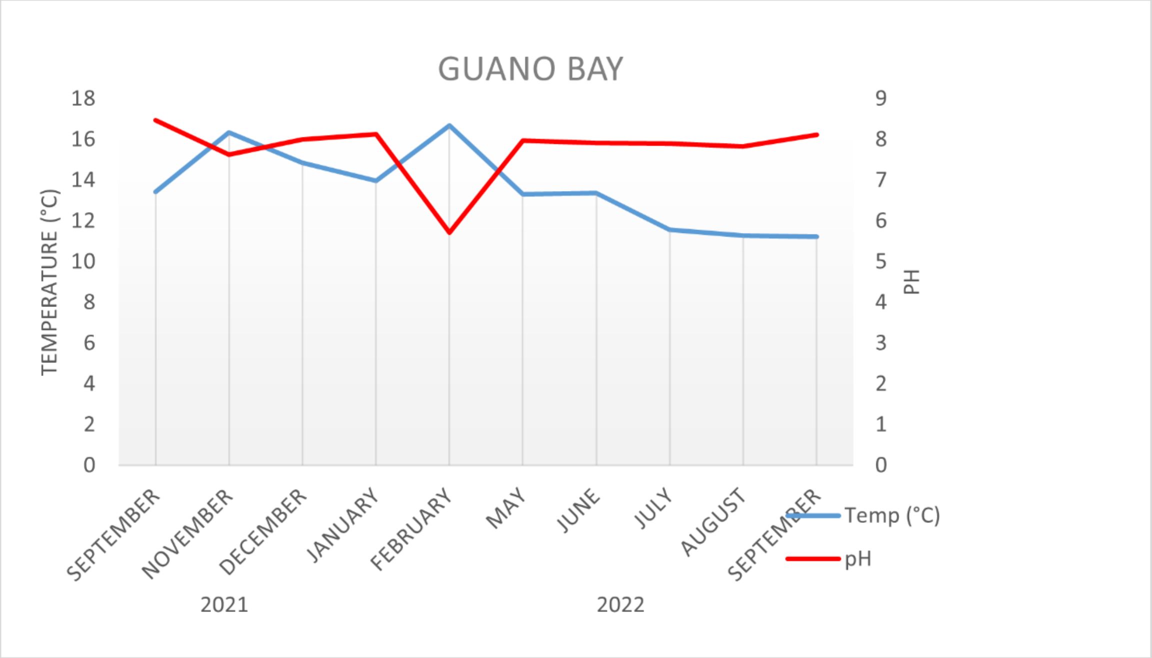


Figure 4.15 shows the seasonal variations of temperature and pH at Guano Bay.

The pH value and pattern observed at Guano Bay were consistent with those measured at Grossebucht. This showed that the geochemical parameters at these sites are closely related throughout the Lüderitz area.

A further seasonal variability comparison of pH and DO at Cultivation site and Grossebucht (control) showed that higher amount of pH and D.O were observed during the peak of the upwelling which is Q4 and Q3 whereas the lowest during Q2 and Q1 respectively (Figure 4.16).

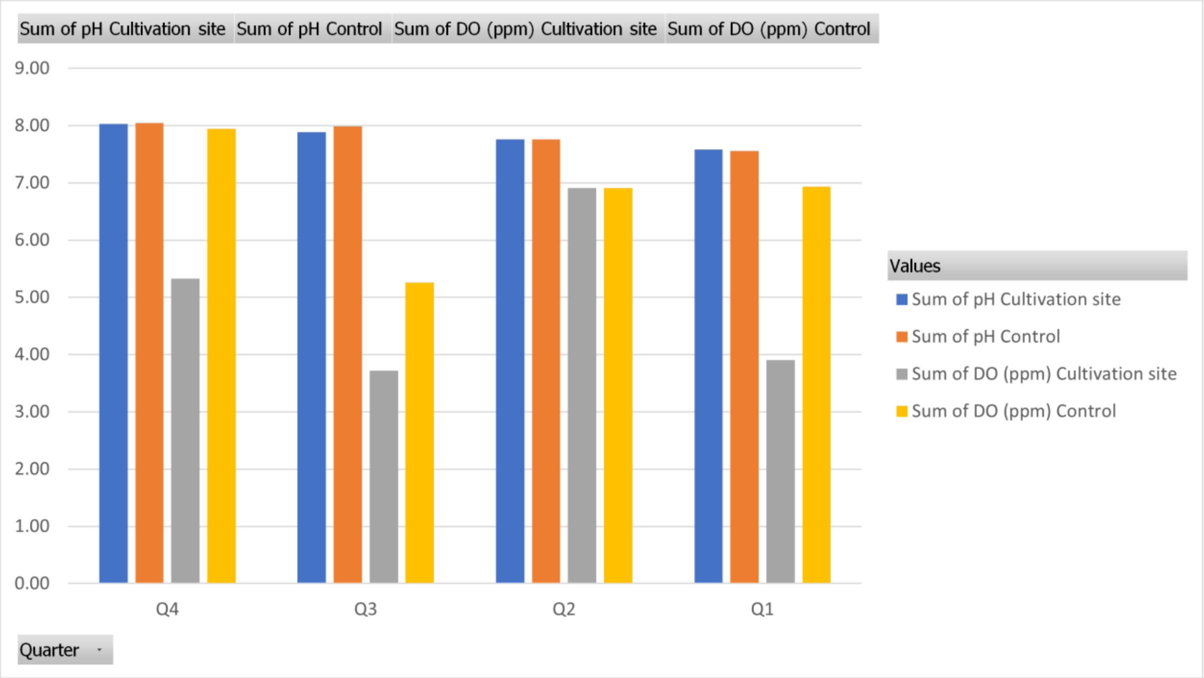


Figure 4.16 shows the seasonality trends of pH and D.O at both the Pilot (Cultivation site) and Grossebucht (Control site), during this season the higher amount of pH and D.O were observed during the peak of the upwelling which is Q4 and Q3 whereas the lowest during Q2 and Q1 respectively.

The upwelling of cold, deep waters to the surface led to a significant drop in sea surface temperatures in the areas where ocean water was monitored. This phenomenon is known as the central Benguela upwelling system (Lüderitz active upwelling cell) at the study location. Cold water from the subsurface is rich in nutrients, and when it rises to the surface, it brings these nutrients to the photic zone, promoting high biological productivity. As a result, the surface waters of the Benguela upwelling system are generally cooler compared to the surrounding ocean regions (Lett et al., 2007; Morgan et al., 2019; Pitcher et al., 2021; Reeder et al., 2022; Wasmund et al., 2016).

The upwelling of deep, cold waters also has an impact on pH in the Benguela system. Cold waters tend to have higher dissolved oxygen levels because cold water can hold more dissolved gases (Duarte et al., 2017; Hoshijima & Hofmann, 2019; Panassa et al., 2018; Sondak et al., 2017). The increased dissolved oxygen in the upwelled waters promotes biological respiration and the consumption of carbon dioxide (CO_2) by marine organisms (Saderne, Fusi, Thomson, Dunne, Pelembe, et al., 2020). As CO_2 is removed from the water during respiration, the concentration of carbonic acid (H_2CO_3) decreases, leading to a rise in pH and this is what will contribute highly to the growth of the kelp cultivation and leading to the thriving of the kelp forest.

4.2 Nutrient results

Nutrient measurement plays a vital role in influencing carbon sequestration in aquatic ecosystems, this study showed that the amount of nitrites and phosphate were widely distributed within the sampling areas (Table 4.2). From the results the biggest driver to the variation in nutrients, was the cycling of the nutrients periodically as well as the upwelling season (Bristow et al., 2017; Bullen et al., 2021; Elliott Smith et al., 2018; Weinstock et al., 2022) (Figure 4.17).

Table 4.2 shows the average nutrient distribution of the monitoring areas.

SITE	**LAT**	**LONG**	**DEPTH**	**Phosphate (PO_4^{3-}) [ppm]**	**Nitrite [ppm]**	**Phosphate [µM]**	**Nitrite [µM]**
Boot Bay	-26.45	15.10	1	0.38	0.13	4.02	2.88
Boot Bay	-26.45	15.10	15	0.40	0.05	4.18	1.07
Boot Bay	-26.45	15.10	30	0.33	0.05	3.42	1.16
Pilot	-26.48663	15.06	1	0.31	0.08	3.23	1.78

Pilot	-26.48663	15.06	15	0.37	0.08	3.85	1.60
Pilot	-26.48663	15.06	30	0.33	0.08	3.45	1.64
DF Rocks	-26.50111	15.11833	1	0.28	0.06	2.91	1.41
DF Rocks	-26.50111	15.11833	15	0.39	0.08	4.08	1.70
DF Rocks	-26.50111	15.11833	30	0.43	0.08	4.48	1.64
Halifax	-26.64889	15.08111	1	0.34	0.04	3.60	0.87
Halifax	-26.64889	15.08111	5	0.37	0.04	3.86	0.78
Grossebucht	-26.74139	15.09472	1	0.33	0.07	3.45	1.44
Guano	-26.65376	15.08277	1	0.34	0.06	3.63	1.34
Boot Bay Coastal	-26.4575	15.11778	1	0.23	0.02	0.50	2.46
DF Rocks Coastal	-26.5	15.13861	1	0.30	0.04	0.80	2.36
Pilot Coastal	-26.45861	15.11361	1	0.21	0.04	0.83	2.17

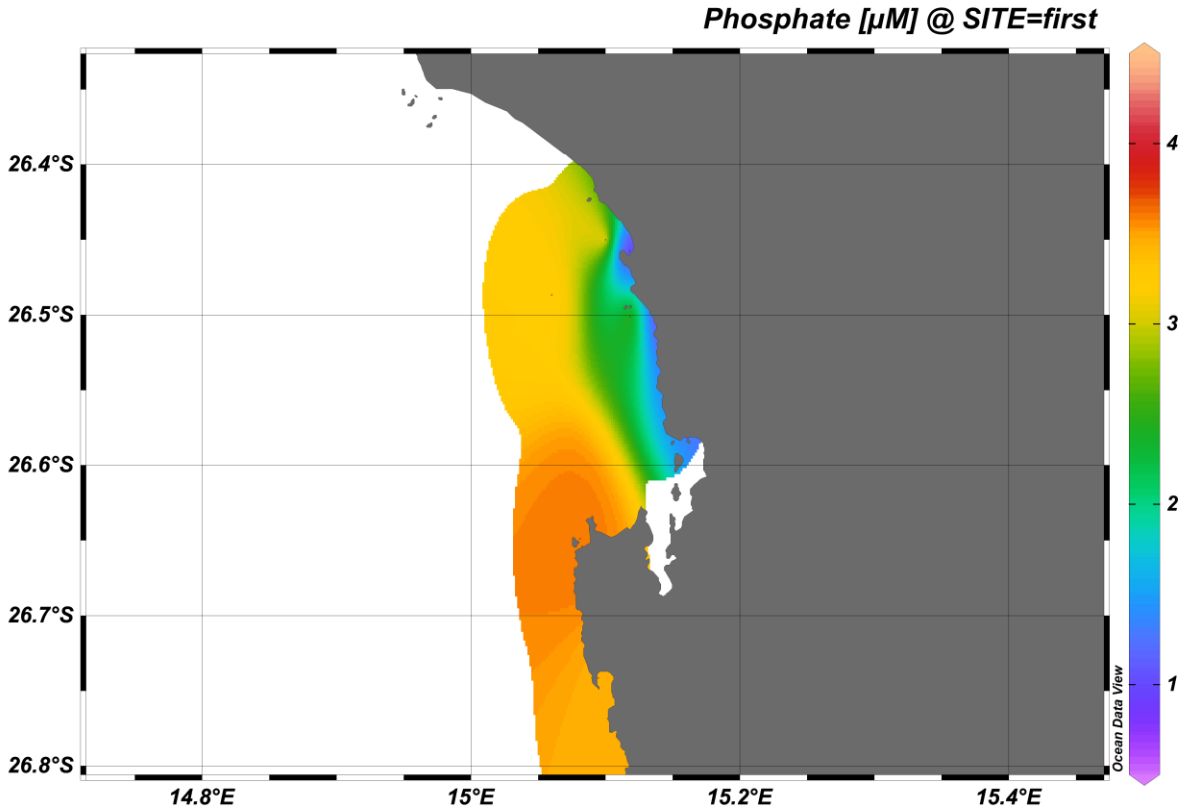


Figure 4.17 shows the phosphate variation, where higher concentrations of phosphates were in the southern part of Lüderitz.

The phosphate concentration were higher at locations far from the shorelines (Figure 4.17) Also, sites that were closer to islands had the highest phosphate levels; and this can be attributed to the guano in these islands (Schnug et al., 2018; Swart, 1988).

Guano serves as a natural source of phosphorus in the form of phosphate, enriching coastal waters and supporting marine productivity. The relationship between guano and phosphate concentrations plays a vital role in shaping marine ecosystems and the biodiversity found in coastal regions. Guano refers to the accumulated excrement of seabirds and bats, and it is known to be rich in nutrients, particularly phosphorus. The phosphorus in guano comes from the diets of seabirds, which consist of fish and other marine organisms. These marine organisms accumulate phosphorus in their bodies from the marine food web. When seabirds consume these organisms, they assimilate the phosphorus, and it gets concentrated in their excrement (guano). When guano is deposited on islands or coastal areas, it undergoes decomposition (Gagnon et al., 2013; Shatova et al., 2016). During this process, the organic matter in guano breaks down, and phosphorus is released into the surrounding environment in the form of phosphate ions (PO_4^{3-}) (Figure 4.18). This process is known as mineralization, where organic phosphorus is converted into inorganic phosphate, making it available for use by marine plants (phytoplankton) and other organisms (Giurgiu et al., 2013; Lucassen et al., 2017; Rodrigues & Micael, 2021; Sokol et al., 2022).

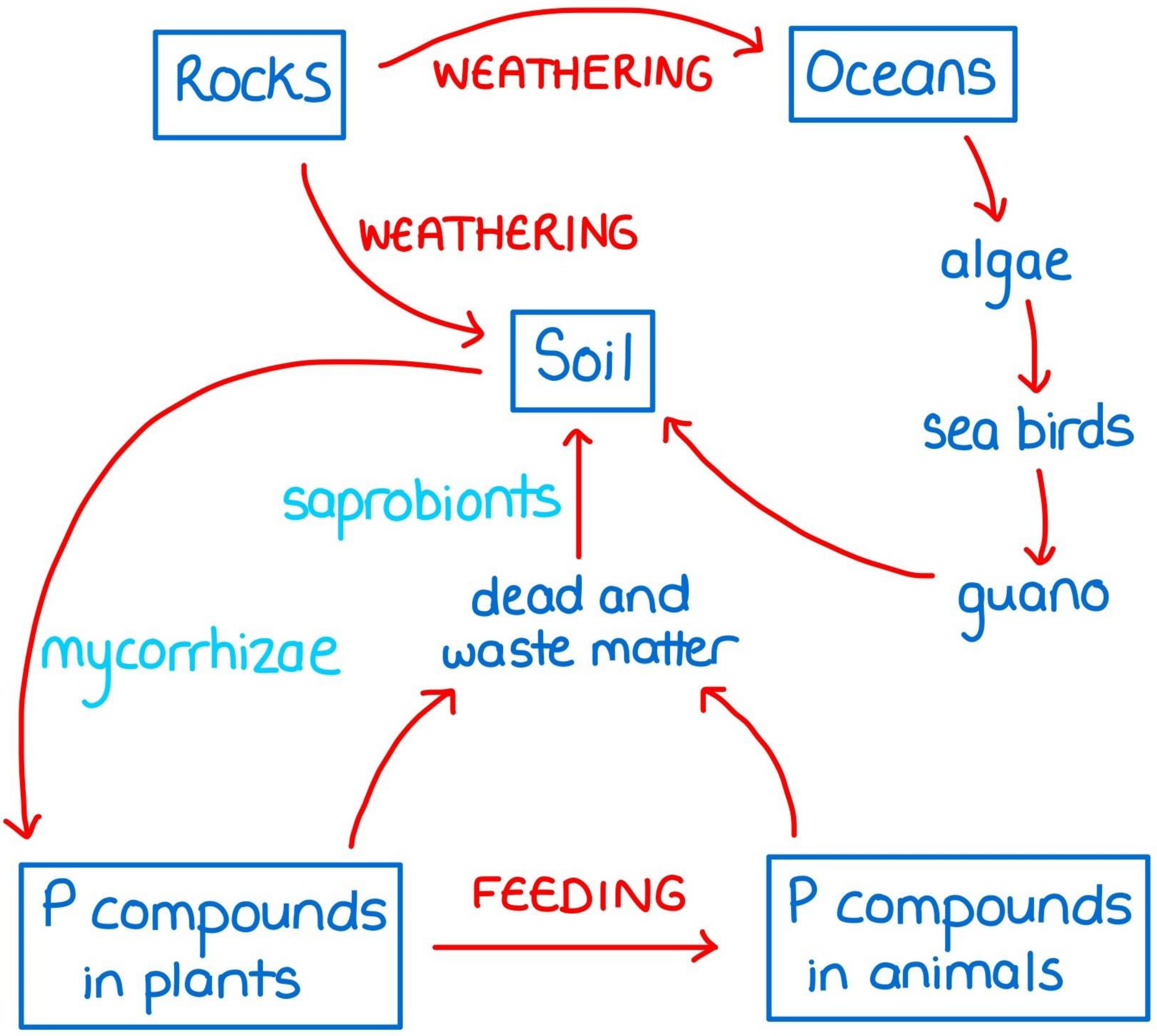


Figure 4.18 shows the phosphorus cycle including how the guano influences the amount of phosphorus in the ocean, soil and geologic rocks. *https://www.google.com.na/imgres?imgurl=https%3A%2F%2Fi0.wp.com%2Fzhtutorials.com%2Fwp-content%2Fuploads%2F2022%2F07%2FThe-phosphorus-cycle.jpg%3Ffit%3D1670%252C1669%26ssl%3D1&tbnid=dl-sT366Su3vRM&vet=12ahUKEwidzvvb3LiAAxVvmScCHbQrChEQMygIegQIARBD..i&imgrefurl=https%3A%2F%2Fzhtutorials.com%2F2022%2F07%2F16%2Fthe-phosphorus-cycle%2F&docid=3tKS2XvoG8EtIM&w=1670&h=1669&q=article%20phosphate%20decomposition%20of%20guanos%20ocean&ved=2ahUKEwidzvvb3LiAAxVvmScCHbQrChEQMygIegQIARBD*. *(Accessed on 31072023).*

The release of phosphate from guano can have a significant impact on marine productivity in the surrounding waters. Phosphate is a crucial nutrient for marine plants, which are primary producers at the base of the marine food web. Increased phosphate concentrations can lead to the stimulation of phytoplankton growth and subsequently support higher trophic levels in the ecosystem which will play a great role in the cultivation of kelp in the Lüderitz area as there won't be any competition of nutrients (Aoyama et al., 2010; Aumont et al., 2016; Schnug et al., 2018; Tyrrell & Lucas, 2002).

According to literature the amount of phosphate required for *M.pyrifera* to survive and flourish is around 1µM and the all the water samples collected have shown the concentration of phosphate at all the sites were above 1 µM (Schiel & Foster, 2015) (Table 4.2).

Nevertheless, the coastal area in the northern monitoring site exhibited lower phosphate concentrations compared to the offshore sites. This phenomenon can be linked to findings from previous studies that have demonstrated a decrease in nutrient levels as one moves further north of the Benguela Upwelling System (BUS) (Flynn et al., 2020; Reeder et al., 2022; Rixen et al., 2021). Moving down south of the monitoring stations it was observed to be opposite. This is correlated with the data collected from the Copernicus satellite dataset (Figures 4.19-4.20).

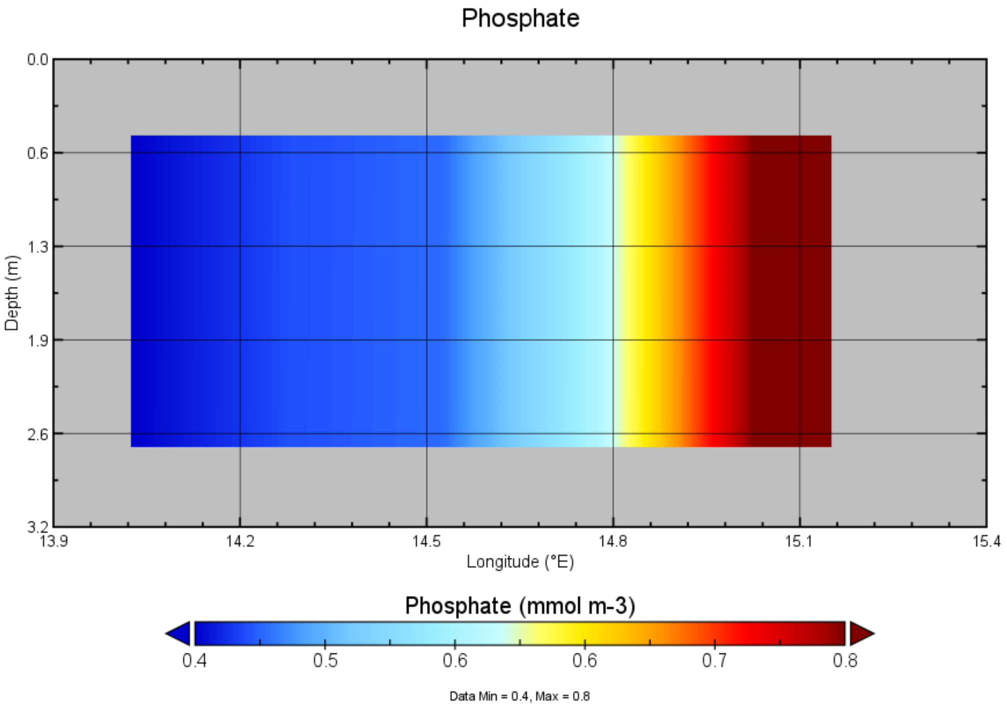
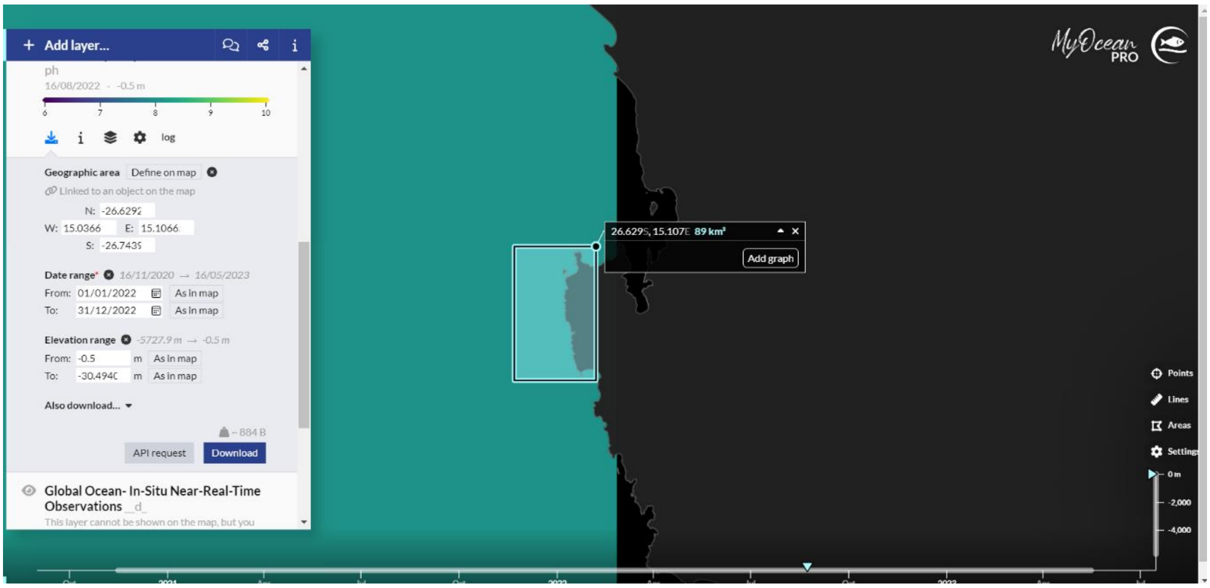


Figure 4.19 shows the satellite data of the southern monitoring sites where higher amount of phosphate concentration (~0.8 mmol/L) nearshore.



ph
16/08/2022 · -0.5 m

Geographic area
N: -26.6292
W: 15.0366
E: 15.1066
S: -26.7439

Date range* 16/11/2020 → 16/05/2023
From: 01/01/2022
To: 31/12/2022

Elevation range -5727.9 m → -0.5 m
From: -0.5 m
To: -30.4940 m

~ 884 B

Global Ocean- In-Situ Near-Real-Time Observations _d_
This layer cannot be shown on the map, but you

26.629S, 15.107E 89 km²

Figure 4.20 shows the southern monitoring sites where the satellite data (above) were collected to ground truth the in-situ measurements.

Satellite observations provide valuable insights into the geochemical baseline of the ocean by capturing large-scale patterns and temporal variations in key biogeochemical parameters which can be used to ground truth the in-situ measurement that was taken (Figure 4.20) (Darnley et al., 1995; Papenfus et al., 2020; Queißer et al., 2019).

During this study, an open access satellite data from the Copernicus Marine Environment Monitoring Services (CMEMS) were obtained where various spatial-temporal geochemical data were retrieved in NetCDF (network Common Data Form) file and later converted into csv (comma-separated values) file using Panoply software and MATLAB (Matrix Laboratory) a programming language.

Nitrite concentration levels were recorded higher in the northern area compared to the southern area (Figure 4.21; Table 4.3).

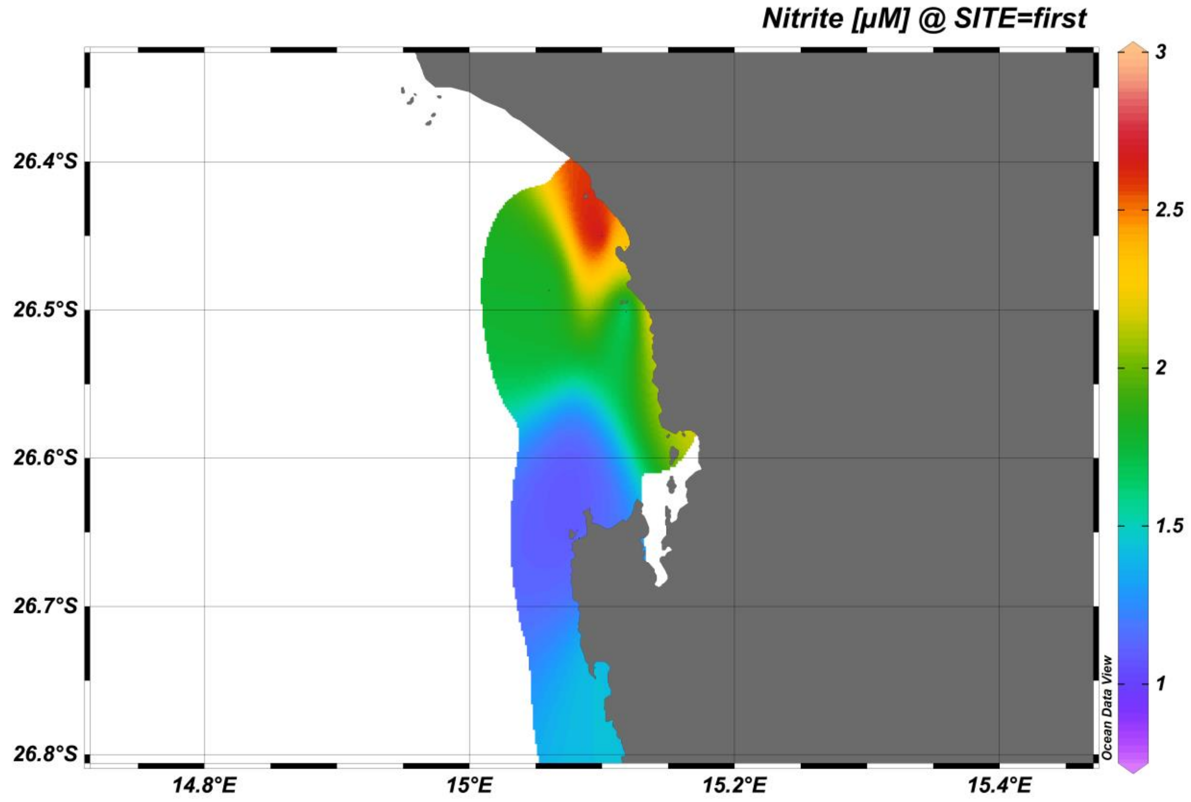


Figure 4.21 shows the distribution of nitrite concentrations at the different monitoring sites.

The nutrients analysed showed an increase in the amount of phosphates, nitrites, and other nutrients (Table 4.2) in the months of October 2022. This can may be due to the predominant upwelling season that is driven by the higher wind speed from the continental margin into the ocean margin (Field et al., 1998; Flynn et al., 2020; Patey et al., 2008; Smith et al., 2022).

Table 4.3 shows the wind data collected from the Diaz lighthouse in Lüderitz.

Dias Point Campbell weather station data - MFMR, Lüderitz					
2022 MONTH	Hourly averages				
	Wind Speed m/s	Wind DIR °	BP mbar	Air TC	RH
JANUARY	8.170	205.29	1009.9	18.5	83.8
FEBRUARY	7.941	202.96	1009.6	18.7	83.9
MARCH	8.310	200.04	1009.9	17.4	85.3
APRIL	8.129	193.26	1011.9	16.2	77.8
MAY	6.163	182.78	1016.2	15.2	77.0
JUNE	5.684	159.30	1016.9	18.1	59.3
JULY	6.640	196.22	1017.0	15.0	77.5

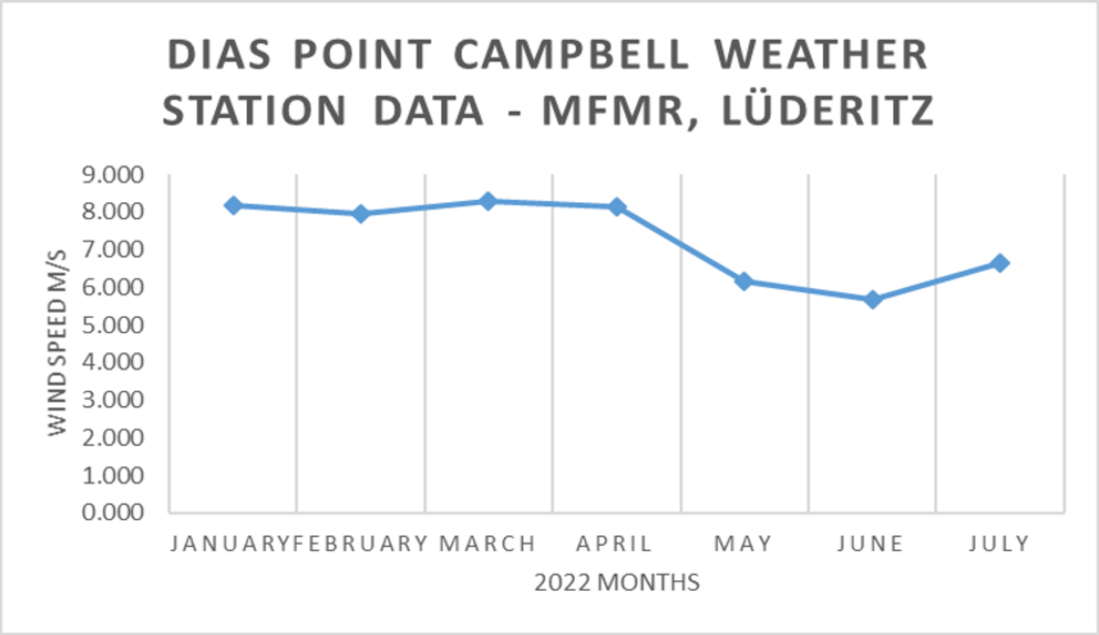


Figure 4.22 shows the graph depicting the average wind speed for the year 2022, which was recorded hourly by the MFMR meteorological station.

Stronger and predominantly wind speed was observed during the season of October to February, this is when the upwelling is at its peak season (Table 4.3; Figure 4.22).

The seasonality of the nutrients at the Pilot (Cultivation site) and one of the control sites was observed which continued to prove that the increase in nutrient concentrations were contributed by the dominant upwellings caused the strong wind season as shown in Figures 4.23 and 4.24 below.

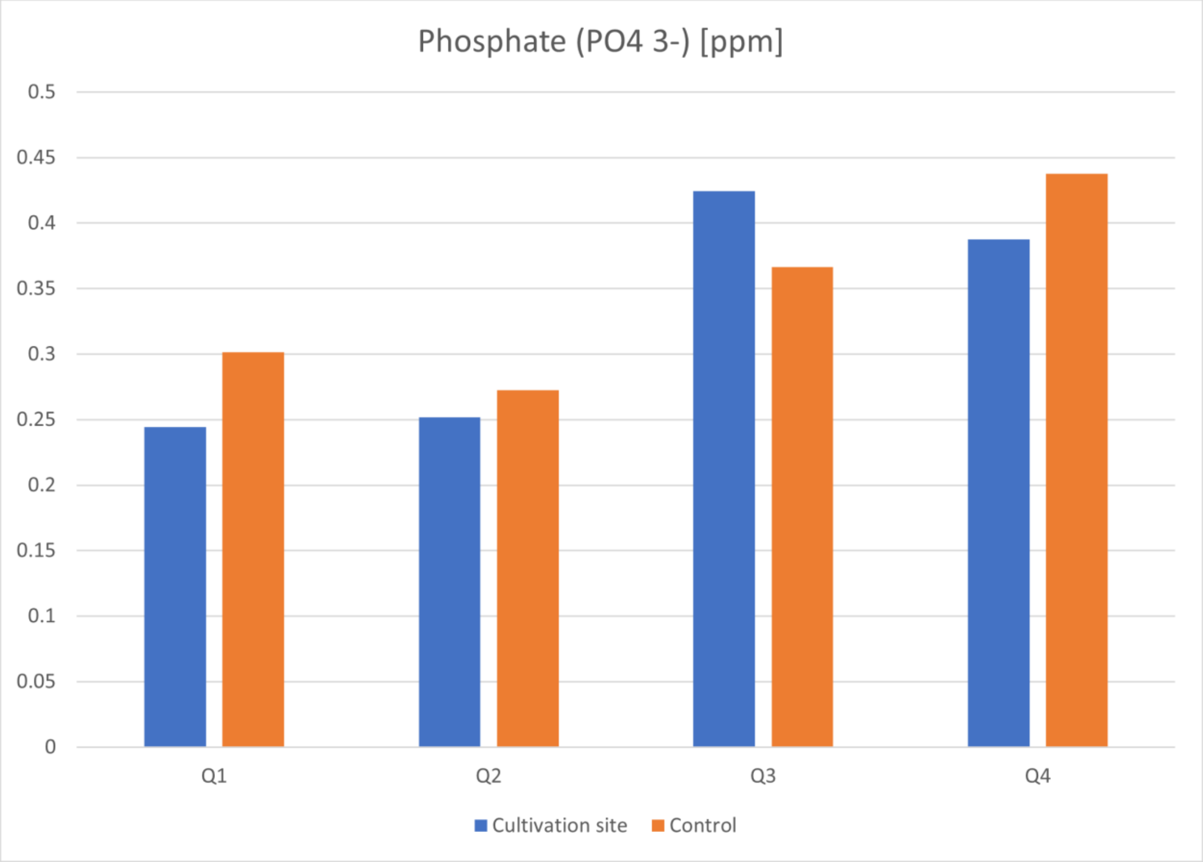


Figure 4.23 shows the seasonal variation of phosphates at Pilot (Cultivation) and Grossebucht (Control). Higher concentrations of phosphate were observed during Q3 and Q4, respectively. Grossebucht also showed a higher amount of phosphate due to the closeness to the shore (coastal).

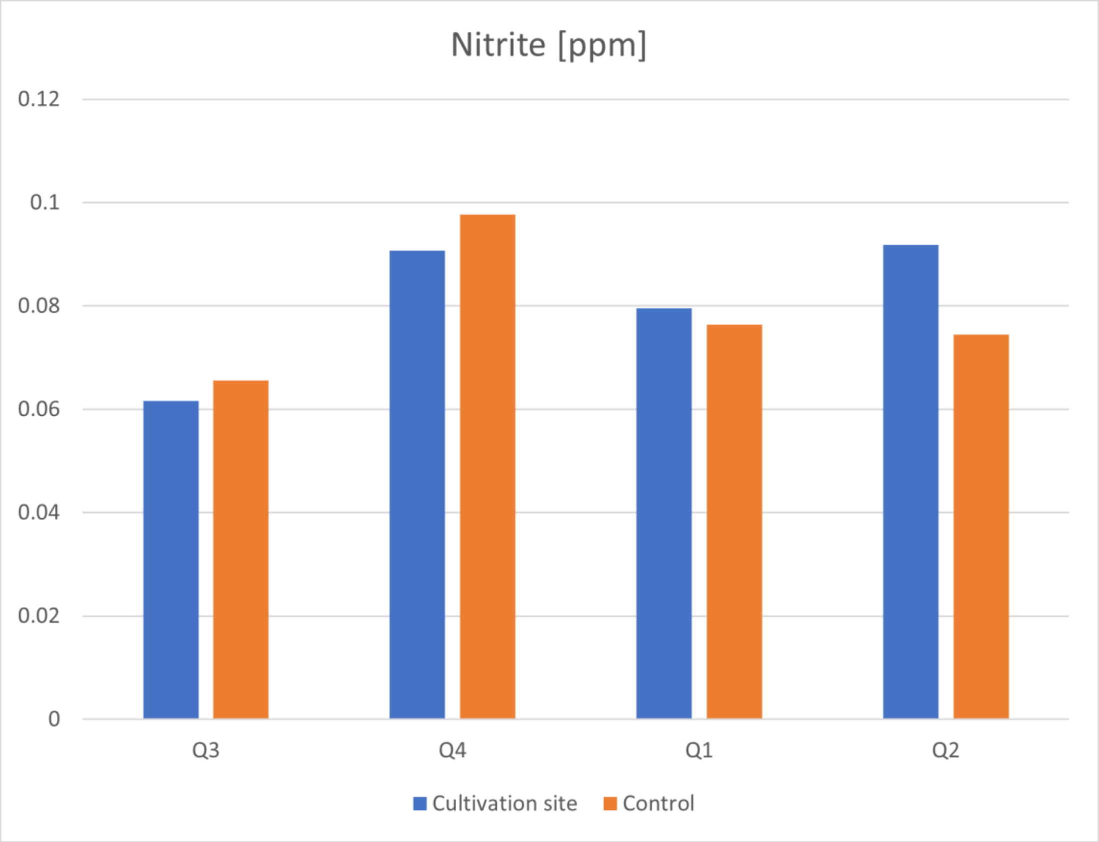


Figure 4.24 shows the seasonal variation of nitrites at Pilot (Cultivation) and Grossebucht (Control). Higher concentrations of nitrites were observed during the Q4 season. Grossebucht also showed higher amount of nitrites due to the closeness to the shore (Bristow et al., 2017).

Nutrients such as phosphate and nitrites play a major role in carbon sequestration, these nutrients are often limited in certain regions of the ocean. When these limiting nutrients are supplied to phytoplankton-rich areas, such as through upwelling or nutrient runoff from land, it leads to a phenomenon known as "nutrient fertilization" or "nutrient loading (Zhang et al., 2022). The availability of sufficient nutrients enhances the growth and productivity of the kelp forest. As the kelp forest photosynthesize, they take up CO_2 from the surrounding seawater to build their organic matter. This process effectively removes CO_2 from the atmosphere and incorporates it into the living cells of these giant kelp. When the kelp detaches from or phytoplankton die, or are consumed by zooplankton and other marine organisms, a portion of the organic matter sinks to the deeper ocean layers. The carbon-rich particles sinking into the deeper ocean carry the captured CO_2 away from the atmosphere, effectively sequestering it in the deep ocean for extended periods.

4.3 Titration results

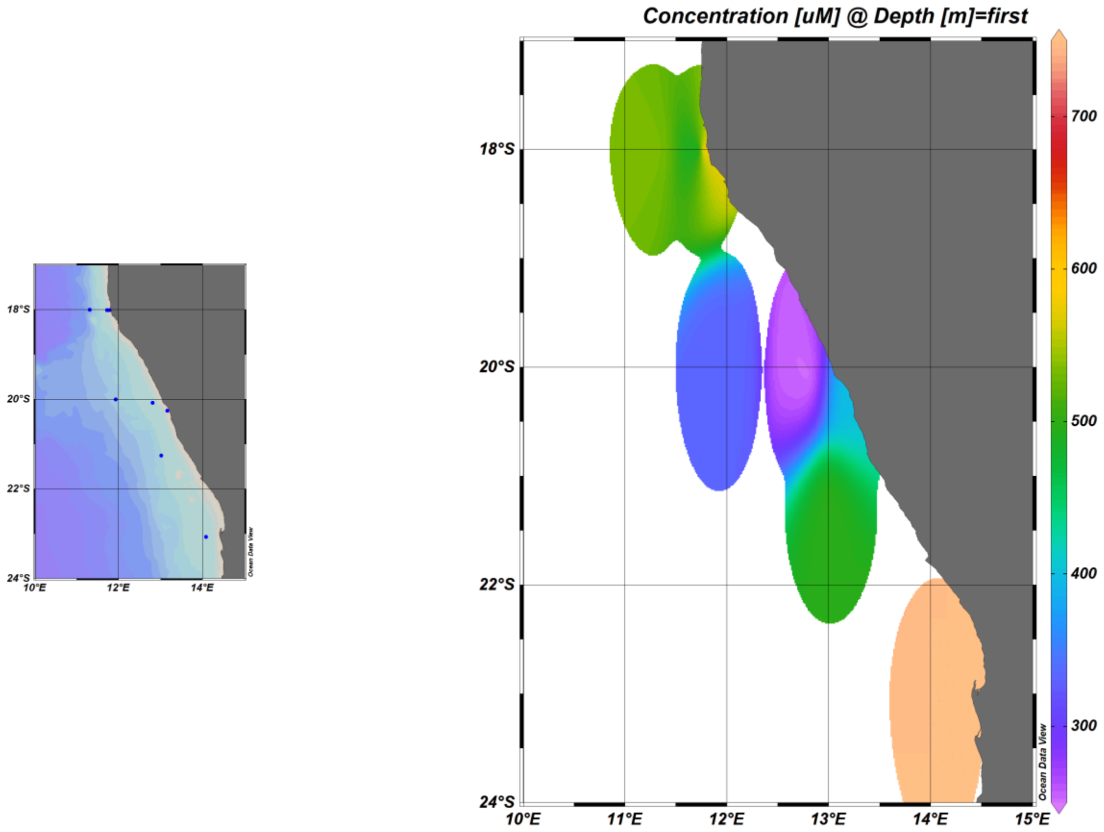


Figure 4.25 shows the concentration of variability for CO_2 determination for the sampling done on RV Mirabilis vessel during the study period.

The concentration of CO_2 consumption reduced the further north (Figure 4.25). The Northern Benguela is known for having high number carbon depocenters in the northern (Tyrrell & Lucas, 2002; Van Der Plas et al., 2007).

The concentration of CO_2 increased closer to the shore than offshore sites, mainly because of the potential of water and sediment remineralization at the intertidal zones (Elliott Smith et al., 2018; Lin et al., 2018).

This trend was also corroborated with satellite data, with alkalinity was higher at coastal zones and at the peak of the upwelling system (August to December months).

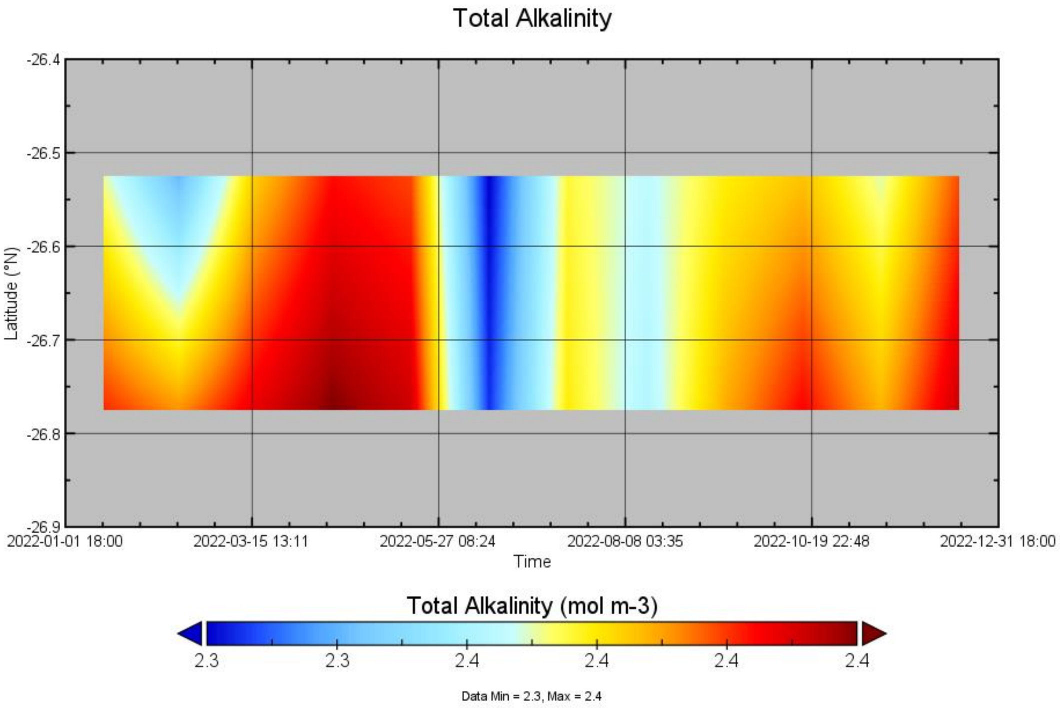


Figure 4.26 shows the total alkalinity in global analysis forecast in the Lüderitz area. From the trends, the total alkalinity fluctuated throughout the season, but higher peaks could be spotted during the upwelling season.

Alkalinity and CO_2 consumption acts as a crucial regulator in the carbon cycle of the ocean by helping to maintain the seawater's pH within a range suitable for marine life. It allows the ocean to effectively take up and release CO_2 while minimizing large swings in seawater acidity that could have detrimental effects on marine organisms.

The results from Pilot shows that the farm will show a pathway on how the kelp detritus will be moved and deposited to the depocenters where the CO_2 is expected increase further north.

4.5 Sediment results

Table 4.4 shows the sediment samples sent for analysis, identity of samples and size:

Sample No.	Sample Identity	Sample mass (g)	Sample type
1	20020-degree line	26	Core
2	Halifax	224	Grab
3	23020-degree line	64	Core
4	Pilot	70	Grab
5	Boot Bay	345	Grab

4.5.1 XRF results

From table 4.4:

Sample No. 1: The results before LOI show a concentration of calcium which was 5.57% and iron of 0.86%, while magnesium is below the detection limit of the portable XRF instrument. However, after LOI the sample contains calcium of 9.82%, iron of 1.44%, while magnesium is below the detection limit of the portable XRF instrument.

Sample No. 2: The results before LOI show a concentration of calcium which is 0.65% and iron of 0.62%, while magnesium is below the detection limit of the portable XRF instrument. However, after LOI the sample contains calcium of 2.16%, iron of 1.40%, while magnesium is below the detection limit of the portable XRF instrument.

Sample No. 3: The results before LOI show a concentration of Iron which is 3.02% and calcium of 1.95%, and magnesium is below the detection limit of the portable XRF instrument.

However, after LOI the samples contains iron of 4.17%, calcium of 3.16%, and magnesium of 1.73%.

Sample No. 4: The results before LOI show a concentration of calcium which is 1.94% and iron of 0.79%, while magnesium is below the detection limit of the portable XRF instrument. However, after LOI the samples contains calcium of 4.18%, iron of 1.84%, and magnesium of 0.98%.

Sample No. 5: The results before LOI show a concentration of iron which is 0.94% and calcium of 0.92%, while magnesium is below the detection limit of the portable XRF instrument. However, after LOI the samples contains iron of 1.04%, calcium of 1.66%, and magnesium of 0.49%.

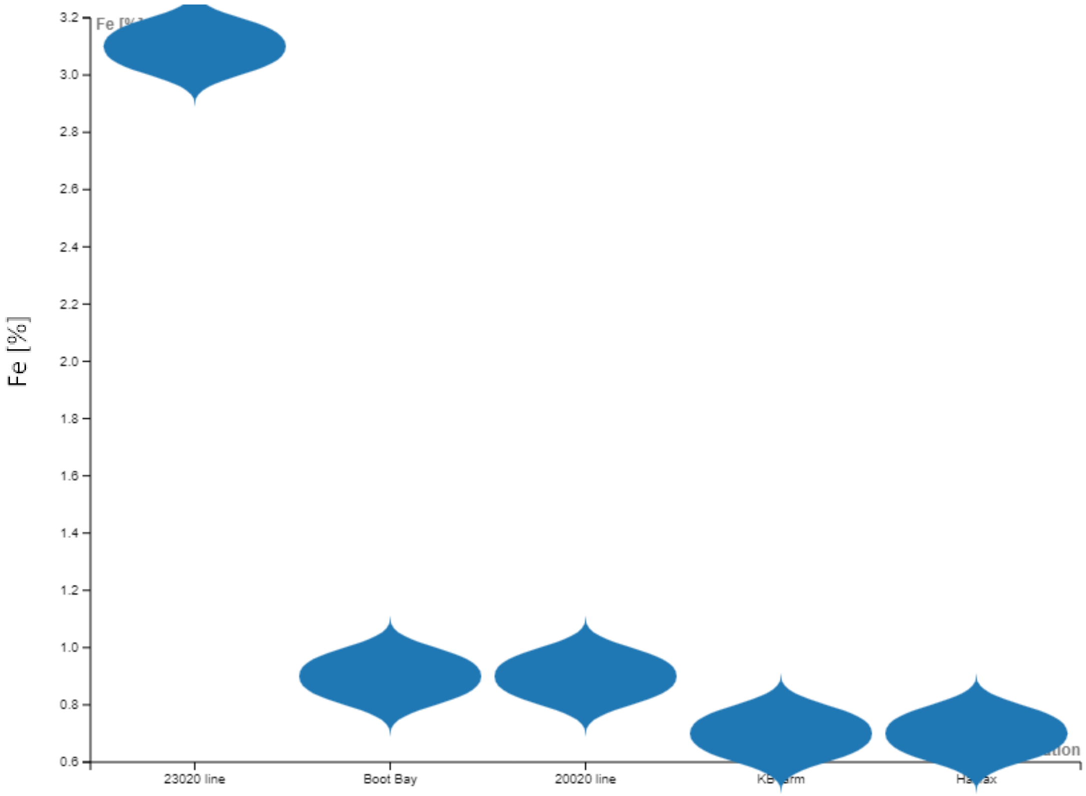


Figure 4.27 shows the violin graph of Iron (Fe) for different sample identity.

With 23020 degree line having the highest Fe, 23020 was 20 nautical miles away from the port of Walvis Bay the high content of Fe can be due to the harbour and other anthropogenic activities at the area (Figure 4.27) (Kangueehi, 2021; Kaonga et al., 2021).

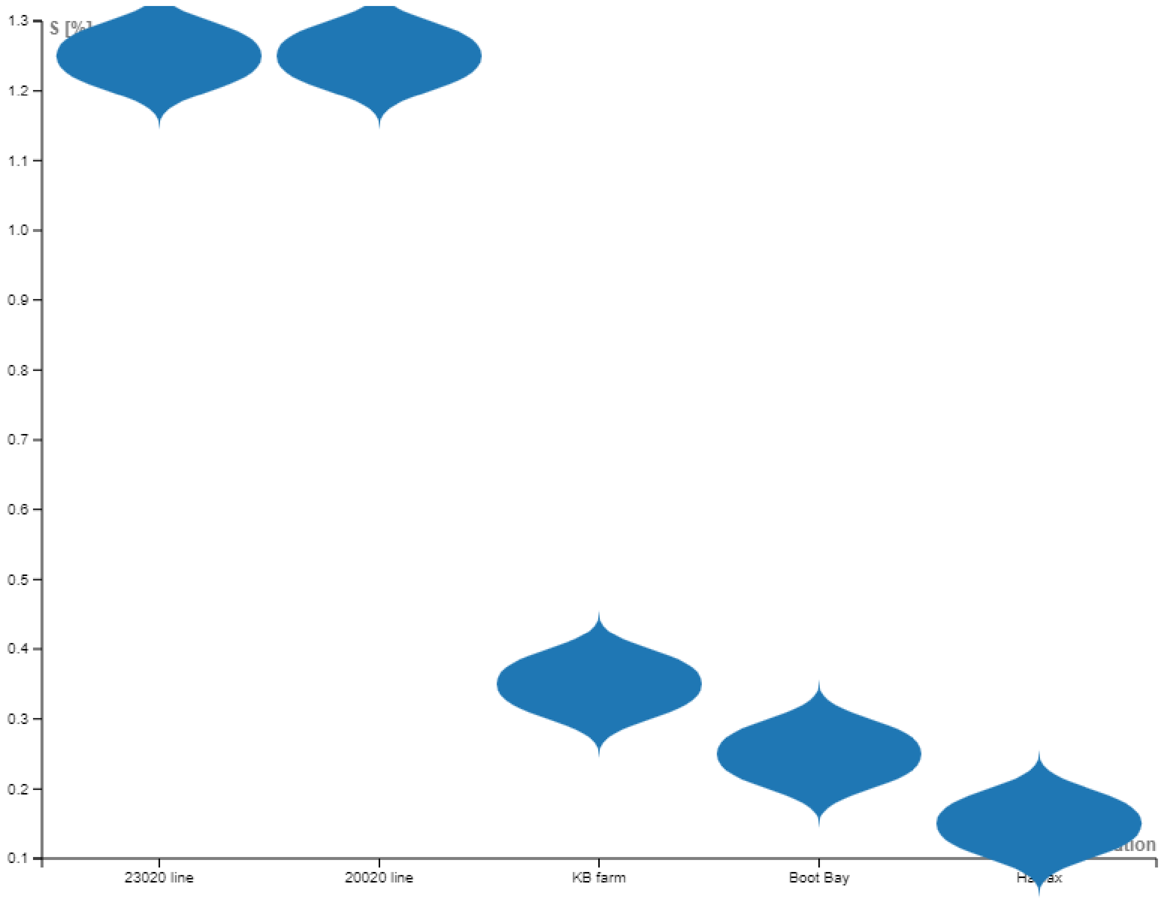


Figure 4.28 shows the violin graph of Sulphur (S) at the different sampling site.

With 23020 and 20020 had the highest level of S this is due to the common sulphur eruptions that occurs in the northern part of BUS which eventually affect the geochemistry, there is small amount of sulphur in the Lüderitz area (Figure 4.28-4.29) (Hutchings et al., 2009; Ohde & Dadou, 2018; Van Der Plas et al., 2007).

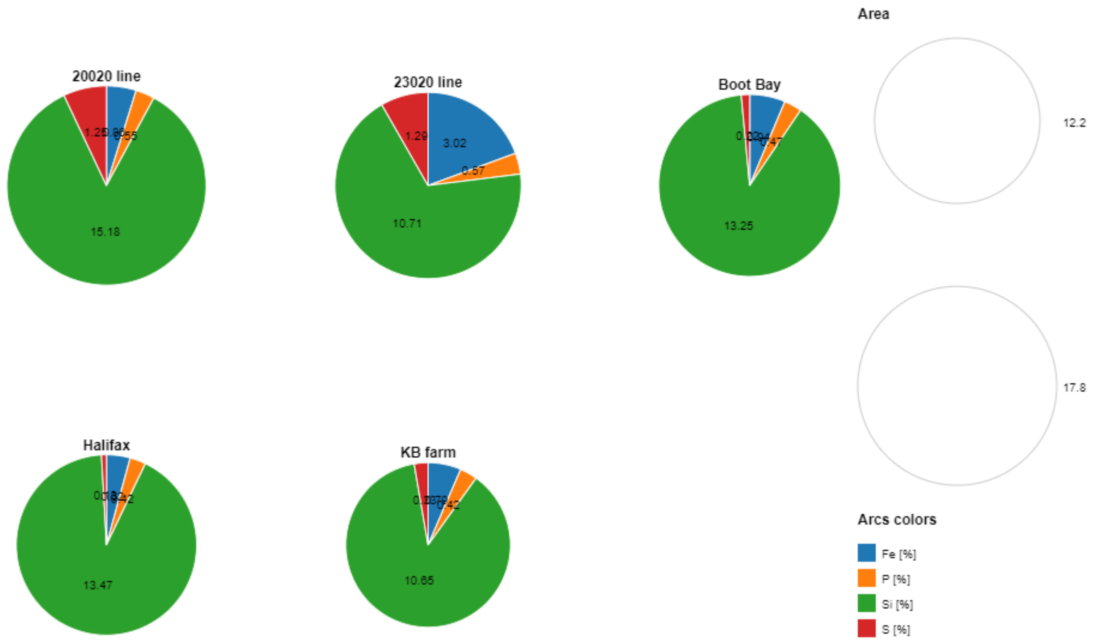


Figure 4.29 show the pie charts of the metal ions distribution at different sample site.

4.5.2 LOI results:

Calculation see appendix:

The Loss on Ignition (LOI) method is of paramount importance in the field of carbon sequestration as it provides a valuable means to quantify the organic carbon content in various environmental matrices, such as soils, sediments, and biomass. By subjecting a sample to high temperatures, the LOI method measures the weight loss due to the combustion of organic matter, thereby estimating the carbon content. This method is crucial for assessing and monitoring carbon sequestration efforts, as it allows researchers and environmental scientists to determine the effectiveness of carbon storage in different ecosystems and land management practices. Accurate quantification of organic carbon sequestration is vital for understanding the impacts of climate change mitigation strategies and sustainable land use, ultimately contributing to informed decision-making for the preservation of our environment and the reduction of greenhouse gas emissions (Abshire et al., 2020; Aumont et al., 2016; Van Der Plas et al., 2007; Venancio et al., 2014).

During this study the sediment collected at the different sample locations (Table 4.4) showed that carbon rich sediments are located further north and higher grade of carbon rich sediments can be found in deeper ocean environments where there is high rate of deposition than erosion (Figure 4.30 and 4.31).

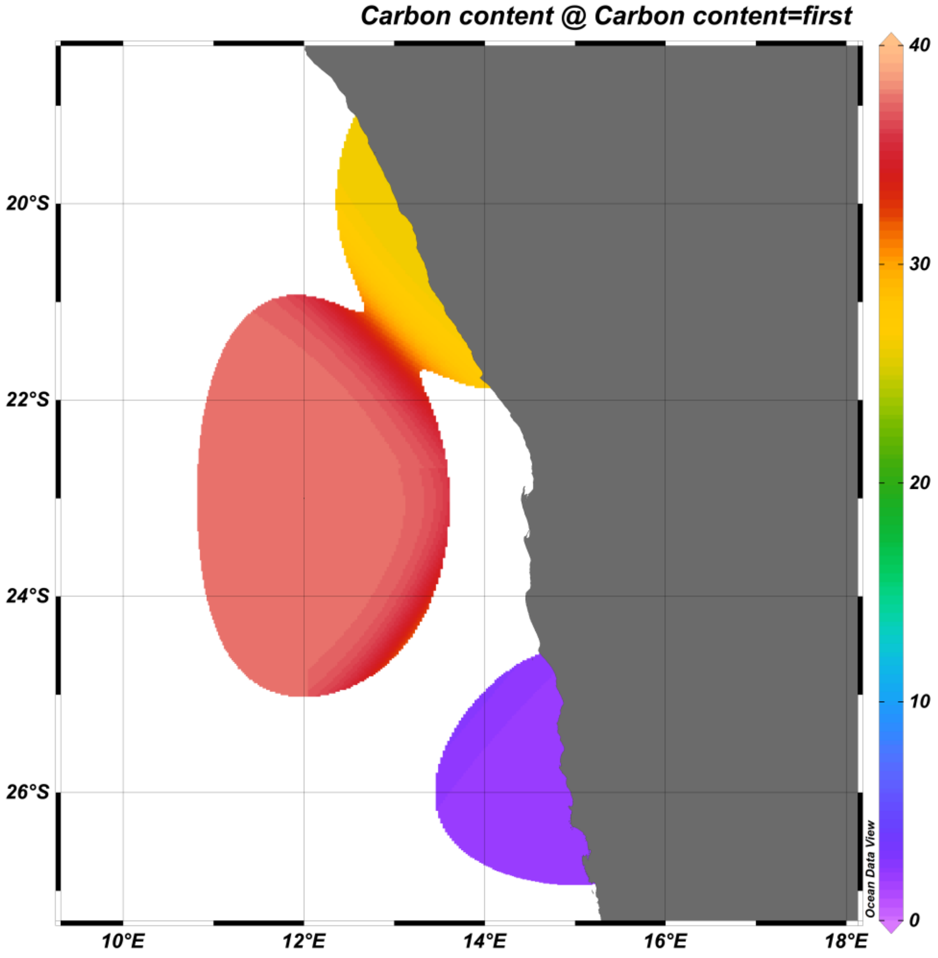


Figure 4.30 shows the sediment carbon moisture content at different sampling locations.

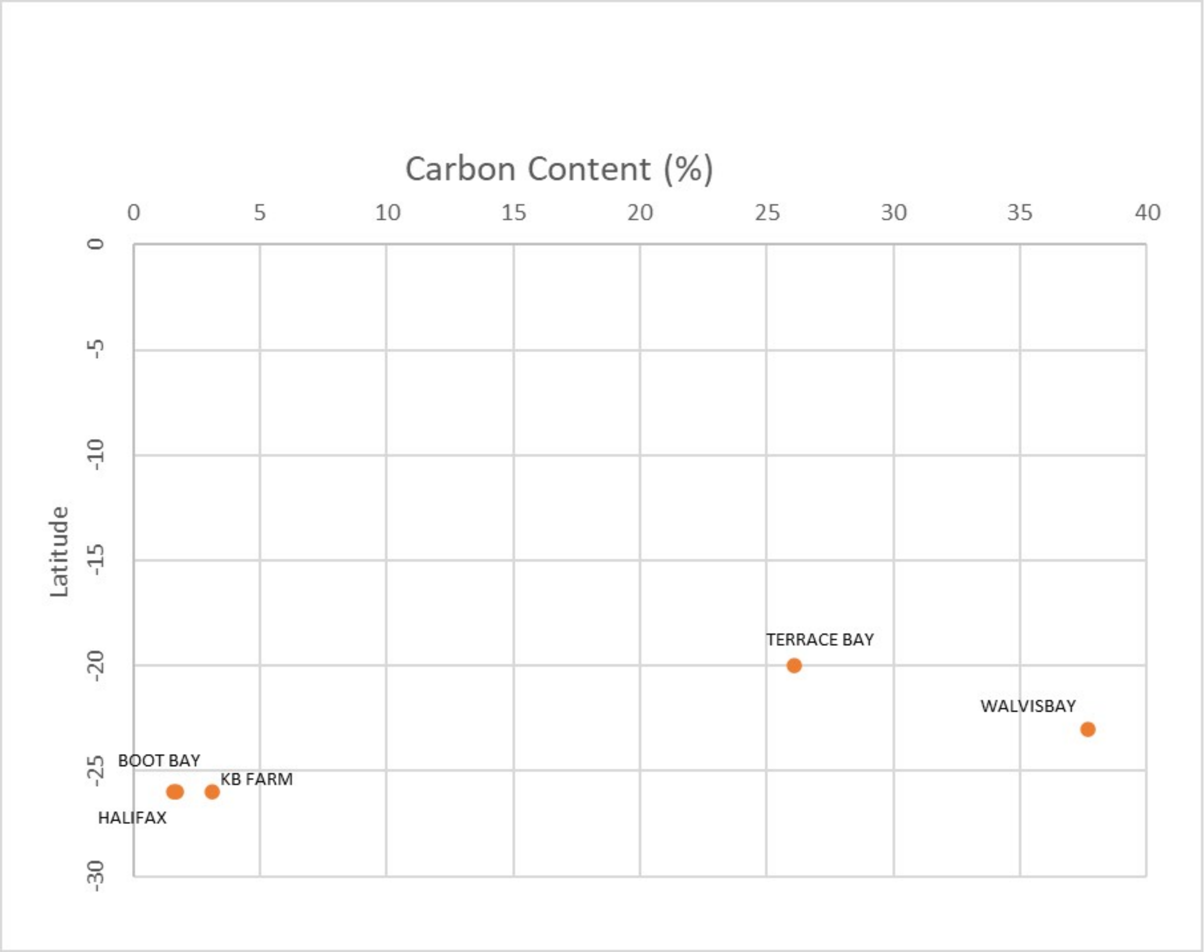


Figure 4.31 shows the sediment carbon content (%) at different sampling locations plotted on Excel.

This can be attributed to the studies that have shown the distribution of carbon rich depocenter within the Namibian coastal continental margin (Figure 4.32) (Paradis et al., 2019, 2023). The depocenter are location where organic rich sediment are deposited including sediment that has sequestered carbon into the deep ocean causing it to be locked in for centuries.

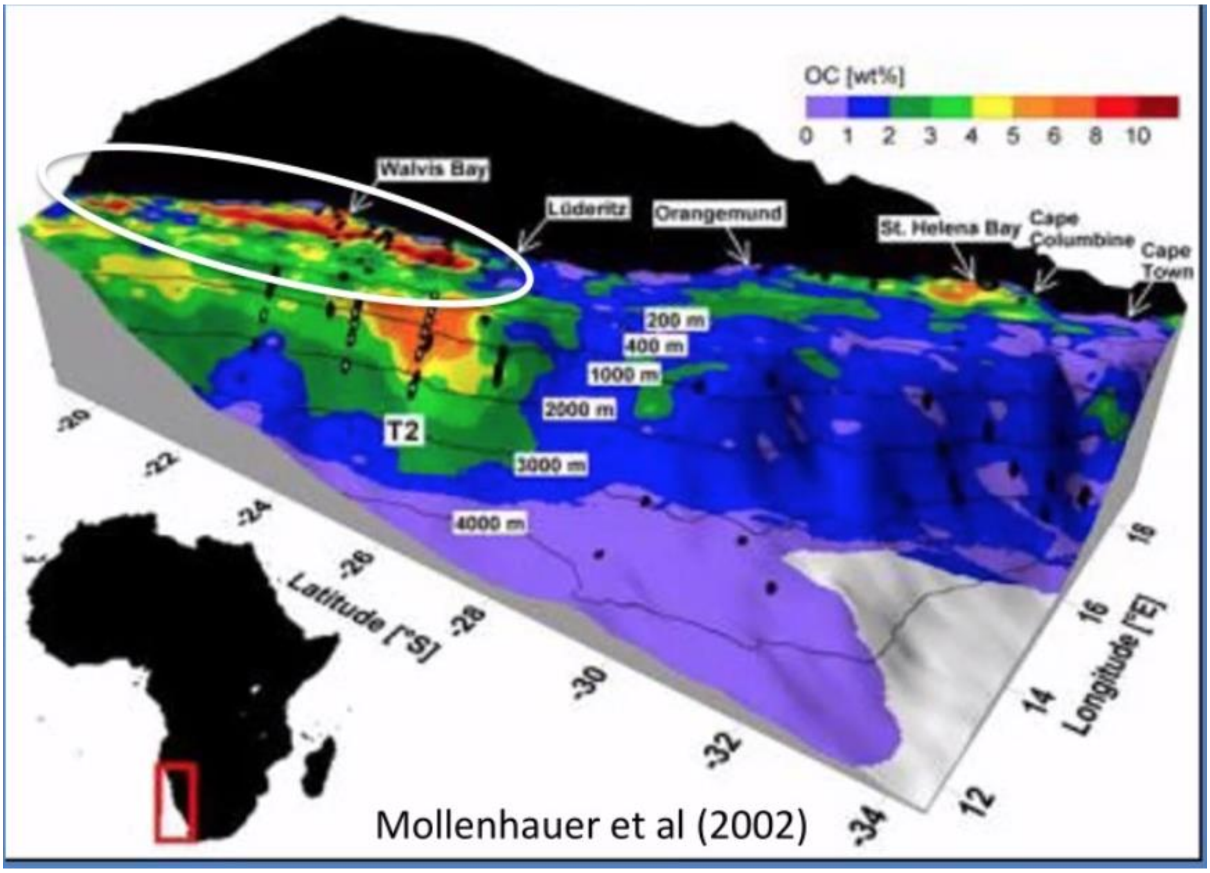


Figure 4.32 shows the location of organic rich depocenters (dark red bands). after Mollenhauer et al.2002. from Abshire et al., 2020.

This XRF and LOI results from the sediment results helps to identify the mineral composition and provide insights into the carbon content of materials as well as determining the weight loss resulting from the combustion of organic matter. LOI is particularly important for estimating the amount of carbon that can be sequestered in soil organic matter and other organic materials. Whereas XRF is valuable for understanding the chemical characteristics of the substrate in which carbon is being sequestered. By analysing the elemental composition, researchers can assess the suitability of a material for carbon sequestration, as well as any potential interactions between carbon and other elements (Bojko & Kabala, 2014; Grandgirard et al., 2002; Hoogsteen et al., 2018).

CHAPTER FIVE: CONCLUSIONS

The geochemical baseline of this study has shown that there is resemblance in the geochemical parameters at most sites. Higher temperature values recorded in the coastal areas showed how the coastal marine areas and biodiversity needs to be monitored, especially when growing kelp forests such as the *M. pyrifera* which is a type of kelp that thrives in the cold rich nutrient waters. If the giant kelp is to be grown in areas that has been exposed to these warm air water masses, a continuous and rigorous monitoring needs to be done. The Lüderitz upwelling cell is an area off the coast of Namibia where cold water from the depths of the ocean rises to the surface, creating a unique marine ecosystem. Studies have shown that the temperature variability in this area is influenced by a combination of factors, including wind patterns, ocean currents, and the movement of warm water from the Benguela Current. Overall, the temperature variability in the Lüderitz upwelling cell is relatively high, with water temperatures fluctuating by several degrees Celsius (between 6-15 °C) over the course of a year. This variability plays a significant role in shaping the local ecosystem and the organisms that live there.

Because of this productive upwelling system, the Kelp Blue project of cultivating and growing this giant kelp has a great potential to increase the level of oxygen at a large, monitored scale level when considering the seasonality changes.

The upwelling of cold, nutrient-rich water from the depths of the ocean leads to increased productivity and oxygen consumption by phytoplankton, resulting in low oxygen levels in the surface waters. However, as the water masses move away from the upwelling cell, oxygen levels begin to increase due to the respiration of phytoplankton and other organisms. Overall, the presence of the giant kelp farm in the Lüderitz upwelling cell will play an important role for marine life and plays a critical role in shaping the ocean's chemistry and ecology.

Seasonality plays a major role in the amount and distribution of the nutrients within the Lüderitz active upwelling cell which includes the Kelp Blue Pilot (KBP). KBP sits between the Southern Benguela Upwelling System (sBUS) and the Northern Benguela upwelling system (nBUS) which are predominantly areas where cold sub-thermocline waters are infused into the sea surface and at the same time, they bring nutrients to light and foster high primary productivity (Andrews & Hutchings, 1980). Because of the dynamic potential of these systems, the KBP is embalmed by a very high phytoplankton productivity which channels into a substantial portion of boosting economically exploited fish stocks and to due to the strong winds in the time frame of October to February/March these active upwelling cell gives a boost to the already productive zone. This has been observed by the high amounts of phosphates, nitrites and nitrates concentration of seawater sampled at the different sites in Lüderitz sampling sites including Pilot area from the existing data on phytoplankton, wind speed and geochemistry results.

Sediment results also showed that there was a lack of sulphur content in the marine sediments in the Lüderitz area which makes it a haven to grown giant kelp. From the results of the sediment analysis heavy metals and major ions can interact with carbon sequestration in various ways. Some of these interactions include heavy metals can act as catalysts for carbon sequestration where they accelerate the formation of carbonates, such as calcite and dolomite, which can absorb carbon dioxide from the atmosphere. They can also act as inhibitors for carbon sequestration by slowing down or preventing the formation of carbonates, which can decrease the rate of carbon sequestration. Major ions, such as calcium and magnesium, can act as important building blocks for carbonates. They can be used to create calcite and dolomite, which can absorb carbon dioxide from the atmosphere. Finally, major ions can also affect the pH of the water, which can impact the rate of carbon sequestration. High pH levels can promote the formation of carbonates, while low pH levels can inhibit the formation of carbonates.

CHAPTER SIX: RECOMMENDATIONS

This study created a baseline, the most important recommendation will be do a study on the impact giant kelp forests will pose on the ocean geochemistry now that a baseline is created.

There is a study currently being done by the University of Cambridge that is developing a Carbon Dioxide Removal (CDR) model that will use the results of this study to ground truth it and show where the high amount of carbon rich kelp detritus will be accumulating and eventually sequestered.

To quantify the amount of carbon these kelp forests have sequestered, a recommended approach will be in developing a sediment carbon baseline which will have synergies with the current baseline of this study. Best recommended approach on the carbon baseline will be to identify and ground truth the carbon depocenters and collect sediment cores at these spots and carbon reefs adjacent to the carbon hotspots, measuring the net primary production of the kelp farm to be able to identify the carbon source within the farm as well as continue to monitor the geochemical impacts after the baseline has been established.

A mean sum of squares total (SST) standard deviation (SD) and coefficient of variation (CV) maps can be generated to further investigate the general temporal trends at the sampling site.

Doing a fully CO_2SYSTEM (CO_2SYS) for alkalinity will also help understand the Dissolved Inorganic Carbon (DIC) in the water samples collected.

This study will also recommend the use of aerial kelp imagery to be able to quantify the kelp biomass that will account for the quantity and health of the kelp at the kelp farms and using Remote Sensing (RS) and Hyperspectral (HS) Imagery to measure the kelp spatial distribution and track the carbon pathway of the farm.

CHAPTER SEVEN: REFERENCES

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CHAPTER EIGHT: APPENDICES

Appendix A: Ethical Clearance and Research Permit

UNAM
UNIVERSITY OF NAMIBIA

ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: SOS-0144 **Date: 27 April 2023**

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

Title of Project:	A GEOCHEMICAL BASELINE STUDY OF GIANT KELP (MACROCYSTIS PYRIFERA) AT THE KELP BLUE FARM TO ASSESS CARBON SEQUESTRATION POTENTIAL
Student:	PROTASIUS MUTJIDA
Student Number:	201202600
Supervisor(s):	Prof. LIKIUS DANIEL Dr. ATEEQ RAHMAN

Centre for Research Services

Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee.
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee.
4. The ethics committee retains the right to:

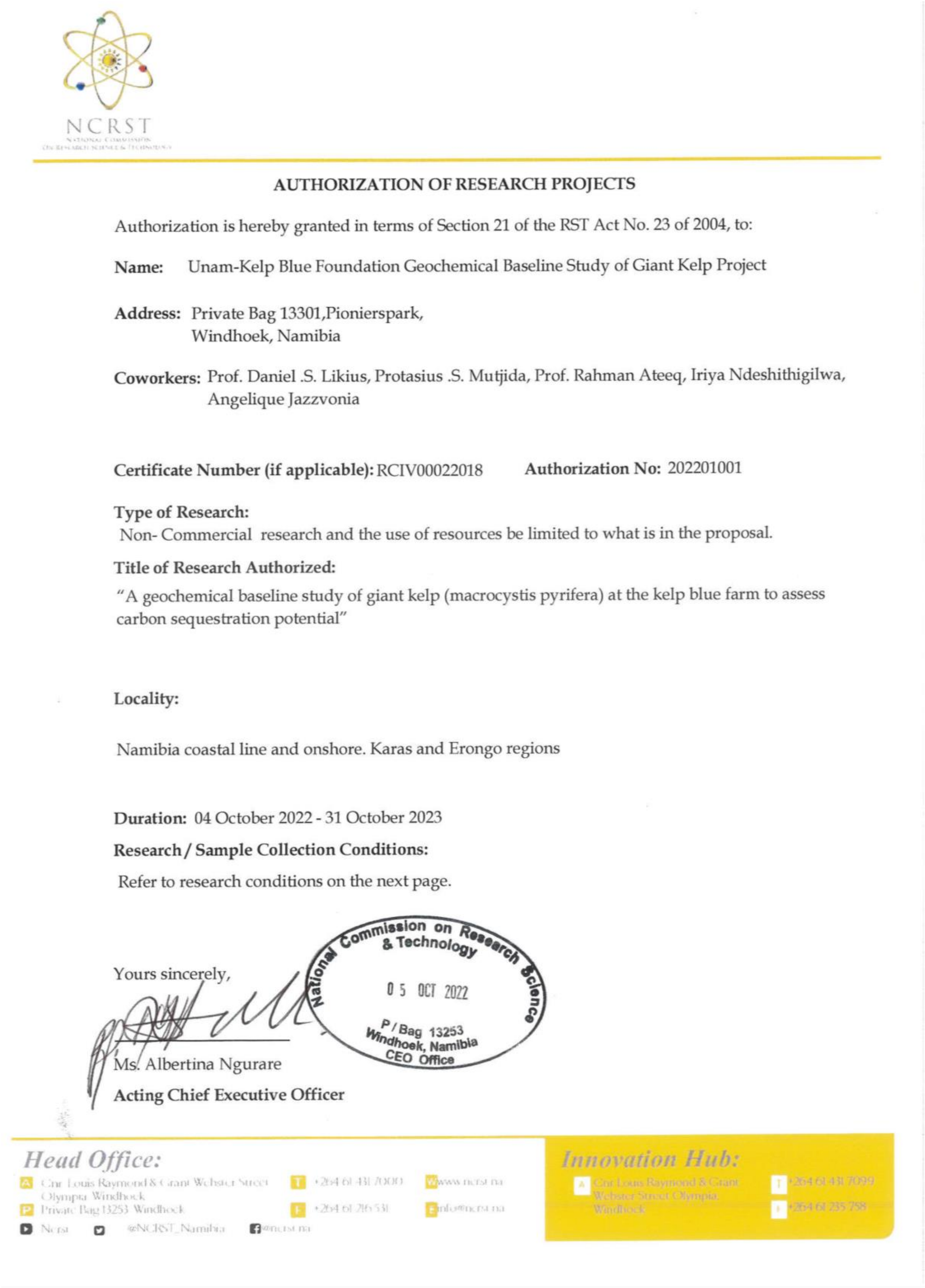
i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,
ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

Dr. Zivayi Chiguvare (Chairperson Ethics Committee)

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

Appendix A1: Ethical clearance



NCRST
NATIONAL COMMISSION ON RESEARCH SCIENCE & TECHNOLOGY

AUTHORIZATION OF RESEARCH PROJECTS

Authorization is hereby granted in terms of Section 21 of the RST Act No. 23 of 2004, to:

Name: Unam-Kelp Blue Foundation Geochemical Baseline Study of Giant Kelp Project

Address: Private Bag 13301,Pionierspark,
Windhoek, Namibia

Coworkers: Prof. Daniel .S. Likius, Protasius .S. Mutjida, Prof. Rahman Ateeq, Iriya Ndeshithigilwa, Angelique Jazzvonia

Certificate Number (if applicable): RCIV00022018 **Authorization No:** 202201001

Type of Research:
Non- Commercial research and the use of resources be limited to what is in the proposal.

Title of Research Authorized:
"A geochemical baseline study of giant kelp (macrocystis pyrifera) at the kelp blue farm to assess carbon sequestration potential"

Locality:

Namibia coastal line and onshore. Karas and Erongo regions

Duration: 04 October 2022 - 31 October 2023

Research / Sample Collection Conditions:

Refer to research conditions on the next page.

Yours sincerely,

05 OCT 2022

Ms. Albertina Ngurare
Acting Chief Executive Officer

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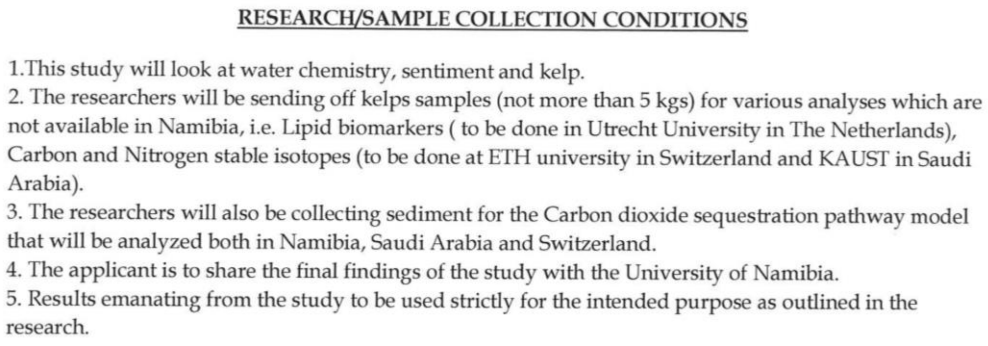
Appendix A2: Kelp Blue NCRST Research permit_1

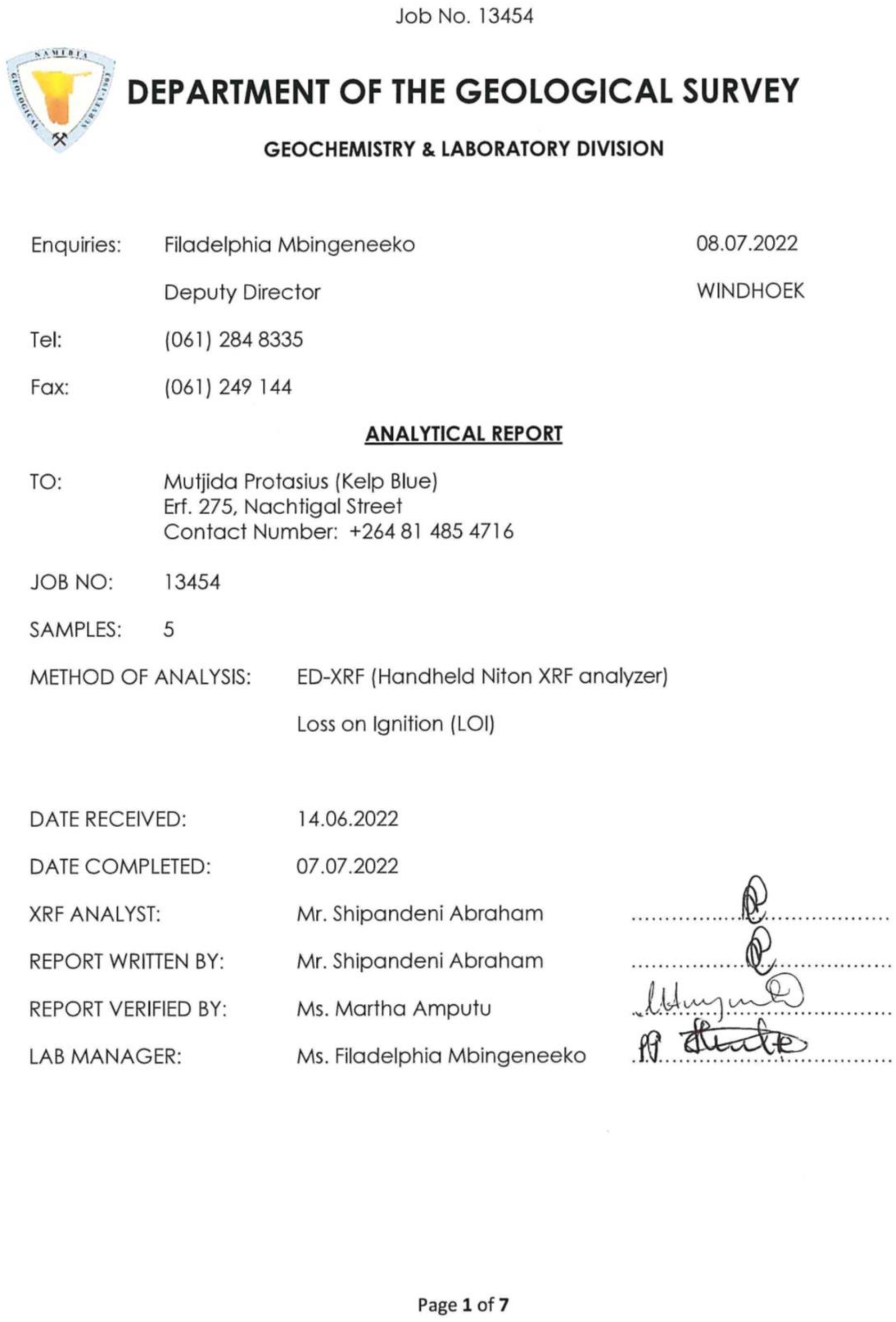


RESEARCH/SAMPLE COLLECTION CONDITIONS

1.This study will look at water chemistry, sentiment and kelp.
2. The researchers will be sending off kelps samples (not more than 5 kgs) for various analyses which are not available in Namibia, i.e. Lipid biomarkers (to be done in Utrecht University in The Netherlands), Carbon and Nitrogen stable isotopes (to be done at ETH university in Switzerland and KAUST in Saudi Arabia).
3. The researchers will also be collecting sediment for the Carbon dioxide sequestration pathway model that will be analyzed both in Namibia, Saudi Arabia and Switzerland.
4. The applicant is to share the final findings of the study with the University of Namibia.
5. Results emanating from the study to be used strictly for the intended purpose as outlined in the research.

Appendix A2: Kelp Blue NCRST Research permit _2

Appendix B: MME sediment results



Job No. 13454

DEPARTMENT OF THE GEOLOGICAL SURVEY

GEOCHEMISTRY & LABORATORY DIVISION

Enquiries: Filadelphia Mbingeneeko
Deputy Director
Tel: (061) 284 8335
Fax: (061) 249 144

08.07.2022
WINDHOEK

ANALYTICAL REPORT

TO: Mutjida Protasius (Kelp Blue)
Erf. 275, Nachtigal Street
Contact Number: +264 81 485 4716

JOB NO: 13454

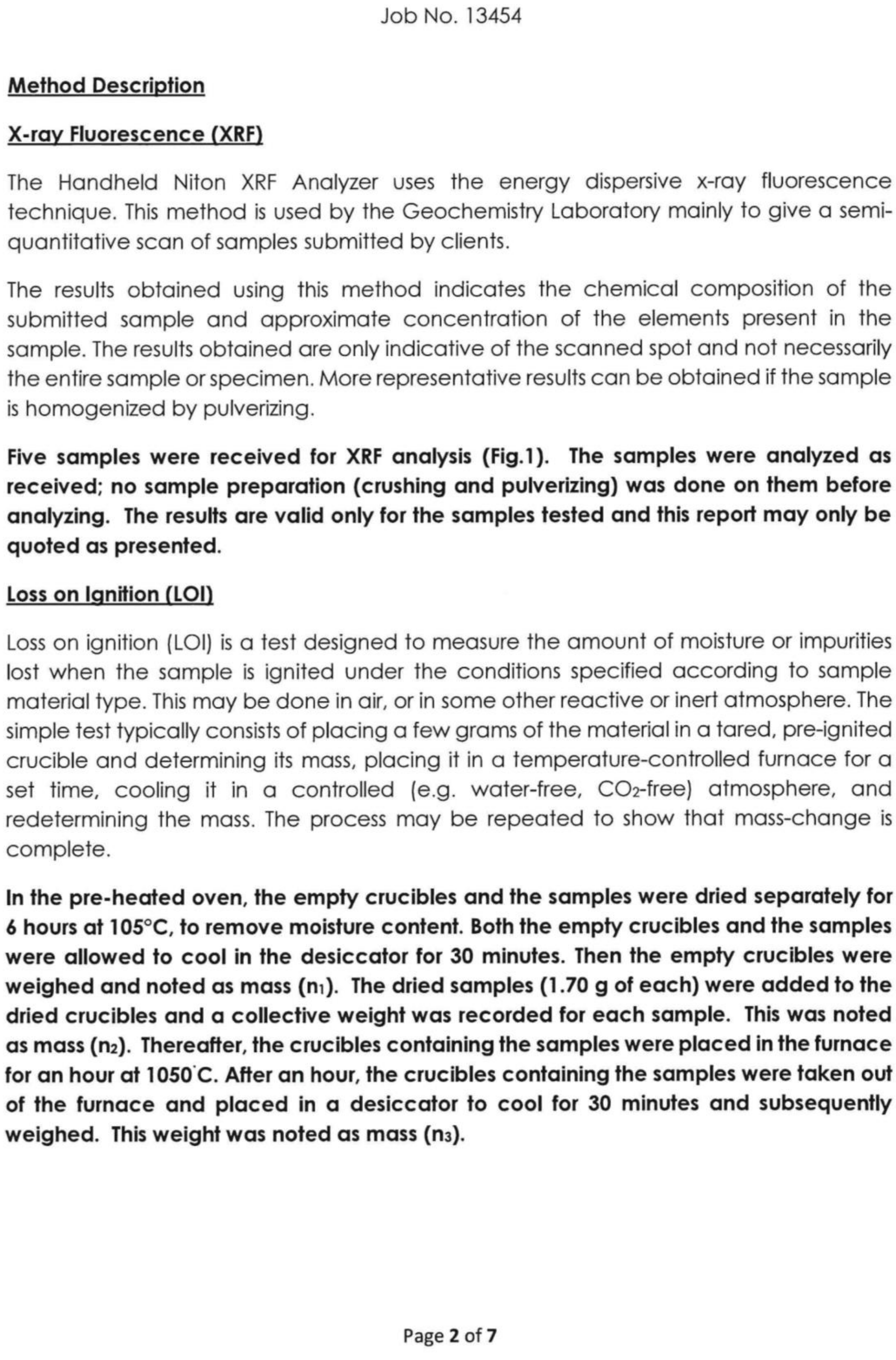
SAMPLES: 5

METHOD OF ANALYSIS: ED-XRF (Handheld Niton XRF analyzer)
Loss on Ignition (LOI)

DATE RECEIVED: 14.06.2022
DATE COMPLETED: 07.07.2022
XRF ANALYST: Mr. Shipandeni Abraham ……………………………………
REPORT WRITTEN BY: Mr. Shipandeni Abraham ……………………………………
REPORT VERIFIED BY: Ms. Martha Amputu ……………………………………
LAB MANAGER: Ms. Filadelphia Mbingeneeko ……………………………………

Page **1** of **7**

Appendix B1: MME front cover report



Method Description

X-ray Fluorescence (XRF)

The Handheld Niton XRF Analyzer uses the energy dispersive x-ray fluorescence technique. This method is used by the Geochemistry Laboratory mainly to give a semi-quantitative scan of samples submitted by clients.

The results obtained using this method indicates the chemical composition of the submitted sample and approximate concentration of the elements present in the sample. The results obtained are only indicative of the scanned spot and not necessarily the entire sample or specimen. More representative results can be obtained if the sample is homogenized by pulverizing.

Five samples were received for XRF analysis (Fig.1). The samples were analyzed as received; no sample preparation (crushing and pulverizing) was done on them before analyzing. The results are valid only for the samples tested and this report may only be quoted as presented.

Loss on Ignition (LOI)

Loss on ignition (LOI) is a test designed to measure the amount of moisture or impurities lost when the sample is ignited under the conditions specified according to sample material type. This may be done in air, or in some other reactive or inert atmosphere. The simple test typically consists of placing a few grams of the material in a tared, pre-ignited crucible and determining its mass, placing it in a temperature-controlled furnace for a set time, cooling it in a controlled (e.g. water-free, CO_2-free) atmosphere, and redetermining the mass. The process may be repeated to show that mass-change is complete.

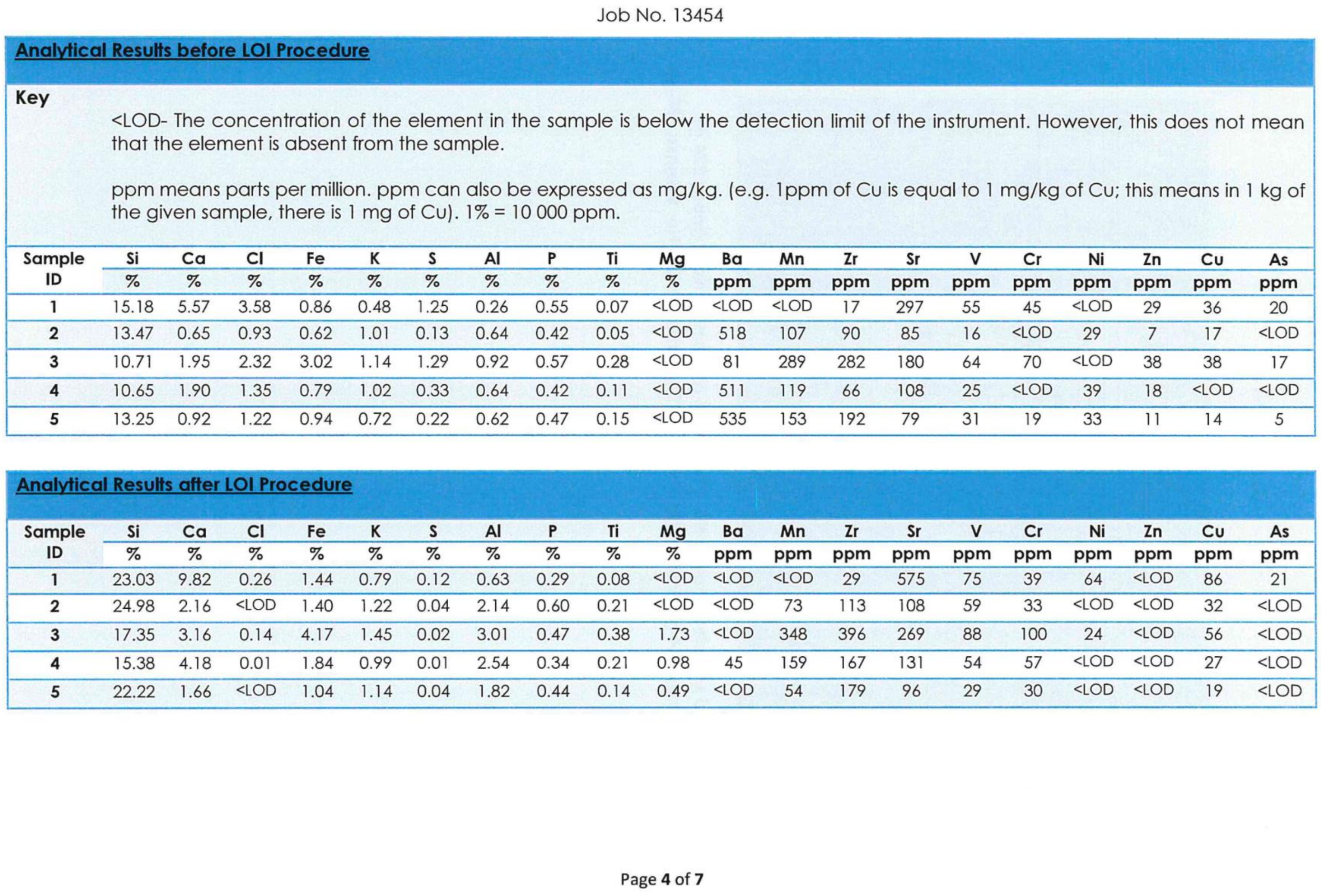
In the pre-heated oven, the empty crucibles and the samples were dried separately for 6 hours at 105°C, to remove moisture content. Both the empty crucibles and the samples were allowed to cool in the desiccator for 30 minutes. Then the empty crucibles were weighed and noted as mass (n_1). The dried samples (1.70 g of each) were added to the dried crucibles and a collective weight was recorded for each sample. This was noted as mass (n_2). Thereafter, the crucibles containing the samples were placed in the furnace for an hour at 1050˙C. After an hour, the crucibles containing the samples were taken out of the furnace and placed in a desiccator to cool for 30 minutes and subsequently weighed. This weight was noted as mass (n_3).

Appendix B2: MME method description

Job No. 13454

Fig. 1: Submitted samples; Sample No. 1 (mass: 26 g), Sample No. 2 (mass: 224 g), Sample No. 3 (mass: 64 g), Sample No. 4 (mass: 70 g), and Sample No. 5 (mass: 354 g).

Appendix B3: Submitted sample picture and weights of each sample (Report)



Job No. 13454

Analytical Results before LOI Procedure

Key

<LOD- The concentration of the element in the sample is below the detection limit of the instrument. However, this does not mean that the element is absent from the sample.

ppm means parts per million. ppm can also be expressed as mg/kg. (e.g. 1ppm of Cu is equal to 1 mg/kg of Cu; this means in 1 kg of the given sample, there is 1 mg of Cu). 1% = 10 000 ppm.

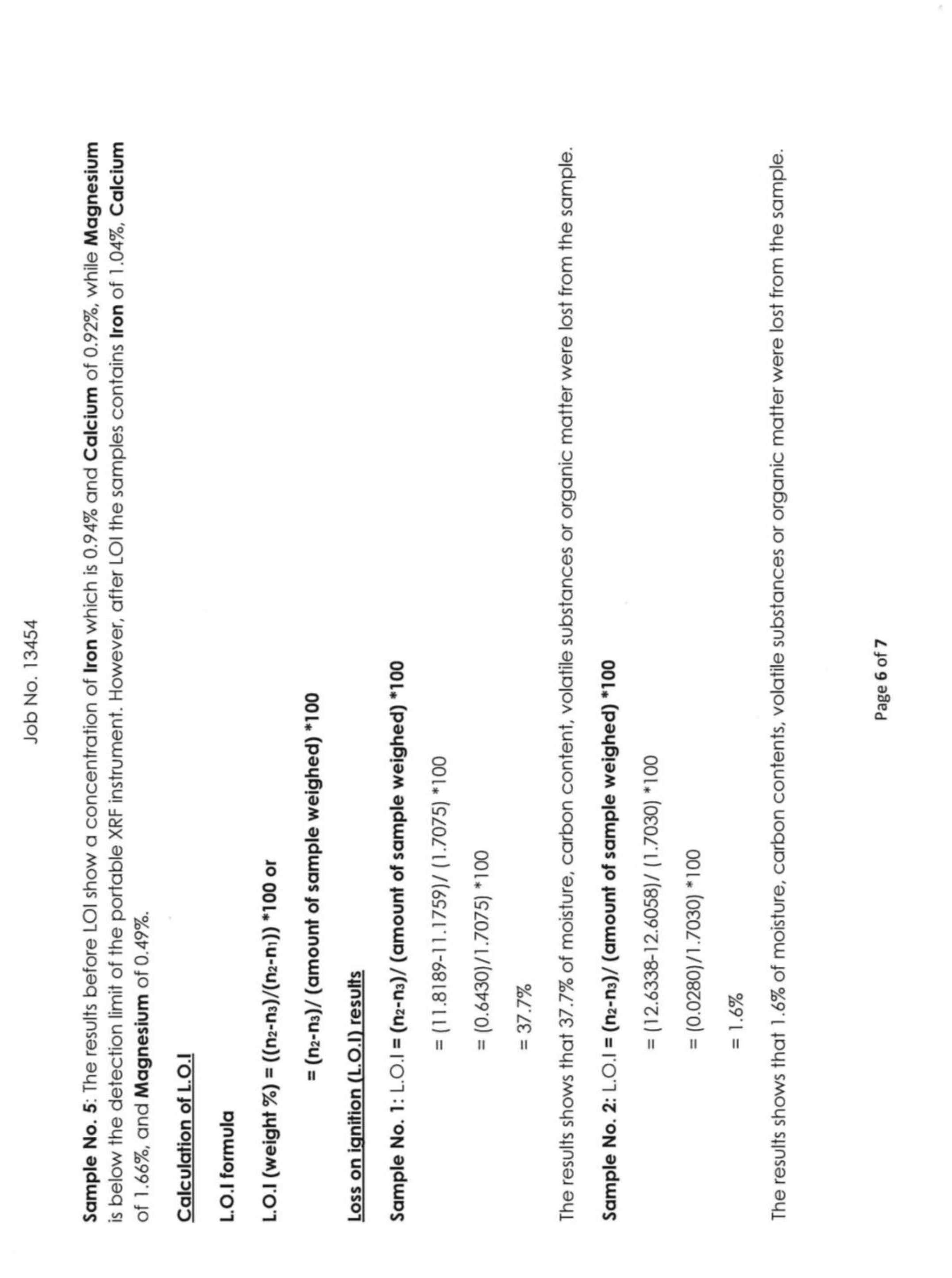
Sample ID	Si	Ca	Cl	Fe	K	S	Al	P	Ti	Mg	Ba	Mn	Zr	Sr	V	Cr	Ni	Zn	Cu	As
	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	15.18	5.57	3.58	0.86	0.48	1.25	0.26	0.55	0.07	<LOD	<LOD	<LOD	17	297	55	45	<LOD	29	36	20
2	13.47	0.65	0.93	0.62	1.01	0.13	0.64	0.42	0.05	<LOD	518	107	90	85	16	<LOD	29	7	17	<LOD
3	10.71	1.95	2.32	3.02	1.14	1.29	0.92	0.57	0.28	<LOD	81	289	282	180	64	70	<LOD	38	38	17
4	10.65	1.90	1.35	0.79	1.02	0.33	0.64	0.42	0.11	<LOD	511	119	66	108	25	<LOD	39	18	<LOD	<LOD
5	13.25	0.92	1.22	0.94	0.72	0.22	0.62	0.47	0.15	<LOD	535	153	192	79	31	19	33	11	14	5

Analytical Results after LOI Procedure

Sample ID	Si	Ca	Cl	Fe	K	S	Al	P	Ti	Mg	Ba	Mn	Zr	Sr	V	Cr	Ni	Zn	Cu	As
	%	%	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1	23.03	9.82	0.26	1.44	0.79	0.12	0.63	0.29	0.08	<LOD	<LOD	<LOD	29	575	75	39	64	<LOD	86	21
2	24.98	2.16	<LOD	1.40	1.22	0.04	2.14	0.60	0.21	<LOD	<LOD	73	113	108	59	33	<LOD	<LOD	32	<LOD
3	17.35	3.16	0.14	4.17	1.45	0.02	3.01	0.47	0.38	1.73	<LOD	348	396	269	88	100	24	<LOD	56	<LOD
4	15.38	4.18	0.01	1.84	0.99	0.01	2.54	0.34	0.21	0.98	45	159	167	131	54	57	<LOD	<LOD	27	<LOD
5	22.22	1.66	<LOD	1.04	1.14	0.04	1.82	0.44	0.14	0.49	<LOD	54	179	96	29	30	<LOD	<LOD	19	<LOD

Page 4 of 7

Appendix B4 LOI results before and after LOI procedure.



Job No. 13454

Sample No. 5: The results before LOI show a concentration of **Iron** which is 0.94% and **Calcium** of 0.92%, while **Magnesium** is below the detection limit of the portable XRF instrument. However, after LOI the samples contains **Iron** of 1.04%, **Calcium** of 1.66%, and **Magnesium** of 0.49%.

<u>Calculation of L.O.I</u>

L.O.I formula

L.O.I (weight %) = $((n_2-n_3)/(n_2-n_1))$ *100 or

= (n_2-n_3)/ (amount of sample weighed) *100

<u>Loss on ignition (L.O.I) results</u>

Sample No. 1: L.O.I **= (n_2-n_3)/ (amount of sample weighed) *100**

= (11.8189-11.1759)/ (1.7075) *100

= (0.6430)/1.7075) *100

= 37.7%

The results shows that 37.7% of moisture, carbon content, volatile substances or organic matter were lost from the sample.

Sample No. 2: L.O.I **= (n_2-n_3)/ (amount of sample weighed) *100**

= (12.6338-12.6058)/ (1.7030) *100

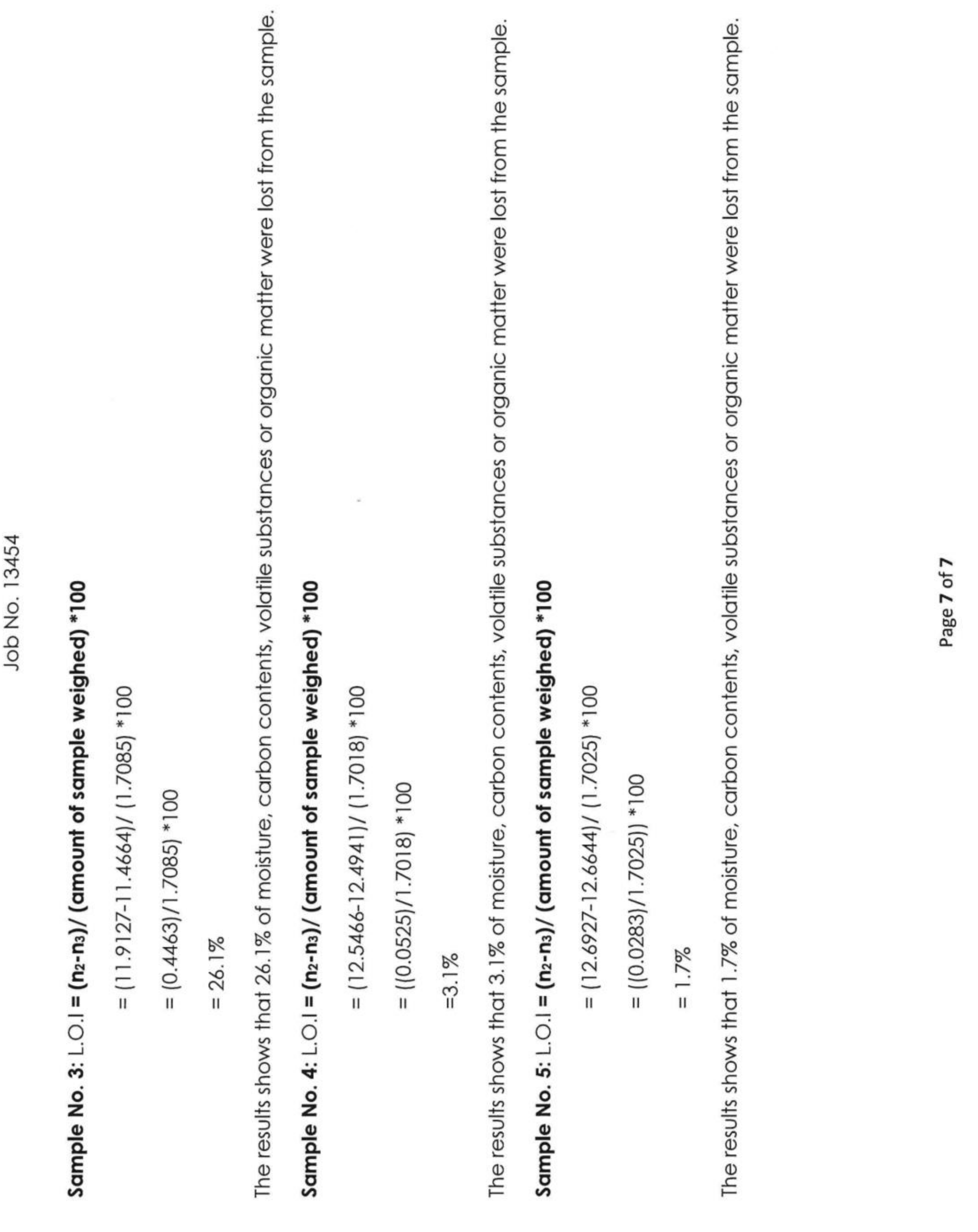
= (0.0280)/1.7030) *100

= 1.6%

The results shows that 1.6% of moisture, carbon contents, volatile substances or organic matter were lost from the sample.

Page **6** of **7**

Appendix B5: The calculation of LOI



Job No. 13454

Sample No. 3: L.O.I **= (n_2-n_3)/ (amount of sample weighed) *100**

= (11.9127-11.4664)/ (1.7085) *100

= (0.4463)/1.7085) *100

= 26.1%

The results shows that 26.1% of moisture, carbon contents, volatile substances or organic matter were lost from the sample.

Sample No. 4: L.O.I **= (n_2-n_3)/ (amount of sample weighed) *100**

= (12.5466-12.4941)/ (1.7018) *100

= ((0.0525)/1.7018) *100

=3.1%

The results shows that 3.1% of moisture, carbon contents, volatile substances or organic matter were lost from the sample.

Sample No. 5: L.O.I **= (n_2-n_3)/ (amount of sample weighed) *100**

= (12.6927-12.6644)/ (1.7025) *100

= ((0.0283)/1.7025)) *100

= 1.7%

The results shows that 1.7% of moisture, carbon contents, volatile substances or organic matter were lost from the sample.

Appendix B6: More calculations on the LOI

Appendix C: RGNO

MINISTRY OF FISHERIES AND MARINE RESOURCES

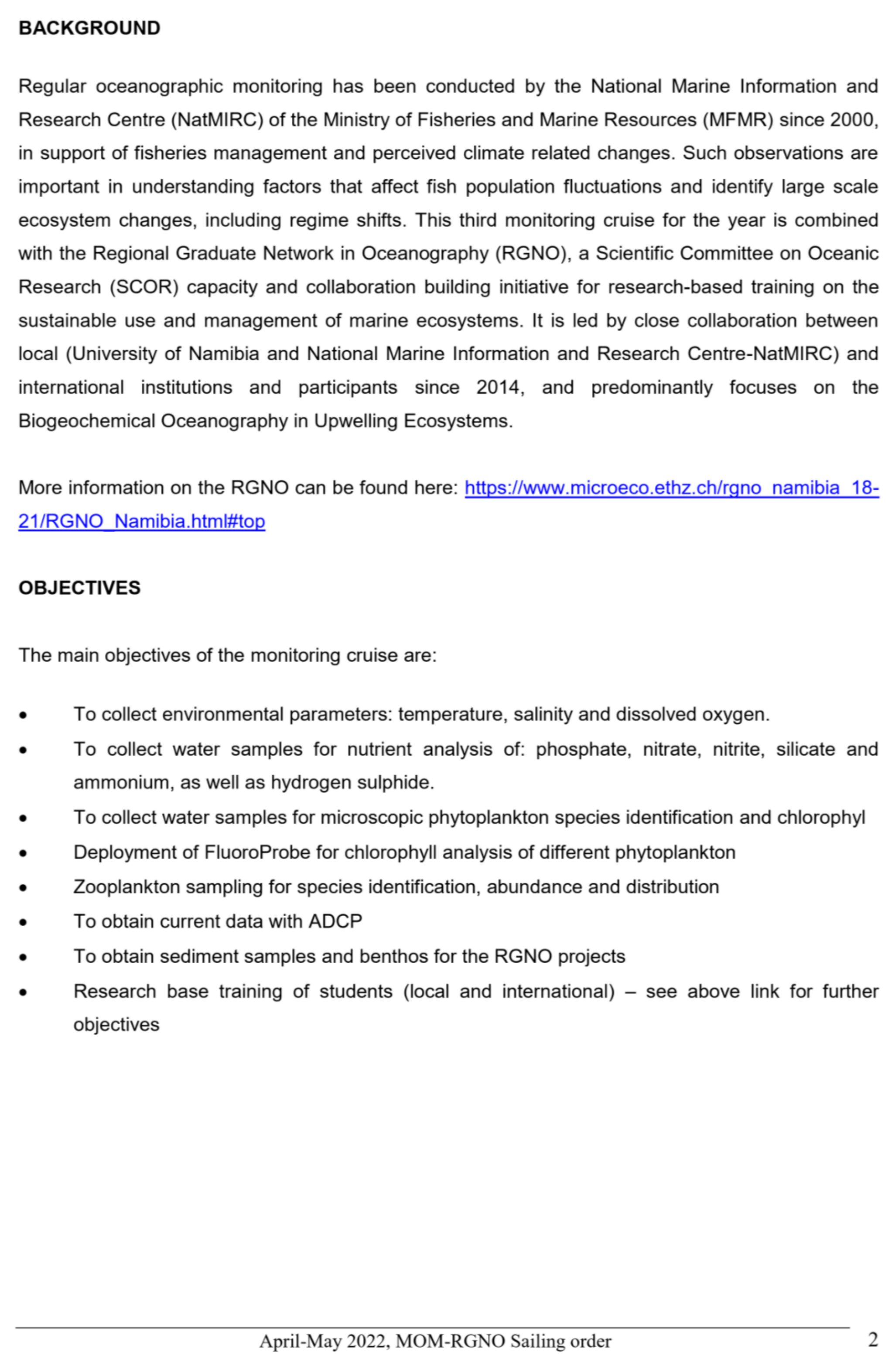
National Marine Information & Research Centre (NatMIRC), Swakopmund

Sailing Order/ Plan: *RV Mirabilis April 2022*

Cruise:	**0422 -** Bimonthly Oceanographic Monitoring (MOM)/ UNAM-RGNO
Vessel:	RV Mirabilis
Departure:	**25 April**, Monday
Time:	09h00 (departure from NatMIRC/ Swakopmund) (all personnel should be on-board by 11h00)
Arrival:	1 May 2022, Sunday
Area of Operation:	Lines 23, 20, 18°S and specific additional stations
Cruise Leader:	Richard Horaeb (064 4101000/173)
Contact person: (On land)	Dr. Anja Kreiner (064 4101000/158) Mrs. Anja van der Plas (064 4101000/111

April-May 2022, MOM-RGNO Sailing order 1

Appendix C1: Sailing order report page 1



BACKGROUND

Regular oceanographic monitoring has been conducted by the National Marine Information and Research Centre (NatMIRC) of the Ministry of Fisheries and Marine Resources (MFMR) since 2000, in support of fisheries management and perceived climate related changes. Such observations are important in understanding factors that affect fish population fluctuations and identify large scale ecosystem changes, including regime shifts. This third monitoring cruise for the year is combined with the Regional Graduate Network in Oceanography (RGNO), a Scientific Committee on Oceanic Research (SCOR) capacity and collaboration building initiative for research-based training on the sustainable use and management of marine ecosystems. It is led by close collaboration between local (University of Namibia and National Marine Information and Research Centre-NatMIRC) and international institutions and participants since 2014, and predominantly focuses on the Biogeochemical Oceanography in Upwelling Ecosystems.

More information on the RGNO can be found here: https://www.microeco.ethz.ch/rgno_namibia_18-21/RGNO_Namibia.html#top

OBJECTIVES

The main objectives of the monitoring cruise are:

- To collect environmental parameters: temperature, salinity and dissolved oxygen.
- To collect water samples for nutrient analysis of: phosphate, nitrate, nitrite, silicate and ammonium, as well as hydrogen sulphide.
- To collect water samples for microscopic phytoplankton species identification and chlorophyl
- Deployment of FluoroProbe for chlorophyll analysis of different phytoplankton
- Zooplankton sampling for species identification, abundance and distribution
- To obtain current data with ADCP
- To obtain sediment samples and benthos for the RGNO projects
- Research base training of students (local and international) – see above link for further objectives

Appendix C2: Sailing order report page 2

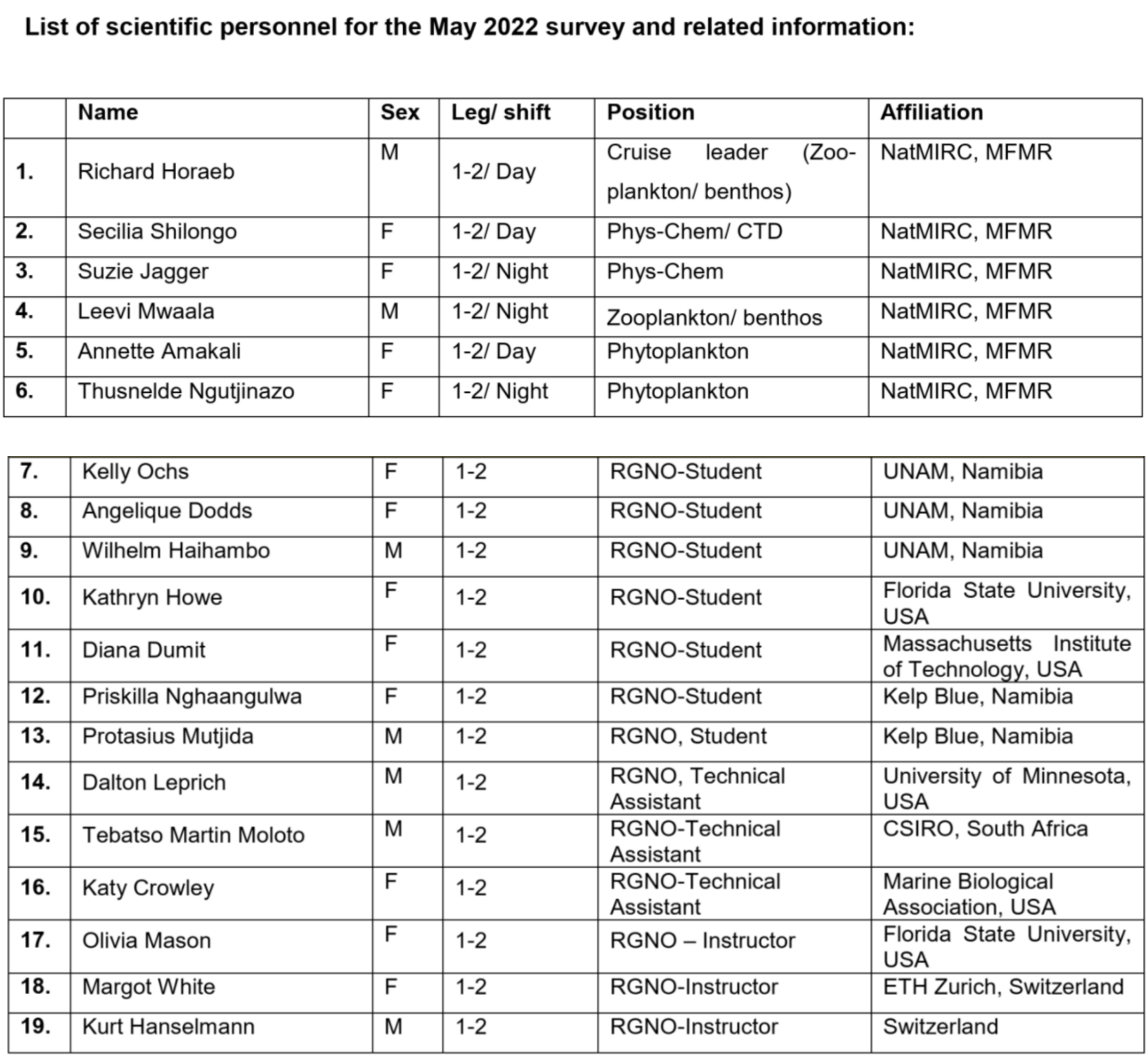
SURVEY PERIOD:

The RV Mirabilis is scheduled to depart for the cruise on 25th April 2022 around 12h00 and is anticipated to return to Walvis Bay no later than 1st May 2022

CRUISE PLAN/ SAMPLING GRID

- On the 25th of April 2022, just after leaving the Walvis Bay harbour and sailing to the first station on the 23°S transect, the Drop Keel will be lowered and all scientific instruments switched on, including seawater pumps. Sampling will commence at the inshore station (Mir23002) of 23°S transect and continue in an offshore direction up to the 90nm station.
- After the completion of the last station on the 23ºS transect, the vessel will sail directly to the zig-zag station 12. This station will be done only if there is an interest from the RGNO participants.
- On completion of the zigzag station 12, the vessel will steam to the 70 nm of the 20°S transect and start sampling towards the inshore station (Mir20002).
- On completion of the 2nm station on the 20°S transect, the vessel will steam to the 18°S transect and commence sampling from 30nm station towards inshore (2nm station).
- Upon completion of the 18°S transect the vessel will sail back to Walvis Bay. Additional stations may be sampled at RGNO stations (Geochem_3 and 1) and ZZG3 depending on the sampling interest of the participants.
- The vessel is anticipated to return no later than 1st May 2022.

NB: Loading and installation/testing of equipment will be done on 22nd April, Friday. All instruments are to be tested to ensure that they are functioning properly on the loading day. (Responsible person: Richard, Leevi, Annette, Secilia). Leevi will be responsible for organising transport to and from the vessel.



List of scientific personnel for the May 2022 survey and related information:

	Name	Sex	Leg/ shift	Position	Affiliation
1.	Richard Horaeb	M	1-2/ Day	Cruise leader (Zoo-plankton/ benthos)	NatMIRC, MFMR
2.	Secilia Shilongo	F	1-2/ Day	Phys-Chem/ CTD	NatMIRC, MFMR
3.	Suzie Jagger	F	1-2/ Night	Phys-Chem	NatMIRC, MFMR
4.	Leevi Mwaala	M	1-2/ Night	Zooplankton/ benthos	NatMIRC, MFMR
5.	Annette Amakali	F	1-2/ Day	Phytoplankton	NatMIRC, MFMR
6.	Thusnelde Ngutjinazo	F	1-2/ Night	Phytoplankton	NatMIRC, MFMR
7.	Kelly Ochs	F	1-2	RGNO-Student	UNAM, Namibia
8.	Angelique Dodds	F	1-2	RGNO-Student	UNAM, Namibia
9.	Wilhelm Haihambo	M	1-2	RGNO-Student	UNAM, Namibia
10.	Kathryn Howe	F	1-2	RGNO-Student	Florida State University, USA
11.	Diana Dumit	F	1-2	RGNO-Student	Massachusetts Institute of Technology, USA
12.	Priskilla Nghaangulwa	F	1-2	RGNO-Student	Kelp Blue, Namibia
13.	Protasius Mutjida	M	1-2	RGNO, Student	Kelp Blue, Namibia
14.	Dalton Leprich	M	1-2	RGNO, Technical Assistant	University of Minnesota, USA
15.	Tebatso Martin Moloto	M	1-2	RGNO-Technical Assistant	CSIRO, South Africa
16.	Katy Crowley	F	1-2	RGNO-Technical Assistant	Marine Biological Association, USA
17.	Olivia Mason	F	1-2	RGNO – Instructor	Florida State University, USA
18.	Margot White	F	1-2	RGNO-Instructor	ETH Zurich, Switzerland
19.	Kurt Hanselmann	M	1-2	RGNO-Instructor	Switzerland

Appendix C3: Sailing order report page 3

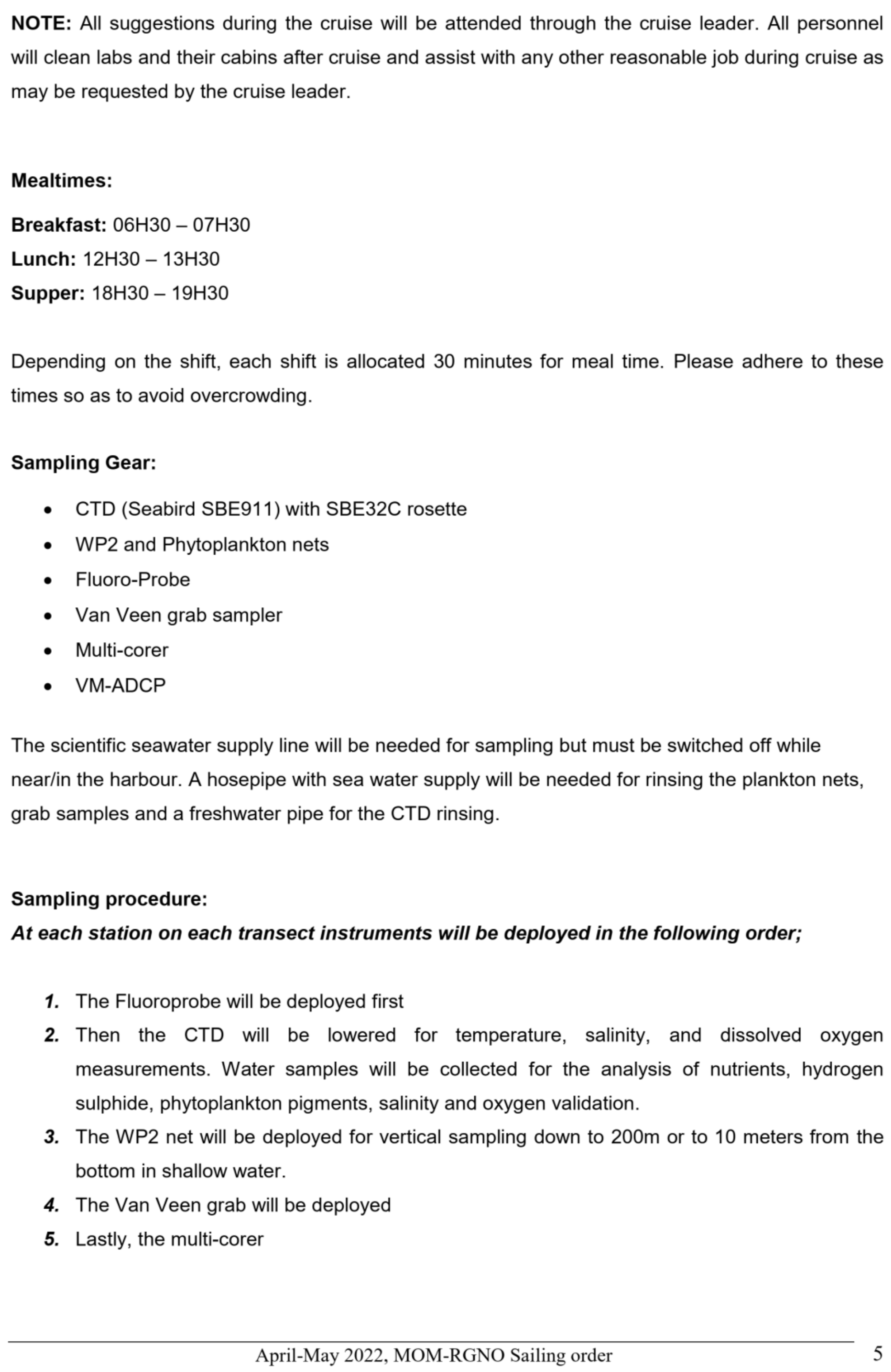
RESPONSIBILITIES:

Aid requested from the ship's staff/bridge: The crew should help with loading/offloading. Notification when sampling points have been reached and notification to CTD lab of the depth of each station. The crew’s assistance is required for winching, deploying, and retrieving the CTD, Fluoroprobe/ WP2/ grab/multi-corer. The cruise leader will allocate berths to scientific staff.

Scientific staff responsibilities:

- Richard Horaeb, Leevi Mwaala: deployment of WP2 net and fixation of zooplankton samples. Deployment of Van Veen grab sampler and preservation of samples. Cleaning of wet lab. Richard will they also operate CTD and will be the cruise leader and responsible for overall coordination of the cruise and compilation of the final cruise report.
- Secilia Shilongo & Suzie Jagger: Responsible for preparing and testing of CTD for deployment, collection of water samples from CTD. Loading/offloading and preparation of labs and equipment, cleaning of CTD and wet labs.
- Thusnelde Ngutjinazo and Annette Amakali: Chlorophyll filtrations. Phytoplankton sample fixation and water sampling at CTD for phytoplankton. Deployment of Fluoroprobe. Loading/off-loading and setting up lab and testing filtration device. Assist with cleaning of wet and analysis lab.

Appendix 4: Sailing order report page 4



NOTE: All suggestions during the cruise will be attended through the cruise leader. All personnel will clean labs and their cabins after cruise and assist with any other reasonable job during cruise as may be requested by the cruise leader.

Mealtimes:

Breakfast: 06H30 – 07H30
Lunch: 12H30 – 13H30
Supper: 18H30 – 19H30

Depending on the shift, each shift is allocated 30 minutes for meal time. Please adhere to these times so as to avoid overcrowding.

Sampling Gear:

- CTD (Seabird SBE911) with SBE32C rosette
- WP2 and Phytoplankton nets
- Fluoro-Probe
- Van Veen grab sampler
- Multi-corer
- VM-ADCP

The scientific seawater supply line will be needed for sampling but must be switched off while near/in the harbour. A hosepipe with sea water supply will be needed for rinsing the plankton nets, grab samples and a freshwater pipe for the CTD rinsing.

Sampling procedure:
At each station on each transect instruments will be deployed in the following order;

1. The Fluoroprobe will be deployed first
2. Then the CTD will be lowered for temperature, salinity, and dissolved oxygen measurements. Water samples will be collected for the analysis of nutrients, hydrogen sulphide, phytoplankton pigments, salinity and oxygen validation.
3. The WP2 net will be deployed for vertical sampling down to 200m or to 10 meters from the bottom in shallow water.
4. The Van Veen grab will be deployed
5. Lastly, the multi-corer

April-May 2022, MOM-RGNO Sailing order 5

Appendix C5: Sailing order report page 5

Note: Several repetitions of some instruments, especially the Van Veen grab and multi-corer may be necessary at some stations.

IMPORTANT:

1. **Please ensure that no bilge water is dumped at stations, as this will contaminate the water samples and readings being taken!!**
2. **No SMOKING near CTD or LABS!!**

OTHER MATTERS:

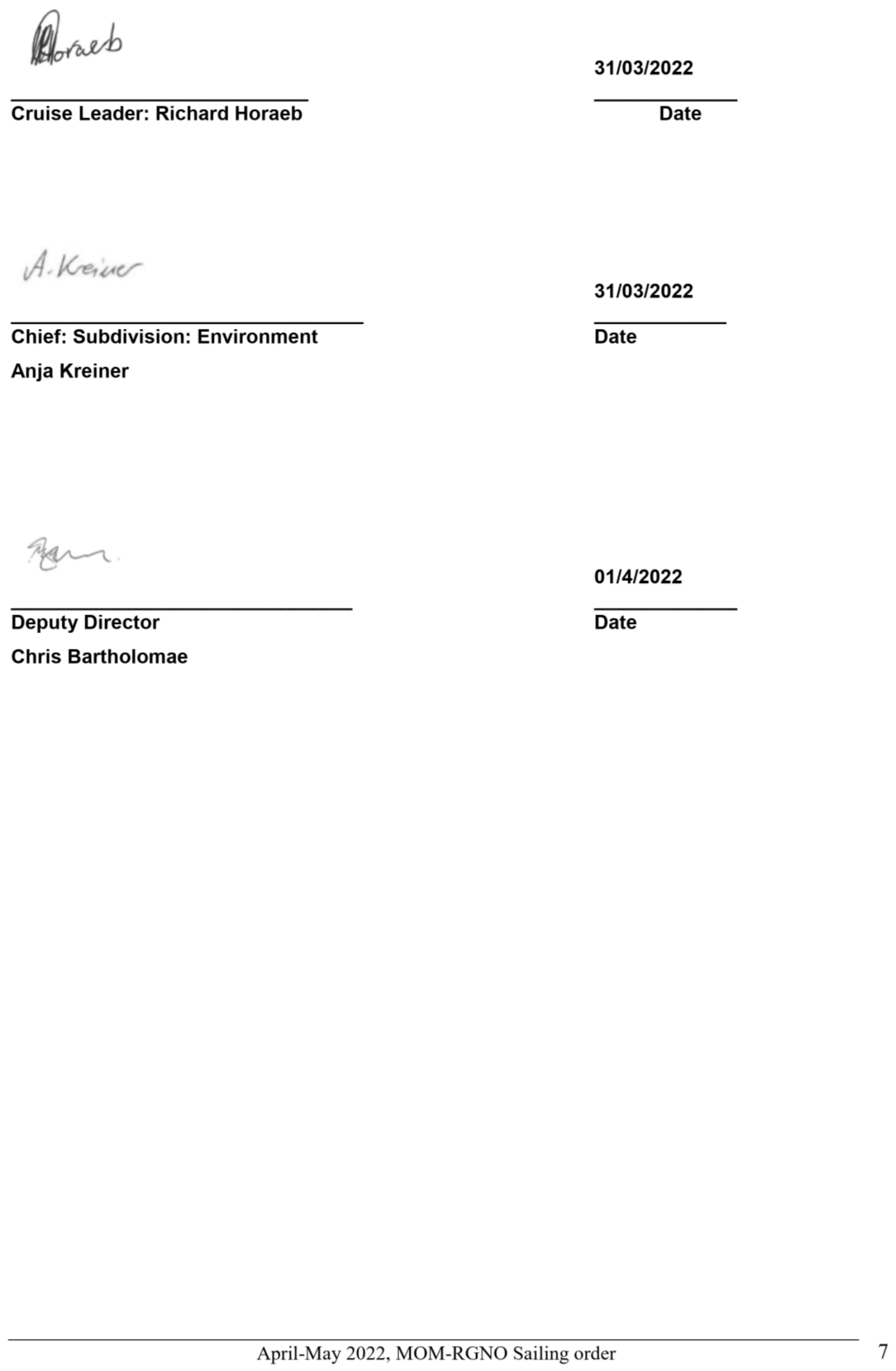
Contact person:
During the survey Dr. Kreiner (064-410 1158) or Mrs. Van der Plas (064 4101111 will be the contact person to whom messages will be sent and who will be responsible to inform staff on-board the vessel on matters needing urgent attention and *vice versa*.

Transport:
Leevi will be responsible for the necessary transport arrangements for equipment and staff to and from the ship.

Pre-cruise meeting:
A meeting will be held Monday, 25th April on-board the vessel before departure with all cruise participants and crew. There will be a safety drill either while the vessel is in port or steaming to the first station, but this will be communicated at the meeting.

Meals:
Participants who have dietary preferences are advised to inform the kitchen department timely.

Appendix C6: Sailing order report page 6



Horaeb

31/03/2022

Cruise Leader: Richard Horaeb **Date**

A. Kreiner

31/03/2022

Chief: Subdivision: Environment **Date**

Anja Kreiner

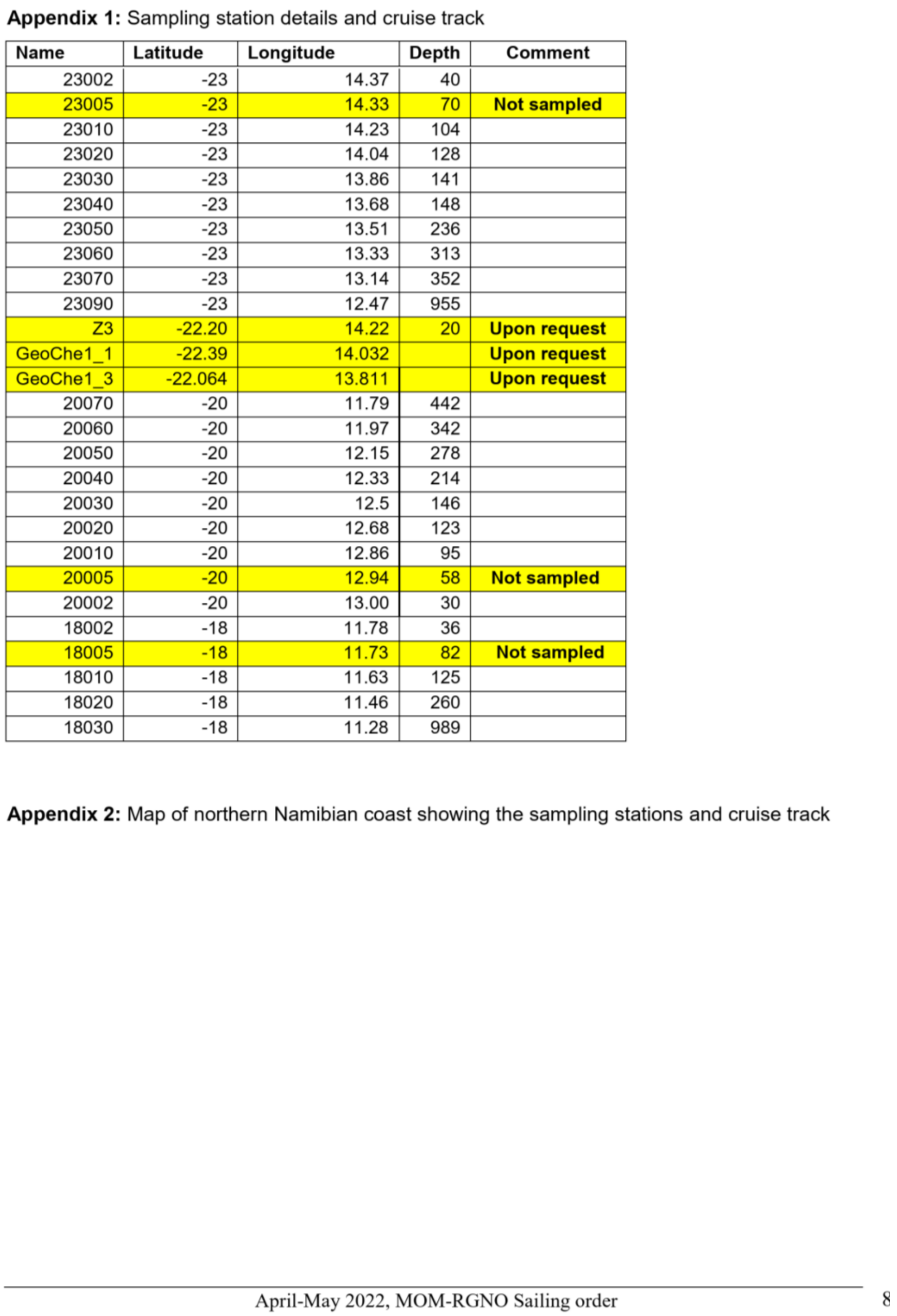
01/4/2022

Deputy Director **Date**

Chris Bartholomae

April-May 2022, MOM-RGNO Sailing order 7

Appendix C7: Sailing order report page 7



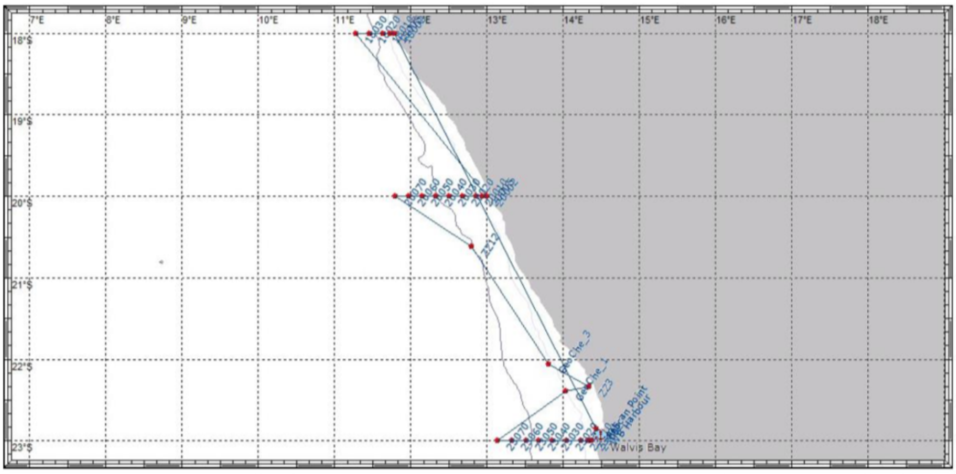
Appendix 1: Sampling station details and cruise track

Name	Latitude	Longitude	Depth	Comment
23002	-23	14.37	40	
23005	-23	14.33	70	**Not sampled**
23010	-23	14.23	104	
23020	-23	14.04	128	
23030	-23	13.86	141	
23040	-23	13.68	148	
23050	-23	13.51	236	
23060	-23	13.33	313	
23070	-23	13.14	352	
23090	-23	12.47	955	
Z3	-22.20	14.22	20	**Upon request**
GeoChe1_1	-22.39	14.032		**Upon request**
GeoChe1_3	-22.064	13.811		**Upon request**
20070	-20	11.79	442	
20060	-20	11.97	342	
20050	-20	12.15	278	
20040	-20	12.33	214	
20030	-20	12.5	146	
20020	-20	12.68	123	
20010	-20	12.86	95	
20005	-20	12.94	58	**Not sampled**
20002	-20	13.00	30	
18002	-18	11.78	36	
18005	-18	11.73	82	**Not sampled**
18010	-18	11.63	125	
18020	-18	11.46	260	
18030	-18	11.28	989	

Appendix 2: Map of northern Namibian coast showing the sampling stations and cruise track

April-May 2022, MOM-RGNO Sailing order 8

Appendix C8: Sailing order report page 8



April-May 2022, MOM-RGNO Sailing order 9

Appendix C9: Sailing order report page 9 (Monitoring stations)

RGNO*

Biogeochemical Oceanography in Upwelling Ecosystems

A GEOCHEMICAL STUDY OF THE nBUS IN RELATION TO CARBON SEQUESTRATION

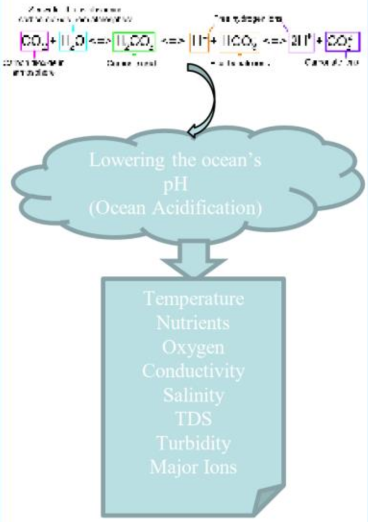
Protasius Mutjida, Kelp Forest Foundation[1]

Objectives

The research aimed to accomplish the following objectives:

- Monitor the changes in the ocean geochemistry at different sampling stations and transects.
- Compare the geochemical parameters of the stations.
- Identify major ions and trace metals in sediments
- Relate the Carbon Dioxide (CO_2) sequestration potential with geochemical parameters.

Concept



$CO_2 + H_2O <=> H_2CO_3 <=> H^+ + HCO_3^- <=> 2H^+ + CO_3^{2-}$

Lowering the ocean's pH (Ocean Acidification)

Temperature
Nutrients
Oxygen
Conductivity
Salinity
TDS
Turbidity
Major Ions

Concept methodology

Figure 1 shows how the concept of the geochemical study was done, water and sediment samples were collected using a CTD rosette and a multi-corer and a grab respectively.

Preliminary Results / Ideas 1

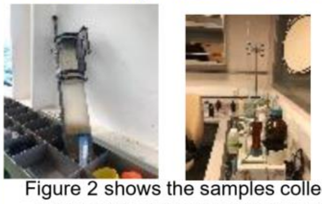
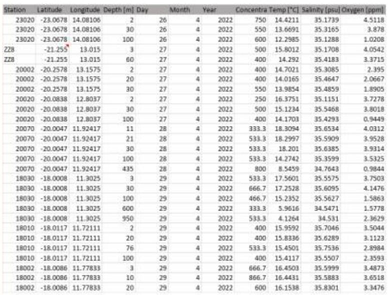


Figure 2 shows the samples collected and analyzed (sediment and water)



Station	Latitude	Longitude	Depth [m]	Day	Month	Year	Concentra	Temp [°C]	Salinity [psu]	Oxygen [ppm]
23020	-23.0678	14.08106	2	26	4	2022	750	14.4211	35.1739	4.5118
23020	-23.0678	14.08106	30	26	4	2022	550	13.6691	35.3165	3.878
23020	-23.0678	14.08106	100	26	4	2022	600	12.2985	35.1288	1.0208
ZZ8	-21.255	13.015	3	27	4	2022	500	15.8012	35.1708	4.0542
ZZ8	-21.255	13.015	60	27	4	2022	400	14.292	35.4183	3.3715
20002	-20.2578	13.1575	2	27	4	2022	400	14.7021	35.3085	2.395
20002	-20.2578	13.1575	20	27	4	2022	400	14.0165	35.4647	2.0667
20002	-20.2578	13.1575	30	27	4	2022	550	13.9854	35.4859	1.8905
20020	-20.0838	12.8037	2	27	4	2022	250	16.3751	35.1151	3.7278
20020	-20.0838	12.8037	30	27	4	2022	500	15.1234	35.5468	3.8018
20020	-20.0838	12.8037	100	27	4	2022	400	14.1703	35.4293	0.9449
20070	-20.0047	11.92417	11	28	4	2022	333.3	18.3094	35.6534	4.0312
20070	-20.0047	11.92417	21	28	4	2022	533.3	18.2997	35.5909	3.9528
20070	-20.0047	11.92417	30	28	4	2022	533.3	18.201	35.6385	3.9314
20070	-20.0047	11.92417	100	28	4	2022	533.3	14.2742	35.3599	3.5325
20070	-20.0047	11.92417	435	28	4	2022	800	8.5459	34.7643	0.9844
18030	-18.0008	11.3025	3	29	4	2022	533.3	17.5601	35.5575	3.7503
18030	-18.0008	11.3025	30	29	4	2022	666.7	17.2528	35.6095	4.1476
18030	-18.0008	11.3025	100	29	4	2022	466.7	15.2352	35.5627	1.5863
18030	-18.0008	11.3025	600	29	4	2022	333.3	5.9616	34.5471	1.5778
18030	-18.0008	11.3025	950	29	4	2022	533.3	4.1264	34.531	2.3629
18010	-18.0117	11.72111	2	29	4	2022	400	15.9592	35.7046	3.5044
18010	-18.0117	11.72111	20	29	4	2022	400	15.8336	35.6289	3.1123
18010	-18.0117	11.72111	76	29	4	2022	533.3	15.4501	35.7536	2.8984
18010	-18.0117	11.72111	100	29	4	2022	400	15.4117	35.5507	2.3593
18002	-18.0086	11.77833	3	29	4	2022	666.7	16.4503	35.5999	3.4873
18002	-18.0086	11.77833	10	29	4	2022	866.7	16.4431	35.5883	3.6518
18002	-18.0086	11.77833	20	29	4	2022	600	16.1538	35.8301	3.3476

Table 1 shows the geochemical parameters at station were titrations were conducted

Preliminary Results / Goals 2

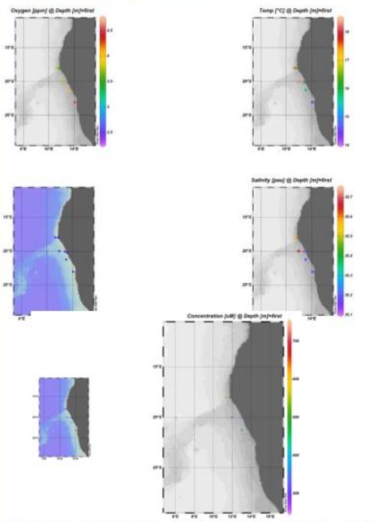


Figure 3 shows the ODV surface plots of the different stations were titration were conducted

Discussion

Water samples collected at the different stations were analysed for acid base titration to determine the amount of CO_2 consumed.

At concentration of oxygen was directly proportional to temperature except at oxycline regions which was more predominantly in the 18-degree line.

The soil profile of the sediments collected at different lines also varied from the 23-degree line to the 18-degree line.

Legend to figure

Conclusions

This study showed that there were spatial distibution of geochemical parameters at every station line and these parameters differed in relation to the bathymetry.

Determination of $C0_2$ system in seawater is more complex as many paramerters are involved including DIC and TA (Total Alkalinity) which were not covered during the survey.

Sediment samples were sent to a Lab in the US for isotopic analysis and some will be sent to the geochemical lab at MME for trace metal analysis.

References

Van Der Plas, A. K., Monteiro, P. M. S., & Pascall, A. (2007). Cross-shelf biogeochemical characteristics of sediments in the central Benguela and their relationship to overlying water column hypoxia. African Journal of Marine Science, 29(1), 37–47. https://doi.org/10.2989/AJMS.2007.29.1.3.68

*** Regional Graduate Network in Oceanography. Sponsors and Network Partners:** SCOR. Agouron Institute, USA. Simons Foundation USA, swiss l i-research & training institute, Switzerland, Sam Nujoma Campus & Marine Research Center of the University of Namibia, Ministry of Fisheries and Marine Resources through the National Marine Information and Research Center, Namibia.

1) Author's contact address: pmutjida@gmail.com

Appendix C10: RGNO article presentation

RGNO online

Invitation

RGNO online

7th Regional Graduate Network in Oceanography (RGNO)

Research Results Symposium at 3pm (UTC +2)
on Thursday, May 19th 2022, online

With presentations offered by the 2022 RGNO participants

Time	Title / Hosts / Moderators	Speaker
15.00	Welcome and Introduction	Margot White ETH Zürich
Session 1	Kelly Ochs & Protasius Mutjida & Diana Dumit	
15.10	Horizontal distribution of Copepods along three transects (18˚S, 20˚S and 23˚S) of the Northern Benguela System	Wilhelm Haihambo UNAM, Henties Bai
15.30	Microbial community/diversity in the Oxygen Minimum Zone of the Benguela Upwelling System	Diedré Dawids SANUMARC, UNAM
15.50	An analysis of the biodiversity and spatial distribution of marine phytoplankton in the North Benguela Upwelling System (nBUS)	Angelique Dodds UNAM & KFF
16.10	BREAK	
Session 2	Angelique Dodds & Diedré Dawids	
16.20	An assessment of the relationship between the physio-chemical environment and the diversity of phytoplankton in the Northern Benguela Upwelling System	Kelly Ochs UNAM
16:40 - 6 hrs	Novel lineages of anoxygenic phototrophs in the BUS	Catherine Crowley MBL, Woods Hole
17.00	BREAK	

Appendix C11: RGNO symposium programme part 1

Time	Title / Hosts / Moderators	Speaker
Session 3	Wilhelm Haihambo & Katie Crowley	
17.10 -6 hrs	A characterization of carotenoid distribution in modern environments	Diana Dumit MIT, Cambridge
17.30	Geochemical study of the nBUS in relation to Carbon sequestration potential	Protasius Mutjida UNAM & KFF
17.50	Spatial distribution of planktonic dimethylated-sulfur compounds in the northern Benguela upwelling system during austral autumn	Tebatso Martin Moloto Norh West University
18.10	SUMMARY and END OF SYMPOSIUM	Kurt Hanselmann swiss i-r&t

Zoom meeting connection

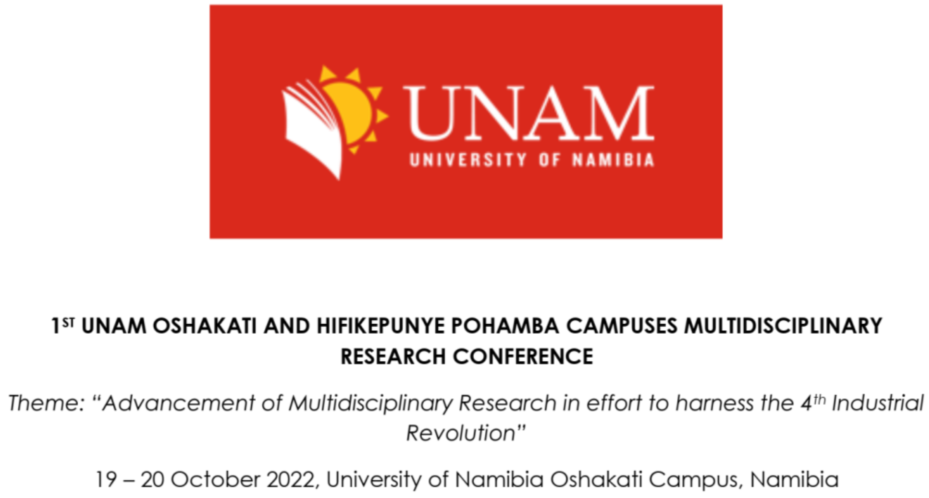
https://us02web.zoom.us/j/7248896698?pwd=eTRITll2aWlKY1E2ZUVBZUo4dy9NZz09
Meeting ID: 724 889 6698
Passcode: 982323

Find your local number: https://us02web.zoom.us/u/kEnGtJiNj

At a later date	Title	Speaker
- 6 hrs	Microbial nitrous oxide production along an oxygen gradient in the BUS	Kathryn Howe FSU, Tallahassee
- 7 hrs	Microscopy of Thiomargarita cell structure	Dalton Leprich U.Minnesota

Appendix C12: RGNO symposium programme part 2

Appendix D: UNAM OHP presentation



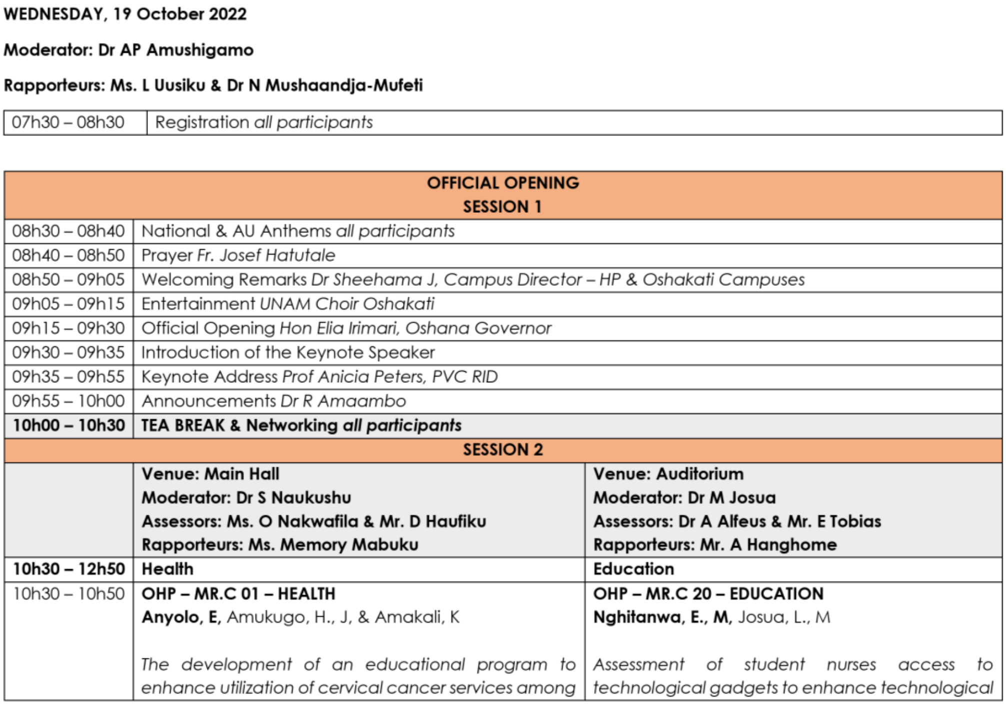
UNAM
UNIVERSITY OF NAMIBIA

1ST UNAM OSHAKATI AND HIFIKEPUNYE POHAMBA CAMPUSES MULTIDISCIPLINARY RESEARCH CONFERENCE

Theme: "Advancement of Multidisciplinary Research in effort to harness the 4th Industrial Revolution"

19 – 20 October 2022, University of Namibia Oshakati Campus, Namibia

Appendix D1: Conference programme page 1



WEDNESDAY, 19 October 2022

Moderator: Dr AP Amushigamo

Rapporteurs: Ms. L Uusiku & Dr N Mushaandja-Mufeti

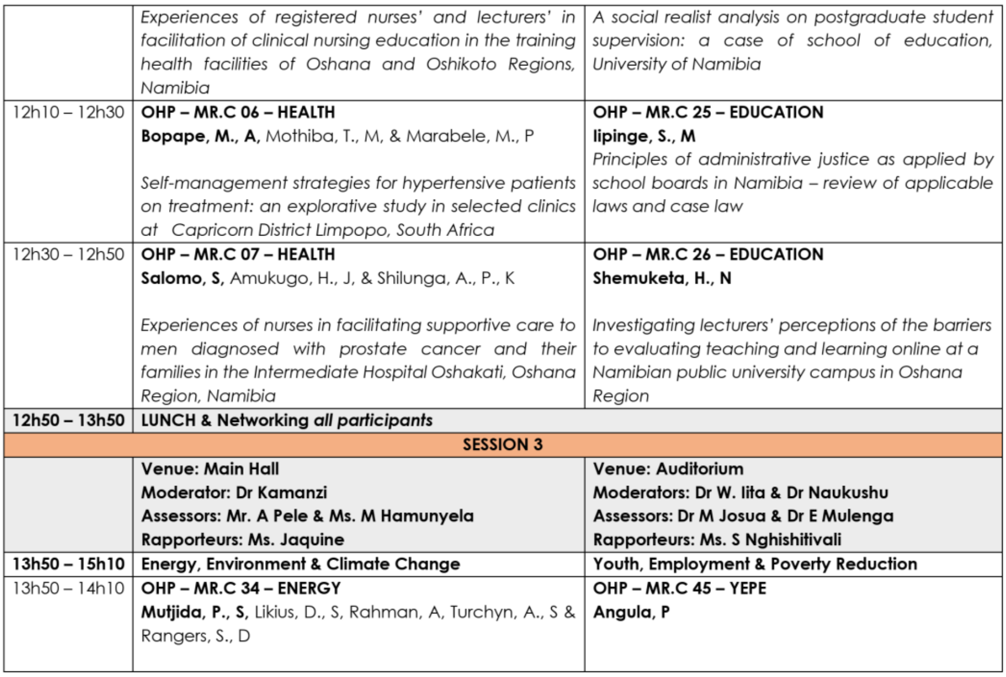
07h30 – 08h30	Registration *all participants*

<table>
<tr><th colspan="3">OFFICIAL OPENING
SESSION 1</th></tr>
<tr><td>08h30 – 08h40</td><td colspan="2">National & AU Anthems <i>all participants</i></td></tr>
<tr><td>08h40 – 08h50</td><td colspan="2">Prayer <i>Fr. Josef Hatutale</i></td></tr>
<tr><td>08h50 – 09h05</td><td colspan="2">Welcoming Remarks <i>Dr Sheehama J, Campus Director – HP & Oshakati Campuses</i></td></tr>
<tr><td>09h05 – 09h15</td><td colspan="2">Entertainment <i>UNAM Choir Oshakati</i></td></tr>
<tr><td>09h15 – 09h30</td><td colspan="2">Official Opening <i>Hon Elia Irimari, Oshana Governor</i></td></tr>
<tr><td>09h30 – 09h35</td><td colspan="2">Introduction of the Keynote Speaker</td></tr>
<tr><td>09h35 – 09h55</td><td colspan="2">Keynote Address <i>Prof Anicia Peters, PVC RID</i></td></tr>
<tr><td>09h55 – 10h00</td><td colspan="2">Announcements <i>Dr R Amaambo</i></td></tr>
<tr><td>10h00 – 10h30</td><td colspan="2">TEA BREAK & Networking <i>all participants</i></td></tr>
<tr><td colspan="3">SESSION 2</td></tr>
<tr><td></td><td>Venue: Main Hall
Moderator: Dr S Naukushu
Assessors: Ms. O Nakwafila & Mr. D Haufiku
Rapporteurs: Ms. Memory Mabuku</td><td>Venue: Auditorium
Moderator: Dr M Josua
Assessors: Dr A Alfeus & Mr. E Tobias
Rapporteurs: Mr. A Hanghome</td></tr>
<tr><td>10h30 – 12h50</td><td>Health</td><td>Education</td></tr>
<tr><td>10h30 – 10h50</td><td>OHP – MR.C 01 – HEALTH
Anyolo, E, Amukugo, H., J, & Amakali, K

<i>The development of an educational program to enhance utilization of cervical cancer services among</i></td><td>OHP – MR.C 20 – EDUCATION
Nghitanwa, E., M, Josua, L., M

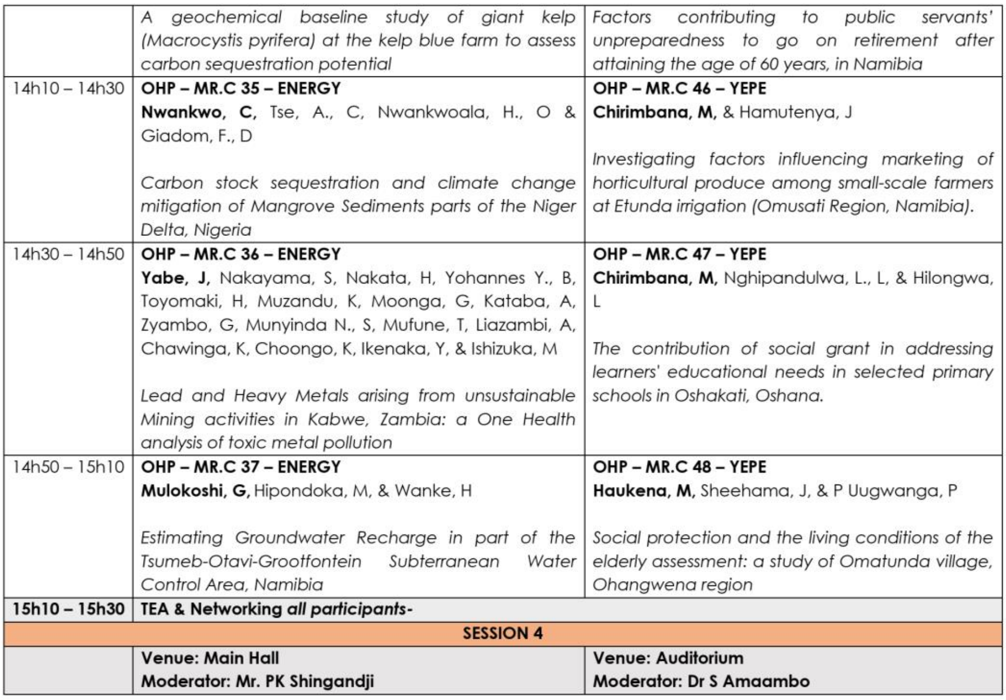
<i>Assessment of student nurses access to technological gadgets to enhance technological</i></td></tr>
</table>

Appendix D2: Conference programme page 2



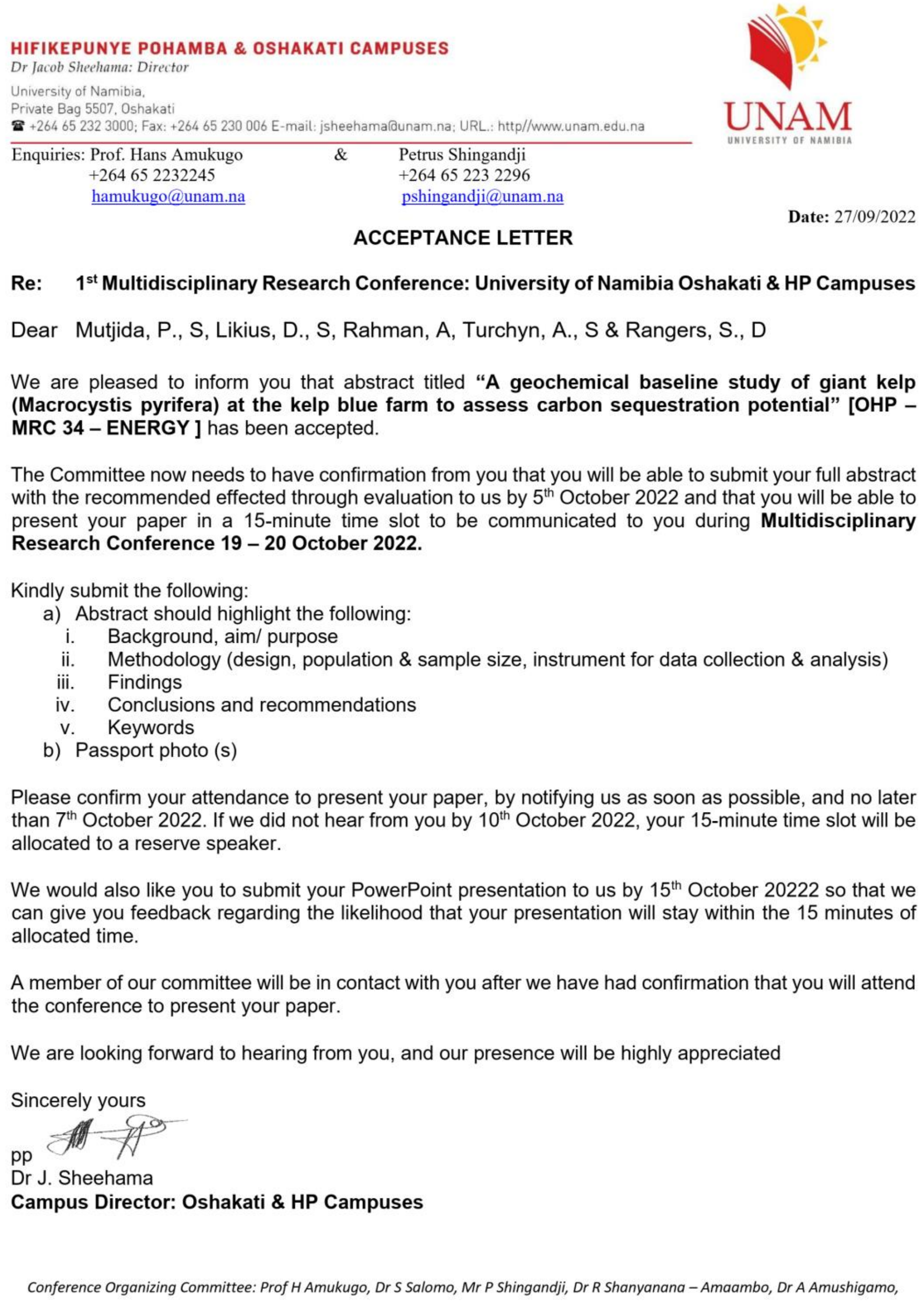
	Experiences of registered nurses' and lecturers' in facilitation of clinical nursing education in the training health facilities of Oshana and Oshikoto Regions, Namibia	*A social realist analysis on postgraduate student supervision: a case of school of education, University of Namibia*
12h10 – 12h30	**OHP – MR.C 06 – HEALTH** **Bopape, M., A,** Mothiba, T., M, & Marabele, M., P *Self-management strategies for hypertensive patients on treatment: an explorative study in selected clinics at Capricorn District Limpopo, South Africa*	**OHP – MR.C 25 – EDUCATION** **Iipinge, S., M** *Principles of administrative justice as applied by school boards in Namibia – review of applicable laws and case law*
12h30 – 12h50	**OHP – MR.C 07 – HEALTH** **Salomo, S,** Amukugo, H., J, & Shilunga, A., P., K *Experiences of nurses in facilitating supportive care to men diagnosed with prostate cancer and their families in the Intermediate Hospital Oshakati, Oshana Region, Namibia*	**OHP – MR.C 26 – EDUCATION** **Shemuketa, H., N** *Investigating lecturers' perceptions of the barriers to evaluating teaching and learning online at a Namibian public university campus in Oshana Region*
12h50 – 13h50	**LUNCH & Networking *all participants***	
	SESSION 3	
	Venue: Main Hall **Moderator: Dr Kamanzi** **Assessors: Mr. A Pele & Ms. M Hamunyela** **Rapporteurs: Ms. Jaquine**	**Venue: Auditorium** **Moderators: Dr W. Iita & Dr Naukushu** **Assessors: Dr M Josua & Dr E Mulenga** **Rapporteurs: Ms. S Nghishitivali**
13h50 – 15h10	**Energy, Environment & Climate Change**	**Youth, Employment & Poverty Reduction**
13h50 – 14h10	**OHP – MR.C 34 – ENERGY** **Mutjida, P., S,** Likius, D., S, Rahman, A, Turchyn, A., S & Rangers, S., D	**OHP – MR.C 45 – YEPE** **Angula, P**

Appendix D3: Conference presentation programme



	A geochemical baseline study of giant kelp (Macrocystis pyrifera) at the kelp blue farm to assess carbon sequestration potential	*Factors contributing to public servants' unpreparedness to go on retirement after attaining the age of 60 years, in Namibia*
14h10 – 14h30	**OHP – MR.C 35 – ENERGY** **Nwankwo, C,** Tse, A., C, Nwankwoala, H., O & Giadom, F., D *Carbon stock sequestration and climate change mitigation of Mangrove Sediments parts of the Niger Delta, Nigeria*	**OHP – MR.C 46 – YEPE** **Chirimbana, M,** & Hamutenya, J *Investigating factors influencing marketing of horticultural produce among small-scale farmers at Etunda irrigation (Omusati Region, Namibia).*
14h30 – 14h50	**OHP – MR.C 36 – ENERGY** **Yabe, J,** Nakayama, S, Nakata, H, Yohannes Y., B, Toyomaki, H, Muzandu, K, Moonga, G, Kataba, A, Zyambo, G, Munyinda N., S, Mufune, T, Liazambi, A, Chawinga, K, Choongo, K, Ikenaka, Y, & Ishizuka, M *Lead and Heavy Metals arising from unsustainable Mining activities in Kabwe, Zambia: a One Health analysis of toxic metal pollution*	**OHP – MR.C 47 – YEPE** **Chirimbana, M,** Nghipandulwa, L., L, & Hilongwa, L *The contribution of social grant in addressing learners' educational needs in selected primary schools in Oshakati, Oshana.*
14h50 – 15h10	**OHP – MR.C 37 – ENERGY** **Mulokoshi, G,** Hipondoka, M, & Wanke, H *Estimating Groundwater Recharge in part of the Tsumeb-Otavi-Grootfontein Subterranean Water Control Area, Namibia*	**OHP – MR.C 48 – YEPE** **Haukena, M,** Sheehama, J, & P Uugwanga, P *Social protection and the living conditions of the elderly assessment: a study of Omatunda village, Ohangwena region*
15h10 – 15h30	**TEA & Networking *all participants-***	
	SESSION 4	
	Venue: Main Hall **Moderator: Mr. PK Shingandji**	**Venue: Auditorium** **Moderator: Dr S Amaambo**

Appendix D4: Conference presentation programme_2



HIFIKEPUNYE POHAMBA & OSHAKATI CAMPUSES
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+264 65 2232245 +264 65 223 2296
hamukugo@unam.na pshingandji@unam.na

Date: 27/09/2022

ACCEPTANCE LETTER

Re: 1st Multidisciplinary Research Conference: University of Namibia Oshakati & HP Campuses

Dear Mutjida, P., S, Likius, D., S, Rahman, A, Turchyn, A., S & Rangers, S., D

We are pleased to inform you that abstract titled **“A geochemical baseline study of giant kelp (Macrocystis pyrifera) at the kelp blue farm to assess carbon sequestration potential” [OHP – MRC 34 – ENERGY]** has been accepted.

The Committee now needs to have confirmation from you that you will be able to submit your full abstract with the recommended effected through evaluation to us by 5th October 2022 and that you will be able to present your paper in a 15-minute time slot to be communicated to you during **Multidisciplinary Research Conference 19 – 20 October 2022.**

Kindly submit the following:

a) Abstract should highlight the following:
   i. Background, aim/ purpose
   ii. Methodology (design, population & sample size, instrument for data collection & analysis)
   iii. Findings
   iv. Conclusions and recommendations
   v. Keywords
b) Passport photo (s)

Please confirm your attendance to present your paper, by notifying us as soon as possible, and no later than 7th October 2022. If we did not hear from you by 10th October 2022, your 15-minute time slot will be allocated to a reserve speaker.

We would also like you to submit your PowerPoint presentation to us by 15th October 20222 so that we can give you feedback regarding the likelihood that your presentation will stay within the 15 minutes of allocated time.

A member of our committee will be in contact with you after we have had confirmation that you will attend the conference to present your paper.

We are looking forward to hearing from you, and our presence will be highly appreciated

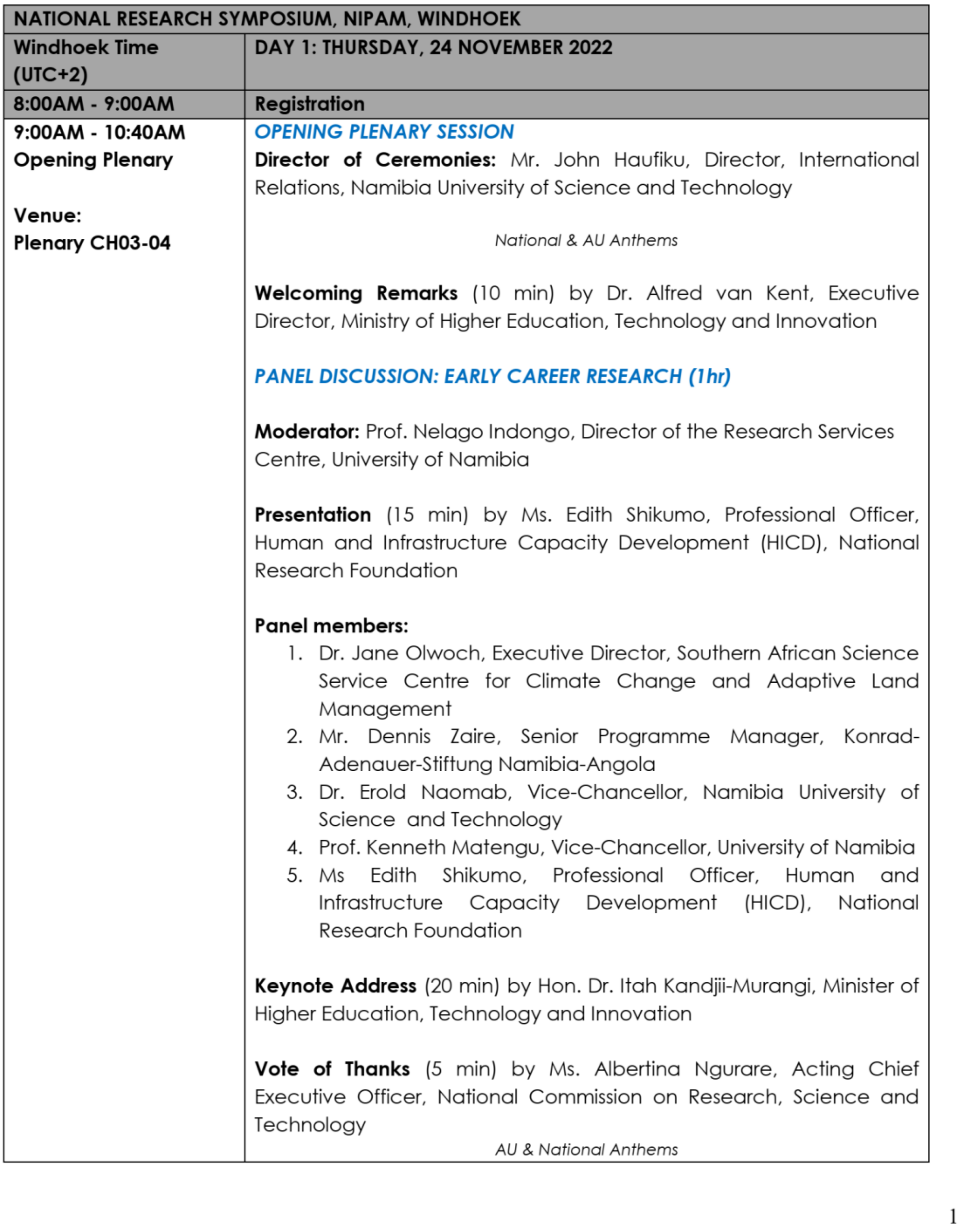
Sincerely yours

pp
Dr J. Sheehama
Campus Director: Oshakati & HP Campuses

Conference Organizing Committee: Prof H Amukugo, Dr S Salomo, Mr P Shingandji, Dr R Shanyanana – Amaambo, Dr A Amushigamo,

Appendix D5: OHP Acceptance letter

Appendix E: NCRST



NATIONAL RESEARCH SYMPOSIUM, NIPAM, WINDHOEK	
Windhoek Time (UTC+2)	**DAY 1: THURSDAY, 24 NOVEMBER 2022**
8:00AM - 9:00AM	**Registration**
9:00AM - 10:40AM **Opening Plenary** **Venue:** **Plenary CH03-04**	***OPENING PLENARY SESSION*** **Director of Ceremonies:** Mr. John Haufiku, Director, International Relations, Namibia University of Science and Technology *National & AU Anthems* **Welcoming Remarks** (10 min) by Dr. Alfred van Kent, Executive Director, Ministry of Higher Education, Technology and Innovation ***PANEL DISCUSSION: EARLY CAREER RESEARCH (1hr)*** **Moderator:** Prof. Nelago Indongo, Director of the Research Services Centre, University of Namibia **Presentation** (15 min) by Ms. Edith Shikumo, Professional Officer, Human and Infrastructure Capacity Development (HICD), National Research Foundation **Panel members:** 1. Dr. Jane Olwoch, Executive Director, Southern African Science Service Centre for Climate Change and Adaptive Land Management 2. Mr. Dennis Zaire, Senior Programme Manager, Konrad-Adenauer-Stiftung Namibia-Angola 3. Dr. Erold Naomab, Vice-Chancellor, Namibia University of Science and Technology 4. Prof. Kenneth Matengu, Vice-Chancellor, University of Namibia 5. Ms Edith Shikumo, Professional Officer, Human and Infrastructure Capacity Development (HICD), National Research Foundation **Keynote Address** (20 min) by Hon. Dr. Itah Kandjii-Murangi, Minister of Higher Education, Technology and Innovation **Vote of Thanks** (5 min) by Ms. Albertina Ngurare, Acting Chief Executive Officer, National Commission on Research, Science and Technology *AU & National Anthems*

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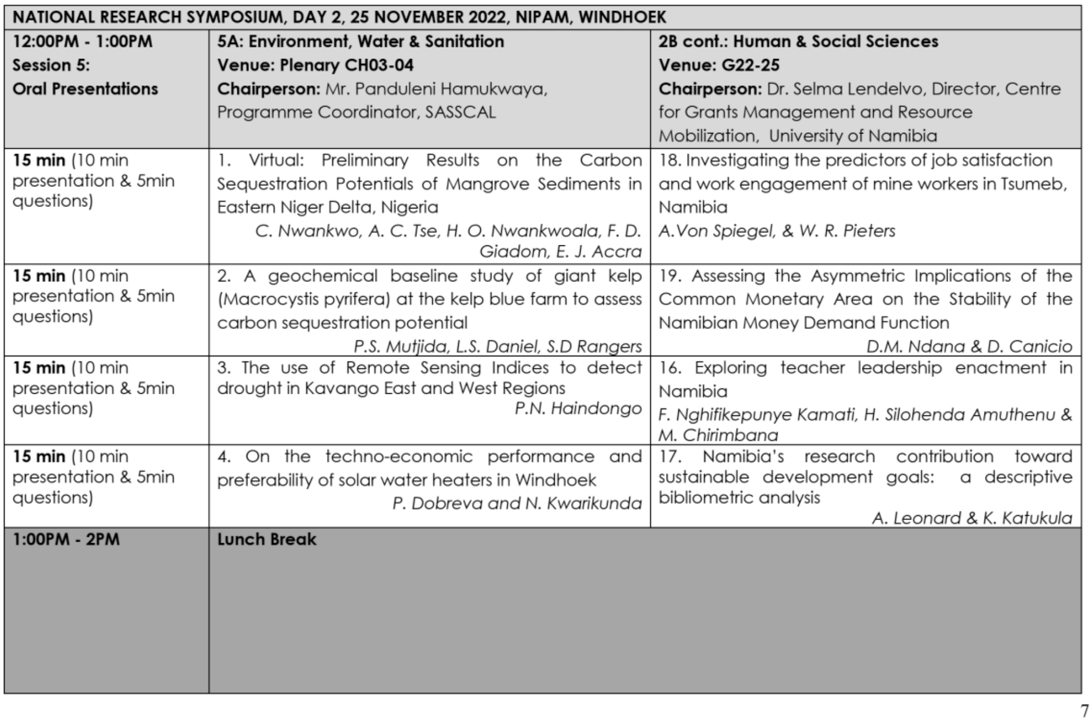
Appendix E1: National Research Symposium (NRS) presentation programme



NATIONAL RESEARCH SYMPOSIUM, DAY 2, 25 NOVEMBER 2022, NIPAM, WINDHOEK		
12:00PM - 1:00PM **Session 5:** **Oral Presentations**	**5A: Environment, Water & Sanitation** **Venue: Plenary CH03-04** **Chairperson:** Mr. Panduleni Hamukwaya, Programme Coordinator, SASSCAL	**2B cont.: Human & Social Sciences** **Venue: G22-25** **Chairperson:** Dr. Selma Lendelvo, Director, Centre for Grants Management and Resource Mobilization, University of Namibia
15 min (10 min presentation & 5min questions)	1. Virtual: Preliminary Results on the Carbon Sequestration Potentials of Mangrove Sediments in Eastern Niger Delta, Nigeria *C. Nwankwo, A. C. Tse, H. O. Nwankwoala, F. D. Giadom, E. J. Accra*	18. Investigating the predictors of job satisfaction and work engagement of mine workers in Tsumeb, Namibia *A.Von Spiegel, & W. R. Pieters*
15 min (10 min presentation & 5min questions)	2. A geochemical baseline study of giant kelp (Macrocystis pyrifera) at the kelp blue farm to assess carbon sequestration potential *P.S. Mutjida, L.S. Daniel, S.D Rangers*	19. Assessing the Asymmetric Implications of the Common Monetary Area on the Stability of the Namibian Money Demand Function *D.M. Ndana & D. Canicio*
15 min (10 min presentation & 5min questions)	3. The use of Remote Sensing Indices to detect drought in Kavango East and West Regions *P.N. Haindongo*	16. Exploring teacher leadership enactment in Namibia *F. Nghifikepunye Kamati, H. Silohenda Amuthenu & M. Chirimbana*
15 min (10 min presentation & 5min questions)	4. On the techno-economic performance and preferability of solar water heaters in Windhoek *P. Dobreva and N. Kwarikunda*	17. Namibia's research contribution toward sustainable development goals: a descriptive bibliometric analysis *A. Leonard & K. Katukula*
1:00PM - 2PM	**Lunch Break**	

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Appendix E2: NRS Presentation schedule