HUMAN IMPACT ON THE BIODIVERSITY OF MACROINVERTEBRATES IN INTERTIDAL ROCKY SHORES ALONG THE NAMIBIAN COAST

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ABSTRACT

The intertidal rocky shores along the central coast of Namibia provide multiple microhabitats supporting a high species biodiversity and a unique heterogeneous environment. Extreme anthropogenic disturbance such as harvesting and trampling due to human visitors may reduce biodiversity, modifying species genetic variability and overall ecosystem functioning. This research compares macroinvertebrate assemblage structures, size and diversity between disturbed and less disturbed sites. The study was conducted in March and June 2022 at six different sites along the coast – four disturbed sites and 2 control (less disturbed) sites. At each site, three line transects were used with a 0.5m x 0.5m quadrat placed at 5m intervals for 50m. In each quadrat, samples were counted and collected for identification and measurements. There was a significant difference in species assemblages in March ($R = 0.557$, $P = 0.001$) and June ($R = 0.\ 618$, $P = 0.001$) among all sites. There was a correlation between macroinvertebrate communities and sites due to environmental differences such as the type of habitat, water temperatures and human harvesting. Alien invasive mussels such as *M. galloprovincialis* and *S. patagonicus* had a significant reduced size ($P < 0.05$) in disturbed sites compared to control sites in both months. Majority of the limpet species such as *S. argenvillei* and *C. granatina* only had a significant smaller size ($P < 0.05$) in March and showed no significant difference in June. *Oxystele variegata* had larger sizes at control sites compared to disturbed sites in both months. There was a significant difference in species diversity between disturbed and less disturbed sites in both March ($Z = -2.905$, $P = 0.002$) and June ($Z= -3.373$, $P < 0.001$) indicating that both control sites had a greater species diversity than the disturbed sites. Human harvesting and trampling along with natural variation may play a crucial role in species assemblage structure, size and species diversity along the Namibian intertidal rocky shore. This study may be useful in filling the knowledge gap about the rocky intertidal structure along the Namibian coast and possibly identifying coastal management requirements.

Keywords: Human disturbance, Macroinvertebrates, Biodiversity, Biomonitors, Rocky shore

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LIST OF ABBREVIATIONS

AB	Afrodite Beach
ANOSIM	Analysis of Similarity
BA	Badewanne
CAP	Canonical Analysis of Principal coordinates
DB	Dolphin Beach
DNA	Deoxyribonucleic Acid
LB	Long Beach
M4	Mile 4
MPA	Marine Protected Area
MFMR	Ministry of Fisheries and Marine Resources
NOAA	National Oceanic and Atmospheric Administration
pH	Potential Hydrogen

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DECLARATIONS

I, Kelly Ochs, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

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Chapter 1

1. Introduction

1.1 Background of the study

The Namibian coast is within the boundaries of the Benguela upwelling system, one of the most productive marine systems globally. According to Sakko (1998) the Benguela current is one of the four major eastern boundary upwelling systems distinguished by relatively cool surface waters, high biological production and unstable environments with changing conditions. Although these conditions may result in unevenly distribution of nutrients, it fuels large- scale fisheries (Moloney *et al.*, 2005; Sakko, 1998). Harris *et al.*, (2013) state that apart from the considerable biomass, the marine system supports a rich biodiversity including high number of endemics, regionally threatened, migratory species and provide a variety of different habitats. Compared to other upwelling systems, the Benguela is characterized by an overall diverse coastal community (Blanchette *et al.*, 2009). The intertidal rocky area provides a vast diversity in habitat niches and species and is fairly accessible to the public (Stevcic *et al*., 2018). As the human population increases at coastal settlements, the universal demand for fisheries, shellfish and marine resources are heightened, leading to overexploitation and destruction of the intertidal marine systems (Bednar, 2015; Conde *et al.*, 2020).

1.2 Intertidal Rocky Shore

Intertidal rocky shores encompass different habitats including tidal pools and large boulders, providing a heterogeneous environment affecting the distribution and abundance of communities and sheltering a large number of marine organisms (Stevcic *et* *al*., 2018). The nature of the many different habitats in the intertidal rocky shores allow for many different species to co-exist. Firth and Crowe (2008) explain that environmental heterogeneity such as rocky shores, can alter species placement leading to spatial segregation which can encourage species coexistence and increase overall biodiversity.

The intertidal rocky shores consist of zonation patterns formed by intertidal organisms dividing this area into three vertical sections: the upper/ high intertidal zone, mid-intertidal zone and low intertidal zone. Intertidal zonation is influenced by elements such as temperature, moisture, wave action, substrate type and tidal dynamics (Harley & Helmuth, 2003). These directly affect the upper and lower limits of different zones and the species that occupy them. According to Stickle, Carrington and Hayford (2017) and Smith (2013) species occupying the upper intertidal zone are influenced by their tolerance to desiccation and harsh temperature ranges whereas lower intertidal species are influenced by biotic relationships. During spring tides, the upper intertidal zone species are not continuously covered with water and are adapted to these conditions, while species on lower intertidal zones evolved to compete for space and resources.

1.3 Macroinvertebrate Significance

Macroinvertebrates are a variety of aquatic animals that lack a backbone, are exothermic and are found in or near aquatic environments at some stages of their life cycle (Michaluk, 2023). Macroinvertebrates can function as biological indicators for monitoring aquatic environments. Pratiwi, Fachrul and Hendrawan (2020) explained that macroinvertebrates are reliable indicators because they have low mobility which presents as an indication of the environmental conditions they are found in. They can also be used to assess and monitor a particular aquatic site. Macroinvertebrates are biomonitors that are costeffective, reliable, easy to collect and identify, sensitive to change and widely distributed (Setiawan, 2009). Ricciardi and Bo (1999) state that intertidal benthic macroinvertebrates are of fundamental and applied importance as they play a vital role in the energy flow between primary producers and major consumers and have a sizeable commercial value. This gives reason to study macroinvertebrate distribution and diversity while also gaining insight on their behavior.

1.4 Statement of the Problem

Approximately 80% of marine pollution comes from land activities such as agricultural run-off, untreated sewage, chemicals discharged from the industrial sector and urbanization (Paul, 2021). Human garbage and waste are often directly dumped into oceans. The ocean is often regarded as a universal absorber of any form of pollution, only in recent decades was concern shown regarding marine pollution limits and the effects on marine life (Suratisa & Rathnayake, 2017). According to Conde *et al.,* (2020) coastal systems are complex and are prone to high rates of population growth and urbanization. Natural environments with constant human traffic due to economic development and recreational activities cause fauna and flora stress in both terrestrial and aquatic ecosystems (Leite, Ciotti & Christofoletti, 2012).

The Namibian coast where sand dunes meet the sea presents a major tourist attraction. Bock (2021) states that increased residential construction, recreational activities and visitors along the Namibian coast pose a major threat to marine organisms. On rocky intertidal shores, overharvesting of food and trampling due to increased human traffic have a negative impact on barnacles, limpets, crabs and bivalves (Stevcic *et al*., 2018). Coastal diamond mining operations make up about 250 km of the Namibian coastline and involves the removal of sand and gravel from the intertidal and subtidal zones ultimately destroying habitats, benthic communities as well as altering the substrates (Pulfrich *et al.*, 2003). Bednar (2015) explains that these negative effects change macroinvertebrate communities in terms of diversity, size and abundance which may also change predator-prey relationships due to prey availability, shifting the composition of intertidal zones to be more similar with less variation in species over a wide geographic range. It can only be assumed that this shift will have an impact on the rocky intertidal system's functionality.

1.5 Research Objectives

a) To compare the macroinvertebrate assemblage structure of the rocky intertidal zone among different sites.

b) To compare the average sizes of different macroinvertebrates between disturbed and less disturbed areas.

c) To determine and compare the species composition and the diversity of macroinvertebrates between disturbed areas and less disturbed areas.

1.6 Research Hypotheses

a) Macroinvertebrate assemblages of the rocky intertidal zone may be explained by habitat heterogeneity.

b) The macroinvertebrate sizes will be smaller in disturbed areas due to increased harvesting.

c) There will be a difference in species composition between disturbed and less disturbed sites and species diversity will be lower in disturbed areas because of more direct human impact (harvesting).

1.7 Significance of the study

Very little rocky intertidal research along the Namibian coast has been published, which may be partially due to restricted zones such as diamond mines and conservation areas (Engledow, 1998). In recent years the central Namibian coast, especially the area between Walvis Bay and Swakopmund, has been subject to intense development and urbanization. According to Barnard (2004) proposed developments such as resorts, residential and recreational establishments were approved between Long Beach and a few kilometers south of Dolphin Beach despite concerns regarding the conservation sites, bird breeding areas and beach pollution. Rebelo *et al*., (2011) state that urbanization creates a challenge for biodiversity conservation efforts.

Recreational harvesting of macroinvertebrate species such as crustaceans and molluscs is accepted because certain species are not of immediate concern and are often harvested at a “greater peace of mind” meaning without fear of possible overexploitation (Keulder, 2020). Often when organisms are not under extreme threat, the rules and regulations may be more relaxed. During harvesting, humans tend to select species with ecological beneficial traits leaving behind less desirable species with less contribution to the functional biodiversity which can also lead to loss of genetic variation, e.g. larger whole individuals (Allendorf *et al.*, 2008; Bednar, 2015).

Research studies along the central Namibian coast may provide baseline data on the macroinvertebrate structure along the intertidal zones as well as comparison of macroinvertebrate biodiversity between frequently disturbed rocky intertidal areas and a control site. Furthermore, the results of this research may aid other studies in filling the knowledge gap about the rocky intertidal structure along the central Namibian coast. Published studies may encourage biomonitoring schemes and stricter policies and restrictions involving over-harvesting along the rocky intertidal section.

Chapter 2

2. Literature Review

2.1 Biodiversity along Namibian Shores

Naeem *et al*., (2016) defines biodiversity as "the variability among living organisms from all sources including taxonomic, phylogenetic, and functional diversity and the ecological complexes of which they are part". Concerning biodiversity and sustainable development, Namibia strives to generate a foundation to boost the wellbeing of coastal communities while maintaining the integrity of the biodiversity and productivity of the coastal system (Braby, 2015). According to Sakko (1998) and Wardell-Johnson (2000) Namibia's marine system and coastal ecosystem remain relatively pristine with the focus on sustainable practices, yet natural and increased anthropogenic disturbances present a threat to biodiversity.

The requirement to carry out monitoring programs for environmental disturbance of coastal and intertidal ecosystems makes it essential to increase the indicator species in order to have a wide range of suitable organisms and higher biodiversity (Reguera, Couceiro & Fernandez, 2018). The Southern African coast is the core of Patellid limpet diversity, the genus *Scutellastra* being the most frequent and common in Namibia which provides research potential due to their role in structuring intertidal communities and maintaining ecosystem health (Mmonwa *et al*., 2017; Vasconcelos *et al*., 2021). About 39 Patellid species are identified worldwide, 20 of which are endemic to the southwestern coast limiting algal growth on rocky intertidal shores and in turn provide habitat for a diverse group of species (Branch *et al*., 2010; Mmonwa *et al*., 2017).

The indigenous mussel *Perna perna* (Brown mussel) is found to be the dominant mussel species appearing along the Namibian coast along with other native species: black mussel *Choromytilus meridionalis* and ribbed mussel *Aulacomya ater* (Hammond & Griffiths, 2006). Dahms, van der Bank & Greenfield (2014) state that both *P. perna and C. meridionalis* are economically and ecologically significant as a protein source, providing clean water through filtration and release nutrients to surrounding marine life. According to Hammond & Griffiths (2006) severe exploitation and alien invasive species are major causes for the decline in mussel diversity in the southern coast of Africa. Invasive blue mussels such as the *Mytilus galloprovincialis* (Mediterranean mussels) are widely distributed serving as ecosystem engineers that generally compete with native species and reduce the variety of species due to their tolerance of a wide range of conditions characteristic to the Benguela upwelling system (Zbawicka, Gardner & Wenne, 2019). According to Ma *et* al., (2020) *Mytilus galloprovincialis* co-occur with other mussels along the Namibian coast similarly to that of the western part of the South African coast. *Semimytilus patagonicus* (Bisexual mussel), a non-native species, invaded Namibian intertidal rocky shores, inhabiting mid to low intertidal zones along with native *P. perna*, showing rapid growth rates- often posing a challenge for other species in terms of habitat and resources requirements (Ma *et al*., 2020; Alexander, Skein & Robinson, 2022).

2.2 Macroinvertebrates as biomonitors

There are different ways to assess, monitor and manage marine pollution. Vieira *et al*., (2021) explains that one can analyze marine water and sediment samples directly but this lacks valuable information about their bioavailability. Macroinvertebrate indicator species however, present an opportunity for pollution analyses relating to ecosystem health and impact on human health. *Perna perna,* commonly found in the productive marine system along the Namibian coast is often used as a biomonitoring species (Dahms, van der Bank and Greenfield, 2014). Dahms, van der Bank and Greenfield (2014) made use of *P. perna* and *C. meridionalis* to study marine pollution along the Namibian coast. Mussels are vital in trace metal analyses due to their function as bio-accumulators and filter-feeding habits (Dahms, van der Bank and Greenfield, 2014). It was found that the most polluted sites were between Walvis Bay and Swakopmund and the metals of concern were cadmium and lead. This study will not focus on heavy metals but highlights the role of mussels in the marine ecosystem.

Resident macroinvertebrates generally respond to disturbances or pollution by changing their behavior, abundance and reflect change in their physiology (Costa *et al*., 2020). A study based on macroinvertebrates as indicators of human impacts on sandy beaches by Costa *et al*., (2020) mainly focused on the effects of harvesting and trampling on the ecological health. It was found that macroinvertebrates such as bivalves (mussels, clams) and gastropods tend to be most sensitive and vulnerable to overharvesting and human traffic.

A literature search by Reguera, Couceiro and Fernandez (2018) revealed that limpets, regardless of species, respond similarly to disturbance or pollution. Limpets tend to have smaller sizes when harvested or trampled, and when exposed to pollution they accumulate heavy metals within tissues and DNA damage is the result of oxidative stress (Reguera, Couceiro & Fernandez, 2018). Bednar (2015) confirms that overharvesting by humans not only reduce population size but also the average body size of individuals, due to the selection of bigger species with higher energy content, thereby impacting on the species fecundity.

2.3 Rocky Intertidal Community Structure

Rocky shores have the greatest biodiversity along the coastal ecosystem as they provide ecological niches due to a variation in food availability, microhabitats created by complex rocky substrates and the varying environmental conditions that prohibit complete species dominance (Smith, 2013). According to Ishida *et al*., (2021) rocky intertidal communities are the most convenient study sites for investigating the species diversity of macroinvertebrates and distribution due the clear zonation patterns and easily identifiable species. The vertical distribution also known as zonation is characterized by specific species that are well adapted to the physical elements and biological interactions of their environment (Tomanek & Helmuth, 2002). Smith (2013) explains that organisms along the shore have a tolerance range that have an upper and lower limit for different physical factors, the tolerance range presenting an optimum range within which the organism can grow and thrive.

The high intertidal zone below the splash zone is mostly composed of bare rocks, sparse tidal pools, barnacles, mobile crab and seaweed (Bednar, 2015; Mohan & Swathi, 2020). According to Bosman, Hockey and Siegfried (1987) higher limpet biomass with a larger than average size is present along upwelling rocky high to mid- intertidal zones where they attach to rocks and large boulders. The higher intertidal zone may also provide a prey refuge, due to harsh conditions such as desiccation and low nutrient availability, unlikely to be occupied by mobile marine predators (Smith, 2013). Organisms in the upper shores have survival mechanisms whereby species with shells are able to close to reduce moisture loss and mobile species retreat to crevices in rocks filled with water (Newell, 1976; NOAA, 2021).

The mid-shore is often the most diverse section of the rocky intertidal shore, generally a transition zone occupied by gastropods and barnacles at intermediate levels of wave exposure and where wave action is the greatest, barnacles may be most diverse (Underwood, Denley & Moran, 1983). According to Bednar (2015) the mid shores provide shelter for a variety of species such as seastars, anenomes, limpets, sponges, brittlestars and crabs. The low intertidal zone has a high species biodiversity and greater abundance due to waves causing less fluctuation in salinity and temperature (Mohan & Swathi, 2020). According to Bednar (2015) the least accessible low intertidal consist of large mussels or bivalve species firmly attached to a substrate, protected by numerous algal species.

2.4 Anthropogenic-induced Disturbance along the Coast

Marine life continues to be threatened by various sources of dumping in oceans ranging from plastic debris to sewage which contribute as one of the leading causes for coastal pollution (Conde *et al.*, 2020; Suaratissa & Rathnayake, 2017). It has been identified that apart from direct dumping, more pollutants from terrestrial areas including domestic, agricultural and industrial waste are carried to marine systems via riverine systems (Dahms, van der Bank & Greenfield, 2014). Construction activities along the Namibian coast involve heavy traffic along with accidental spillage of chemicals and marine litter that are harmful to intertidal communities (Wicks, 2022). According to Windom (1992) although sewage, plastic litter and oil spills pose a threat to the marine system, management plans can be applied to mitigate impacts.

The intertidal rocky shore has increasingly become an area of concern, as activities at first glance seemed harmless are now apparent. The rocky intertidal zone has been mainly damaged and disturbed by human activities more than any other marine ecosystem (Pinn & Rodgers, 2005). Easy accessibility to rocky intertidal areas is part of the cause of destruction and harvesting. Kennedy (2020) states that the two leading threats to intertidal shores are visitors exploring tidal pools, crushing organisms in the process and coastal development through pollution and runoff that contaminate habitats.

Beauchamp and Gowing (1982) and Mendez, Livore and Bigatti (2018) studied the impact of human trampling on the rocky intertidal shore by weighing the effects on separate sites with different levels of human disturbance ranging from no disturbance, moderately disturbed and heavily disturbed. It was found that the site with most human trampling had the least bivalve species, lower algae biomass and lower biodiversity along the shore. Furthermore even the lowest intensity of trampling lead to a loss of more than 40% of mussel bed coverage with changes occurring as fast as two trampling events.

Bednar (2015) compared the body sizes of five different gastropod species (*Lottia gigantea*, *Ocenebra circumtexta*, *Acanthinucella spriata, Acanthinucella punctulata*, *Tegula funebralis*, *Nucella emarginata*, *Nucella ostrina*) found in Marine Protected Areas (MPAs) and in disturbed areas along the central California coast. The study found MPAs were quite successful in terms of producing larger and more abundant gastropods. This may indicate that vulnerable intertidal rocky shores may benefit from protection measures put in place by coastal managers to reduce the harmful impacts from anthropogenic activities such as bulk harvesting.

Chapter 3

3. Materials and Methods

3.1 Study Sites

The study was conducted along the central Namibian coast where six sites were selected. Four of the sites are easily accessible to humans and experience human activities such as urbanization and recreational fishing - Dolphin Beach (DB), Long Beach Ext. 1 (LB), Badewanne (BA), Mile 4 (M4). Two of the sites are less accessible (control sites), either within or close to a conservation area – Afrodite Beach (AB) and Patrysberg (PB).

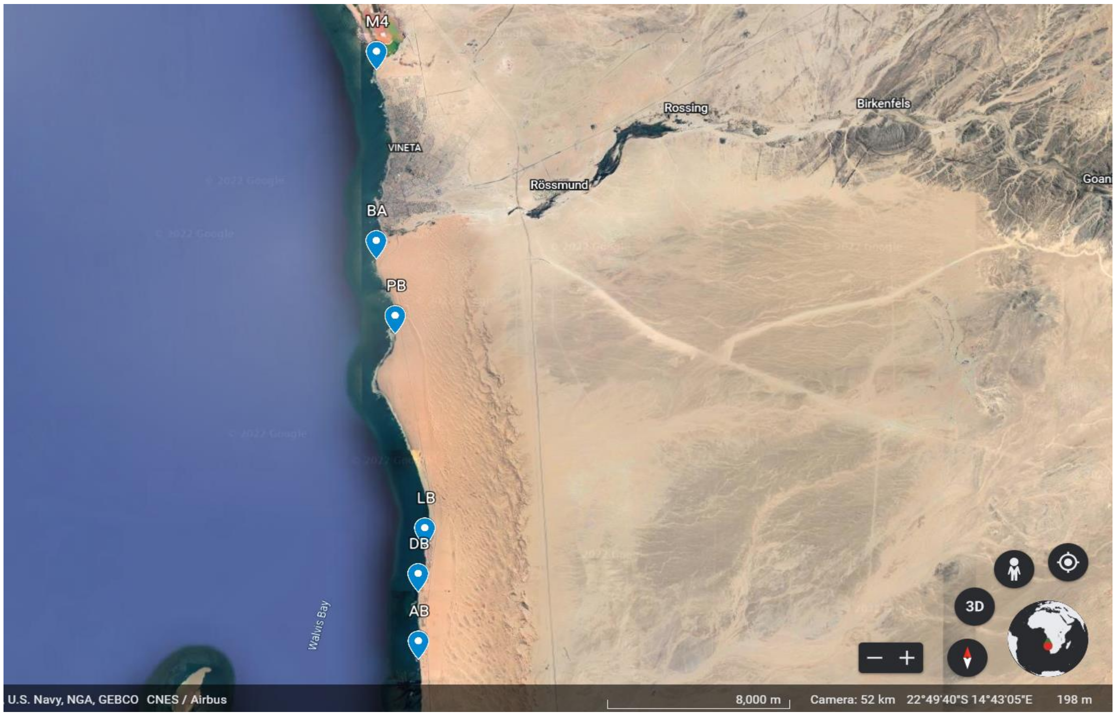


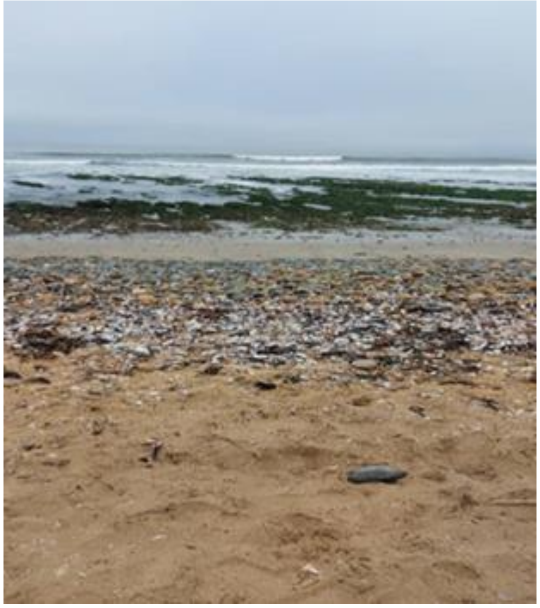
Figure 1: Map of the Sampling Sites along the Central Coast of Namibia (retrieved from Google Earth).

Table 1: Location, habitat type according vegetation coverage and description of sites sampled along with water temperature and pH measured at the start of each transect during 15-19 March and 13-16 June 2022

Site	**Location Coordinates**		**Habitat Type**	**Habitat Description**	**Transect**	**Water temperature (˚C)**		**pH**	
	Latitude	Longitude				March	June	March	June
Patrysberg	-22.730654	14.528812	Semi-exposed	Rocky and sandy areas, tidal pools and large rocks with several microhabitats	1	18.1	15.1	7.08	7.06
				Situated next to conservation area, closed off to visitors	2	17.7	15.4	7.5	7.06
					3	17.7	16.1	7.52	7.39
Afrodite Beach	-22.864673	14.538704	Exposed	Strong substrate, abundant green and red algae, no large boulders	1	17.2	17.1	7.36	6.85
				Found next to conservation area, Private Area	2	17.2	17.1	7.38	7.07
					3	17.3	17.1	7.7	7.05
Dolphin Beach	-22.836874	14.538571	Semi-exposed	Rocky with small crevices, strong substrate and abundant green algae	1	16.8	15.8	7.57	6.58
				Near Recreational Park, used for events and residential area	2	19.4	16.2	7.4	6.81
					3	17.3	16.2	7.56	6.89
Long Beach	-22.818072	14.541395	Sheltered	Tidal pools, large boulders and crevices for shelter	1	17.8	15.8	7.48	6.66
				Residential area	2	17.2	15.3	7.32	6.84
					3	16.9	15.7	7.46	6.75
Mile 4	-22.621961	14.520911	Exposed	Strong rocky substrate with small pools, abundant green algae and harsh waves	1	18.9	16.7	7.76	6.8
				Area used for recreational fishing and next to well-liked hotel	2	18.9	16.2	7.71	6.8
					3	19.1	16.2	7.56	6.84
Badewanne	-22.699811	14.520822	Sheltered	Large rocky columns, tidal pools and crevices with abundant green and red algae	1	18.7	16.8	7.92	7.31
				Hot spot for crayfish diving, fishing and off-road driving	2	20.8	16.9	8.08	7.35
					3	19.3	17.1	8.01	7.5

(a)

(b)



(c)

(d)

(e) (f)

Figure 2: Study Sites (a) Patrysberg, (b) Afrodite Beach, (c) Mile 4, (d) Long Beach, (e) Badewanne and (f) Dolphin Beach.

3.2 Sampling Methods

Sampling was done in March 2022 and June 2022 during low tide which was identified using the Walvis Bay tide timetable (https://www.cellstop.com.na/weather/walvis-bay-tides.html). At each site a systematic sampling technique was followed whereby a 50m single line transect was placed at three different areas about 20m apart. The line transects were laid from the spring low tide to the spring high tide mark. 0.5m x 0.5m quadrats were placed at alternating 5m intervals for about 50m in the intertidal rocky zone. In each of the quadrats macroinvertebrate samples were collected from a 20cm x 20cm section. In total 11 quadrats were laid at each area- four quadrats in the low and mid intertidal zones and three quadrats in the high intertidal zone. The pH and water temperature were measured using a digital water pH and TDS reader and recorded at each of the different areas within all the sites. The percent cover (%) of macroinvertebrates in each quadrat along the line transect was recorded.

3.3 Sorting of Samples

Samples stored in labelled zip lock bags in a freezer were sorted in the laboratory at the University of Namibia (UNAM) Main Campus. Samples were defrosted, strained and cleaned using two sieves with a mesh size of 2mm and 0.5mm respectively. All species were identified using an identification guide (Branch, et al., 2010). All individuals of all species were counted and recorded using a categorical method (Abundant: 50+ counts, Common: 21-50 counts, Uncommon: 6-20 counts, Rare: 1-5 counts). The size of each of the individual macroinvertebrate samples were measured with calipers and recorded. All the information was entered into Microsoft Excel 2013 for further data analysis.

(a) (b)

(c) (d)

(e)

Figure 3: (a) Defrosting species in Ziploc bags, (b) Marked Ziploc bags indicating transect and distance number, (c) Sorting of species using sieve with a mesh size 0.5mm, (d)

Digital calipers to measure species and species identification book, (e) Shell length measurement in mm using Digital calipers.

3.4 Data Analysis

Primer 7 with add-on Permanova was used to analyze the relationship between environmental factors and the community structure of species in different zones within each site. The abundance data were used and transformed to square root to limit the impact of high abundant species. Environmental data include temperature, pH and habitat type. Due to different units between variables, temperature and pH data were normalized. The ANOSIM test was carried out to analyze the level of separation among sites. The Pairwise test was used to analyze differences between sites. The Bray-Curtis was used to calculate the resemblance matrix to analyze the similarities among all of the different sites. Canonical Analysis of Principal coordinates (CAP) analysis was executed to interpret macroinvertebrate assemblages at different sites using environmental variables and species composition.

The Shapiro-Wilk test of normality was used to determine whether the size of specific macroinvertebrate species has a normal distribution. In all cases there was a normal distribution and an Independent T test was carried out to compare shell sizes of macroinvertebrates between control and disturbed sites in March and June.

The Shannon-Wiener Index of diversity was used to calculate the species diversity at each of the six sites in March and June. The Mann- Whitney U test was carried out to determine the diversity of macroinvertebrates between disturbed areas and less disturbed areas.

Chapter 4

4. Results

4.1 The macroinvertebrate assemblage structure among different sites in March

There was a significant difference ($P = 0.001$) in species assemblages among the different sites. The statistic (R) = 0.59, indicated a separation between Badewanne (BA) and the other sites. There was a significant difference ($P < 0.05$) in species assemblages between each paired site. *Oxystele variegata*, *C. granatina* and *S. argenvillei* were strongly associated with Badewanne (BA). *M. galloprovincialis* (invasive species) and *S. granularis* were strongly associated with Long Beach, Dolphin Beach, Patrysberg and Mile 4 while *S. capensis* was more common at Afrodite Beach (control site) (figure 4). The data explain 75% of the variance.

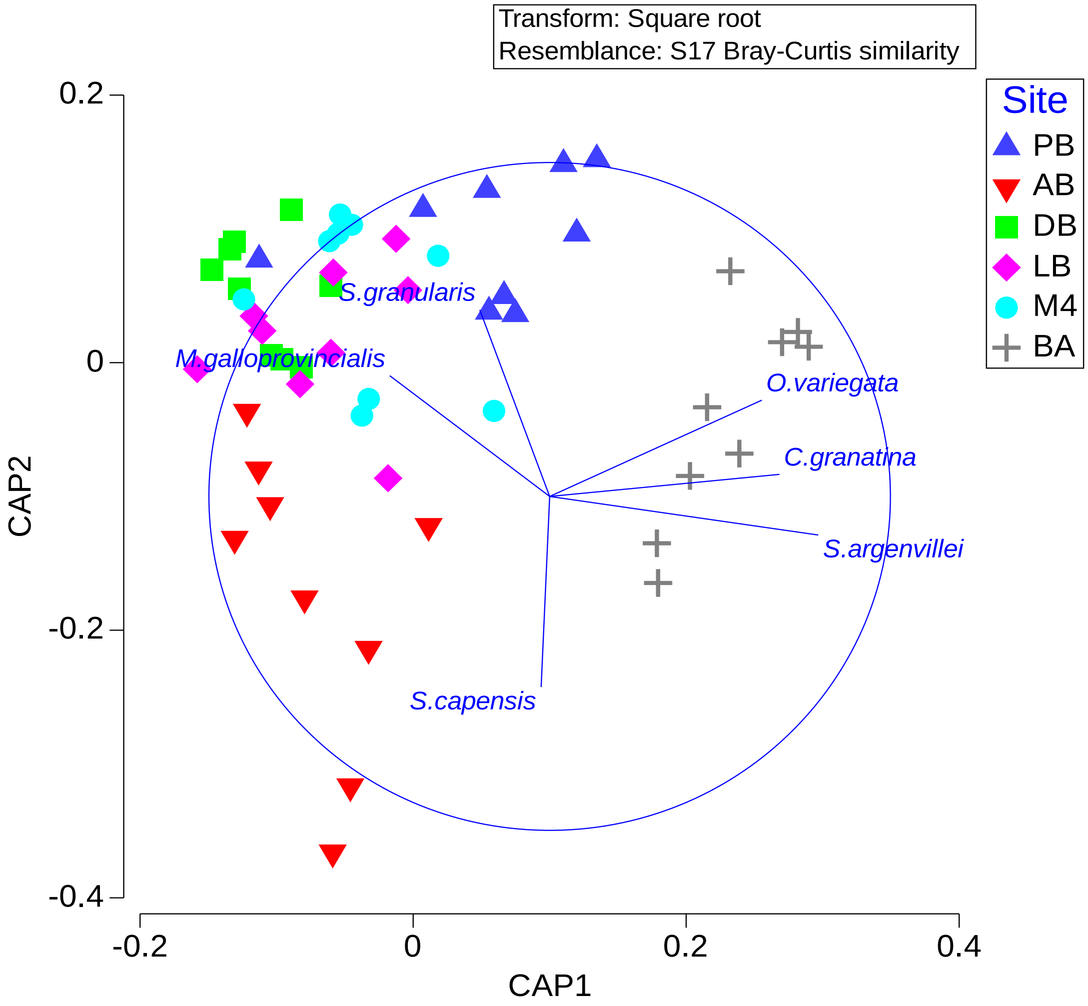


Figure 4: Canonical analysis of principal coordinates (CAP) ordination of macroinvertebrate assemblage structure for the different sites during 15 - 19 March 2022.

4.2 The macroinvertebrate assemblage structure among different sites in June

There was a significant difference (P= 0.001) in the species assemblages among the different sites. The statistic (R) = 0.62, indicated a sizable separation between Patrysberg (PB) and Dolphin Beach (DB). There was a significant difference ($P < 0.05$) in species assemblages between each paired site. *Perna perna* was strongly linked to Patrysberg (control site) whereas *C. granatina* and *O. variegata* were associated with both

Badewanne (BA) and Patrysberg (PB). *Ophioderma wahlbergii* was most common at Afrodite Beach. Similarly to March, *M. galloprovincialis* was linked to Dolphin Beach and Long Beach (figure 5). The data explain 72% of the variance.

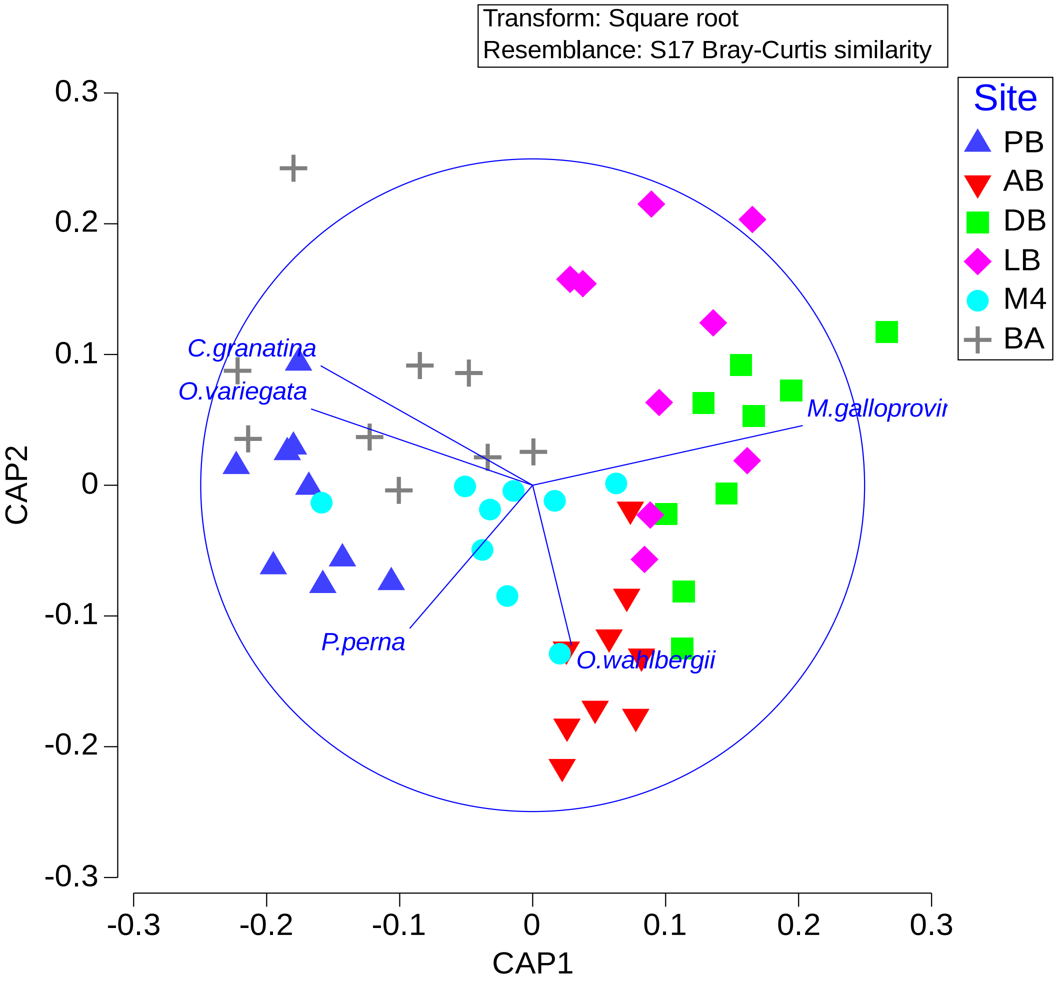


Figure 5: Canonical analysis of principal coordinates (CAP) ordination of macroinvertebrate assemblage structure for the different sites during 13 - 16 June 2022.

4.3 Comparison of mussel size among the different sites in March

Table 2: The average size of different mussel species (± SE) among the six sites during 15 - 19 March 2022.

	Patrysberg	Afrodite Beach	Dolphin Beach	Long Beach	Mile 4	Badewanne	P value
Species							
P. perna	61.67 ± 1.89	46.49 ± 2.63	36.16 ± 1.32	48.17 ± 2.45	69.79 ± 1.65	51.47 ± 1.81	0.947
C. meridionalis	45.4 ± 6.05	42.38 ± 3.03	-	-	35 ± 3.00	36.17 ± 5.24	0.082
S. patagonicus	52.55 ± 3.69	-	29.6 ± 1.40	-	-	-	<0.001
M. galloprovincialis	55.5 ± 4.84	52.4 ± 8.58	37.64 ± 1.31	42.53 ± 2.52	53.89 ± 3.72	49 ± 10.12	0.041

There was no significant difference in *P. perna* (t = 0.067, df = 666, P = 0.947) and *C. meridionalis* sizes (t = 1.775, df = 50, P = 0.082) between disturbed sites and control sites. The *P. perna* mussel was present and collected at all six sites, while *C. meridionalis* was absent from Dolphin Beach and Long Beach.

There was a significant difference in *S. patagonicus* (t = 4.806, df =17, P < 0.001) and *M. galloprovincialis* sizes (t = 2.057, df = 186, P = 0.041) between disturbed sites and control sites. *Semimytilus patagonicus* was present in Dolphin Beach (DB) and Patrysberg (PB). The average size of *S. patagonicus* was larger at Patrysberg (PB) and smaller at Dolphin

Beach (DB) with an average size difference of more than 40mm. *Mytilus galloprovincialis* was found at all six sites. The average size of *M. galloprovincialis* was largest at the two control sites (Patrysberg and Afrodite Beach) and smallest in two of the four disturbed sites, Dolphin Beach and Long Beach.

4.4 Comparison of mussel size among the different sites in June

Table 3: The average size of different mussel species (± SE) among the six sites during 13 - 16 June 2022.

	Patrysberg	Afrodite Beach	Dolphin Beach	Long Beach	Mile 4	Badewanne	P value
Species							
P. perna	71.85 ± 1.79	68.85 ± 3.25	60 ± 6.64	64.25 ± 5.21	78.43 ± 1.41	70.68 ± 2.05	0.874
C. meridionalis	40.5 ± 1.60	38.29 ± 1.25	33 ± 3.98	-	-	47.25 ± 2.49	0.186
S. patagonicus	38.46 ± 3.24	36. 51 ± 1.17	25.2 ± 0.30	26.41 ± 0.70	27.91 ± 1.03	-	<0.001
M. galloprovincialis	54.67 ± 0.67	51.92 ± 1.89	35.69 ± 1.45	41.36 ± 1.26	33.68 ± 2.58	44.52 ± 2.39	<0.001

There was no significant difference in *P. perna* (t = -0.159, df = 135, P = 0.874) and *C. meridionalis* sizes (t =1.335, df = 79, P = 0.186) between disturbed sites and control sites. *Perna perna* was found at all six sites that were sampled. *Choromytilus meridionalis* was found at the control sites and two of the four disturbed sites- Badewanne (BA) and Dolphin Beach (DB).

There was a significant difference in *S. patagonicus* (t = 8.716, df = 148, P < 0.001) and *M. galloprovincialis* sizes (t = 6.379, df = 521, P < 0.001) between disturbed sites and control sites. *Semimytilus patagonicus* was found at all the sites except for Badewanne (BA). The average size of *S. patagonicus* was largest at Patrysberg (PB) and Afrodite Beach (AB) and smallest at Dolphin Beach (DB) and Long Beach (LB). The average size of *M. galloprovincialis* was largest at the two control sites, Patrysberg (PB) and Afrodite Beach (AB) and smaller at all the other sites.

4.5 Comparison of True limpet size among the different sites in March

Table 4: The average size of different limpet species (± SE) among the six sites during 15 - 19 March 2022.

	Patrysberg	Afrodite Beach	Dolphin Beach	Long Beach	Mile 4	Badewanne	P value
Species							
S. granularis	30.13 ± 0.68	30.59 ± 1.43	21.08 ± 1.46	26.17 ± 2.57	29.81 ± 2.50	-	0.012
S. argenvillei	36.13 ± 4.02	47.25 ± 7.43	-	12 ± 0.82	-	24.38 ± 0.83	<0.001
C. granatina	55.2 ± 2.07	-	-	-	36.23 ± 2.45	41.47 ± 2.64	<0.001

There is a significant difference in *S. granularis* (t = 2.536, df = 192, P = 0.0012), *S. argenvillei* (t = 6.263, df = 63, P < 0.001) and *C. granatina* sizes (t = 4.29, df = 57, P < 0.001) between disturbed sites and control sites. All three limpet species, *S. granularis*, *S. argenvillei* and *C. granatina* had a larger average size at one or both of the control sites compared to the disturbed sites. There was a 35mm average size difference in *S. argenvillei* species between Afrodite Beach (AB) and Long Beach (LB). The true limpet, *C. granatina* reached an average size of 55mm at Afrodite Beach.

4.6 Comparison of True limpet size among the different sites in June

Table 5: The average size of different limpet species (± SE) among the six sites during 13 - 16 June 2022.

	Patrysberg	Afrodite Beach	Dolphin Beach	Long Beach	Mile 4	Badewanne	P value
Species							
S. granularis	33.66 ± 1.03	34 ± 3	27.78 ± 2.84	30.27 ± 2.22	26.38 ± 0.76	27.79 ± 1.31	<0.001
S. argenvillei	31.43 ± 1.81	40 ± 1	20.8 ± 5.84	30.67 ± 0.67	-	-	0.053
C. granatina	49.5 ± 2.74	-	-	49.71 ± 3.30	46.42 ± 1.45	48.45 ± 2.32	0.600

There was a significant difference (t = 4.398, df = 120, P < 0.001) in *S. granularis* size between disturbed sites and control sites. *Scutellastra granularis* was found in all sites. The average size of *S. granularis* was largest at Afrodite Beach (AB), a control site and the smallest average size of *S. granularis* is 26mm at Mile 4 (M4).

There was no significant difference in *S. argenvillei* (t = 2.102, df =15, P = 0.053) and *C. granatina* size (t = 0.527, df = 56, P = 0.600) between disturbed sites and control sites. Both species were found at four of the six sites.

4.7 Comparison of Variegated topshells (*O. variegata*) size among the different sites in March and June

Table 6: The average size of *O. variegata* species (± SE) among the six sites during 15 - 19 March 2022.

	Patrysberg	Afrodite Beach	Dolphin Beach	Long Beach	Mile 4	Badewanne	P value
Species							
O. variegata	19.26 ± 0.58	-	14.33 ± 0.33	16.17 ± 0.65	17.75 ± 1.65	15.2 ± 0.63	<0.001

Table 7: The average size of *O. variegata* species (± SE) among the six sites during 13 – 16 June 2022.

	Patrysberg	Afrodite Beach	Dolphin Beach	Long Beach	Mile 4	Badewanne	P value
Species							
O. variegata	18.81 ± 0.24	-	-	15.15 ± 0.45	18.36 ± 0.64	17.48 ± 0.34	<0.001

There was a significant difference in *O. variegata* size during March ($t = 4.884$, $df = 97$, $P < 0.001$) and June ($t = 4.294$, $df = 98$, $P < 0.001$) between disturbed sites and control sites. In both March and June, *O. variegata* sizes was largest at Patrysberg (PB) which is a less disturbed sites and smallest at Dolphin Beach (DB), a disturbed sites.

4.8 Species composition and Diversity of all sites in March and June

Table 8: The species composition and abundance of macroinvertebrates collected at the six different sites along the central Namibian coast during 15-19 March and 13-16 June 2022.

Month	Species	Patrysberg	Afrodite Beach	Dolphin Beach	Long Beach	Mile 4	Badewanne	Abundance
March	*Perna perna*	X	X	X	X	X	X	676
	Choromytilus meridionalis	X	X		X	X	X	53
	Semimytilus patagonicus	X		X				32
	Mytilus galloprovincialis	X	X	X	X	X	X	188
	Scutellastra granularis	X	X	X	X	X		195
	Scutellastra argenvillei	X	X		X		X	65
	Cymbula granatina	X	X	X	X	X	X	75
	Oxystele variegata	X	X	X	X	X	X	101
	Aulactinia reynaudi	X	X					9
	Chthamalus dentatus	X	X	X	X	X	X	40
	Latrunculia spinispiraefera	X	X			X		9
	Roweia frauenfeldi	X	X		X	X	X	57
	Discinisca tenuis	X						6
	Plagusia chabrus	X	X			X		5
	Afrolittorina africana		X			X		7
	Venerupis corrugatus						X	1
	Siphonaria capensis				X		X	7
	Pilumnoides rubius						X	1
	Tricolia capensis						X	2
	Afrolittorina knysnaensis				X			7
	Ophiothrix fragilis			X				6
June	*Perna perna*	X	X	X	X	X	X	460
	Choromytilus meridionalis	X	X	X			X	81
	Semimytilus patagonicus	X	X	X	X	X	X	155
	Mytilus galloprovincialis	X	X	X	X	X	X	526
	Scutellastra granularis	X	X	X	X	X	X	122
	Scutellastra argenvillei	X	X	X	X			17
	Cymbula granatina	X			X	X	X	59
	Oxystele variegata	X			X	X	X	100
	Plagusia chabrus	X	X	X			X	12
	Chthamalus dentatus	X	X	X	X	X	X	73
	Ophioderma wahlbergii	X	X	X	X			52
	Afrolittorina knysnaensis	X			X			16
	Cymbula miniata	X	X		X	X	X	17
	Latrunculia spinispiraefera	X	X	X				14
	Venerupis corrugatus	X	X	X				18
	Roweia frauenfeldi	X	X	X	X	X	X	108
	Tricolia capensis	X						5
	Anaspidea spp.	X						1
	Discinisca tenuis	X	X					23
	Siphonaria capensis	X						15
	Asterina stellifera	X						1
	Aulactinia reynaudi	X		X	X		X	54
	Ophiothrix fragilis		X					8
	Burnupena cincta						X	1

There was a significant difference in species diversity between control sites and disturbed sites in March (Z = -2.905, P = 0.002) and June (Z = -3.373, P < 0.001). Control sites had a higher species diversity in both March and June compared to disturbed sites.

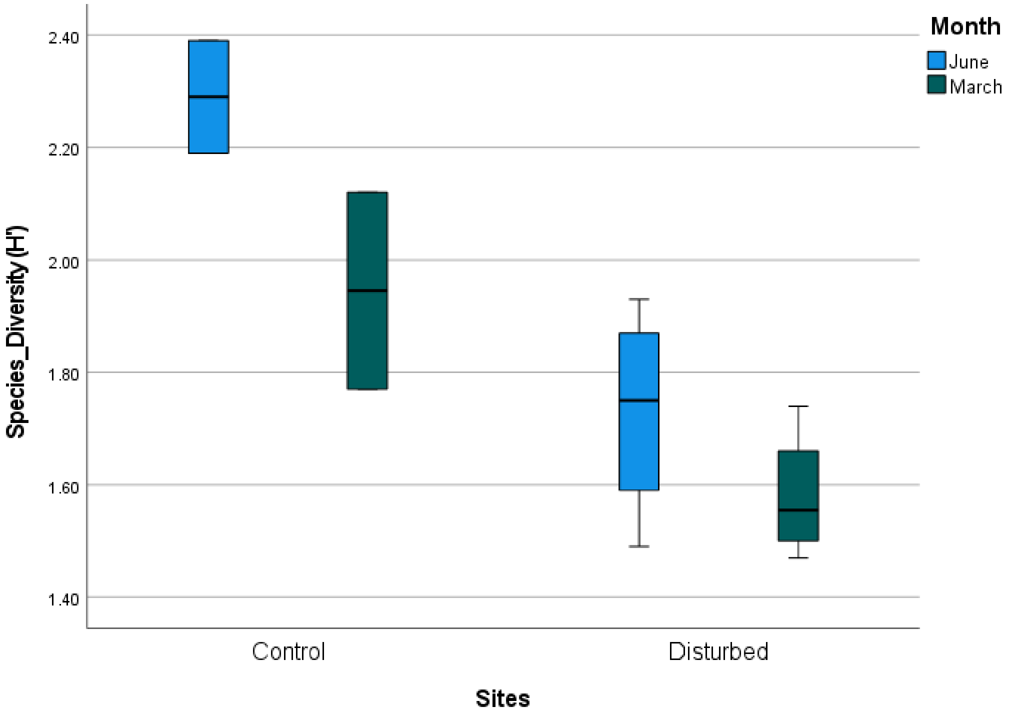


Figure 6**:** The species diversity of macroinvertebrates between control sites (Patrysberg and Afrodite Beach) and disturbed sites (Dolphin Beach, Long Beach, Mile 4 and Badewanne) in March 2022 and June 2022.

Chapter 5

5. Discussion

5.1 The macroinvertebrate assemblage structure among different sites

There was a significant difference in the species assemblages found among the different sites. There was an affiliation between Badewanne (BA), a disturbed site and two species, namely *C. granatina* and *O. variegata*. Badewanne (BA) is a sheltered site that has the highest average temperature in March and second highest in June, resulting in greater algae biomass as observed during the study, hence more food in close proximity for grazers (Ranglová *et al*., 2019). It is believed that the granite limpet (*C. granatina*), which is native to Namibia thrive in rocky habitats that are sheltered, under rocks and covered by algae, keeping them protected from harsh waves, competition and disturbance while providing great amounts of algae as a food source (Langejans, Dusseldorp & Thackeray, 2017; Mmonwa, 2013). *Oxystele variegata* have similar traits to *C. granatina* in terms of distribution, feeding strategy and diet (Langejans, Dusseldorp & Thackeray, 2017; Sousa *et al*., 2017). *Oxystele variegata* (Variegated topshell) is restricted to Southern Africa, belong to an extremely diverse group, and are grazers that rely heavily on green and red algae which are abundant at Badewanne (BA) according to habitat observations (Heller & Dempster, 1991; Van Der Bank *et al*., 2013).

Mytilus galloprovincialis (Mediterranean mussel) was dominant at two of the disturbed sites, Dolphin Beach (DB) and Long Beach (LB), in both March and June. These two sites are very close to each other compared to other disturbed sites. *Mytilus galloprovincialis* invaded the upper intertidal zone along the Namibian coast, inhabiting exposed to semi-exposed habitats and tend to have higher re-colonization and recruitment rates after disturbance, compared to indigenous species (Erlandsson, Pal & McQuaid, 2006; Steffani & Branch, 2005). This may indicate that the Mediterranean mussel is well adapted to survive in frequently disturbed locations. Through extensive studies, it was found that the invasive mussel is unable to compete with indigenous species and opted to co-exist by colonizing higher zones not dominated by *P. perna* (Hockey & van Erkom Schurink, 1992; Rius & McQuaid, 2006). In higher zones the invasive species is more noticeable and susceptible to human harvesting. Nicastro, Zardi and McQuaid (2010) supported by Erlandsson, Pal and McQuaid (2006) add that *M. galloprovincialis* lack in attachment strength compared to *P. perna* and in the event of higher wave actions and storms the invasive species are rendered weaker. These two sites have habitats with either tidal pools, crevices or both which provides shelter against natural disturbance such as wave action to which they are vulnerable and human harvesting.

Siphonaria capensis was strongly affiliated with a control site, Afrodite Beach (AB), in March. According to McQuaid, Cretchley and Rayner (1999) the Cape False limpet, *S. capensis* is common along the Namibian-South African coastline and characterizes the rocky shore due to their abundance, co-existence with other species and ability to deter predators. Waspe (2015) explains that *Siphonaria* organisms feed on sea grasses which are limited by algal growth at higher temperatures, this will either require settling in areas with lower average temperatures or fully functioning ecosystems whereby algal growth is controlled. Afrodite Beach (AB) has a relatively high species count and low average temperature in March compared to other sites.

Furthermore Afrodite Beach lacks large boulders and is characterized by an even landscape allowing a large portion or the intertidal rocky zone to be covered with water during high tide. According to Marshall and McQuaid (1992) *Siphonaria* species tend to lose water at an extremely fast rate due to their shell shapes, which make them more vulnerable to desiccation, affecting their survival. According to Kessel and Phillips (2018) *Siphonaria* species are highly vulnerable to human activities and increased coastal development could possibly affect their growth and maturation and lead to reduced recruitment success. This also explains the strong correlation between *S. capensis* and a control (less disturbed) site.

5.2 Comparison of mussel size among the different sites

There was no significant difference in *P. perna* and *C. meridionalis* size between disturbed sites and control sites in both March and June. The average sizes of *P. perna* are not distinctly different among any of the six sites sampled and different months. Haingura (2018) and Bayne and Worral (1980) state that *P. perna* reach maturity at a much faster rate compared to other mussel species such as *M. galloprovincialis* and can reach a length of 120mm. According to Segnino de Bravo, Chung and Perez (1998) *P. perna* tend to grow well in low-mid intertidal zones where water temperatures are lower. *Perna perna* and *C. meridionalis* experience optimum metabolism and growth at a temperature of 15-20˚C (Resagalla, de Souza Brazil and Salomão, 2007; van Erkom Schurink and Griffiths, 1993). This correlates with the temperature range at which species samples were collected at all the sites in March and June. The lower intertidal zones are also less prone to human harvesting because it requires more effort to reach these areas or they are exposed for shorter durations.

There was a significant difference in *S. patagonicus* and *M. galloprovincialis* size between disturbed sites and control sites in both March and June. In March there was a major difference in the size of *S. patagonicus* between a control site Patrysberg (PB) (53mm) and a disturbed site Dolphin Beach (DB) (19mm). In June the average size of *S. patagonicus* was larger in both control sites compared to disturbed sites. According to Zeeman, Branch and Pillay (2018) the invasive mussel, *S. patagonicus* had a high reproductive output but a surprisingly low survival rate in the face of disturbance, they have very weak shells and grow relatively slow along the southern west coast of Africa. Alexander, Skein & Robinson (2022) add that due to their weak shell and high energy value they are often targeted prey, influencing their survival and growth rate. Ma *et al*., (2020) state that both *S. patagonicus* and *M. galloprovincialis* play a profound role through competitive relationships with indigenous species, affecting the community structure of the benthic zones.

Unlike *S. patagonicus*, *M. galloprovincialis* thrive and grow to great lengths in warmer water temperatures (van Erkom Schurink and Griffiths, 1993; Zeeman, Branch & Pillay, 2018). It was found, however that *M. galloprovincialis* has a wide environmental tolerance (temperature, desiccation and air exposure) compared to indigenous species such as *P. perna* and *C. meridionalis* (Branch & Steffani, 2004). The average mussel size of *M. galloprovincialis* was largest in both control sites (PB and AB). As previously stated, this invasive mussel inhabits upper intertidal zones in accessible areas prone to trampling and harvesting of larger individuals. Rius and Cabral (2004) studied the impact of human harvesting on *M. galloprovincialis* and discovered that the size of the mussel species showed a major decline in more accessible areas compared to less accessible locations as a result of human traffic.

5.3 Comparison of True limpet size among the different sites

There was a significant difference in *S. granularis* size between disturbed sites and control sites, Patrysberg (PB) and Afrodite Beach (AB) in both March and June. Klein and Steele (2013) explain that although factors such as water temperature, salinity, and pH contribute to molluscan size variability over space and time, recent studies suggest that human activities produces substantial differences in average size especially in rocky intertidal communities. The size of *S. granularis* is larger in both control sites compared to disturbed sites regardless of the seasonal environmental conditions. Granular limpets' (*S. granularis*) decline in size can be attributed to easy accessibility on the upper rocky intertidal shore, whereby humans tend to select larger individuals due to easy detection, exposure and higher calorie intake as a source of food (Jerardino, Branch & Navarro, 2008; Klein & Steele, 2013; Steele & Klein, 2008). It is highly possible that a reduction in species size could affect reproductive output and abundance which pose a major issue for the intertidal zone as a whole due to possible organizational and distribution changes (Roy *et al*., 2003; Serranito *et al*., 2022).

There was significant difference in *S. argenvillei* size between disturbed sites (DB, LB, M4 and BA) and control sites (PB and AB) in March, but not in June. Historically, *S. argenvillei* is a large species able to grow up to 100mm in size, however in recent decades there has been a decline in size which is believed to be caused by human predation along the west coast of southern Africa (Ruiz, Steffani & Branch, 2002; Steele & Klein, 2008). Langejans, Dusseldorp and Thackeray (2017) also express that *S. argenvillei* is mostly in exposed habitats making them easily noticed by people and their shells are often detached or loosened from a substrate due incoming water and leading to easy removal during harvesting. In March, there was a wider range in individual sizes. Branch (1971) states that the Argenville's limpet tend to grow rapidly and efficiently in cooler water temperatures and are either absent from warmer environments or grow at a slower pace. Fast growth in winter conditions may contribute to less varying sizes resulting in larger individuals even in the face of disturbance.

Similarly to *S. argenvillei* size, there was a significant difference in *C. granatina* size between disturbed sites and control sites in March. The size of *C. granatina* is approximately 15mm larger at control sites than disturbed sites. It was found that *C. granatina* is highly accessible in the mid intertidal zone which are exposed during low spring tides making them vulnerable to human harvesting causing a decline in individual sizes in south west Africa (Jerardino, Branch and Navarro, 2008; Kyriacou & Parkington, 2015). Henriques, Delgado and Sousa (2017) adds that size-selective harvesting is the most common form of limpet exploitation- larger limpets are easily spotted, have a considerable commercial value and are more overall appealing.

There was no significant difference in the size of *C. granatina* between disturbed and control sites in June. The average size was above 40mm at all the sites collection took place. The granite limpet undergoes rapid growth in southwest Africa which is attributed to nutrition availability, resilience and fast maturity (Branch, 1974; Jerardino, Branch and Navarro, 2008).

5.4 Comparison of Variegated topshells (*O. variegata*) size among the different sites

A significant difference in *O. variegata* size was found between control sites and disturbed sites in both March and June. Sousa *et al*., (2017) explain that topshells play an important role as an indicator of human harvesting, causing a variation in species size. The size of these species did not exceed 20mm in both months. Sousa *et al*., (2017) add that according to studies performed by Ramirez, Tuya and Haroun (2009), a decrease in topshell sizes is a direct result of overexploitation, due to a correlation between smaller individual sizes and most populated areas. According to Sousa, Vasconcelos and Riera (2020) topshell species recovery after pulses of heavy human traffic and harvesting are quite slow which is caused by various factors such as reduced reproductive output, intense harvesting and predator-prey shifts. The available information regarding the Variegated topshell is insufficient due to lack of published research and the effects of anthropogenic activities on this species remain to be explored.

5.5 Species Composition and Diversity of all sites

There was a significant difference in species diversity between control sites and disturbed sites in both March and June. The control sites had a higher species diversity compared to disturbed sites. Studies carried out by Stevcic *et al*., (2018) and Villamor and Becerro (2012) found that species, trophic and functional diversity of macroinvertebrates and mobile invertebrates are significantly different between sites with no or limited access and unprotected sites. The control sites ultimately had a higher species diversity compared to disturbed sites. This may be due to both human activity (harvesting and trampling) and natural habitat preferences (Stevcic *et al.*, 2018). According to Bloch and Klingbeil (2014) there is a strong correlation between anthropogenic activities and species diversity of immobile macroinvertebrates, whereby a decline in biodiversity, abundance and coverage of species are found to be the general trend closest to population pressures along the coast. Bednar (2015) states that human harvesting reduces population size, genetic variability and in turn may reduce species diversity and composition. Stevcic *et al*., (2018) further explain that human visitors may affect top predators and keystone species resulting in changes in functional diversity, with changes being more evident among sessile macroinvertebrates.

One of the control sites, PB has tidal pools, sandy spots and large boulders providing different microhabitats serving different species and their habitat preferences. Similarly, one of the disturbed sites –LB has tidal pools, extremely large boulders and strong substrates which played a major role in species adaptation to extreme wave action. In a survey carried out by MFMR (2019) it was found that as a result of the large boulders/rocky substrate present at both LB and PB, these sites had a high percentage coverage of *Chthamalus dentatus* (barnacle). It may be said that all the different sites visited had some similarities in landscape characteristics. According to observations and the species composition list, many of the disturbed sites had similar species along the rocky intertidal area. Ssemakula (2013) stated that the rocky intertidal zone between Walvis Bay and Swakopmund, namely Dolphin and Long Beach had no significant differences in species composition but rather differences in species abundance.

Chapter 6

6. Conclusion & Recommendations

6.1 Conclusion

This research focused on human impact on the size, species composition and diversity of immobile macroinvertebrates along the rocky intertidal shores along the central Namibian coast as well as the macroinvertebrate assemblages among the different sites.

The study revealed that there was a strong correlation between the macroinvertebrate assemblage structure of the rocky intertidal zone and anthropogenic disturbance. Species that were found at vulnerable sites in terms of disturbance have adaptations that allow them to recover from certain impacts but not without consequence. The invasive mussels studied, namely *M. galloprovincialis* and *S. patagonicus* showed a major decline in size between disturbed and less disturbed (control) sites. It was found that these invasive mussels are unable to outcompete native mussels such as *P. perna* and even though they are able to co-exist, it caused invasive mussels to be more vulnerable to human harvesting affecting the size of individuals. The invasive mussels are forced to move to upper intertidal zones making them more prone to human harvesting and trampling. The limpets studied, *S. granularis*, *S. argenvillei* and *C. granatina* had a significantly reduced size at disturbed sites either in both months (*S. granularis*) or only in March as in the case with *S. argenvillei* and *C. granatina*. Although these true limpet species are resilient, they are extremely vulnerable to human harvesting due to their position on the upper rocky intertidal shore, exposure and high energy value. The false limpet, *O. variegtata* are major indicators of human harvesting through extreme decelerated growth. They had a significantly lower size at disturbed sites compared to the control sites.

Human activities may negatively impact on the number of different species and diversity which may have dire consequences on species relationships, functional diversity, intertidal heterogeneity and the ecosystem structure which may in turn affect Namibia’s economy due to the complete loss of valuable macroinvertebrates.

6.2 Recommendations

The study highlighted possible threats to macroinvertebrates along the central Namibian coast, however a one-year period is simply not enough time to fully monitor and evaluate the extent of human disturbance. Long-term research and monitoring of immobile macroinvertebrates is required in order to authorize proper coastal management strategies including policies directed to mitigate the negative impacts and conserve rocky intertidal species. In future studies it may be advised that comparisons among sites should be done after high visitation events/seasons and relatively low visitation seasons. The use of historical data such as archived specimens may be helpful for long-term comparisons. This study may provide a foundation for future research opportunities, such as using *O. variegata* and other human harvesting indicator species to survey more locations along the coast. The study may be expanded to include human impacts on plant species along the rocky intertidal area and possible impacts on herbivorous organisms.

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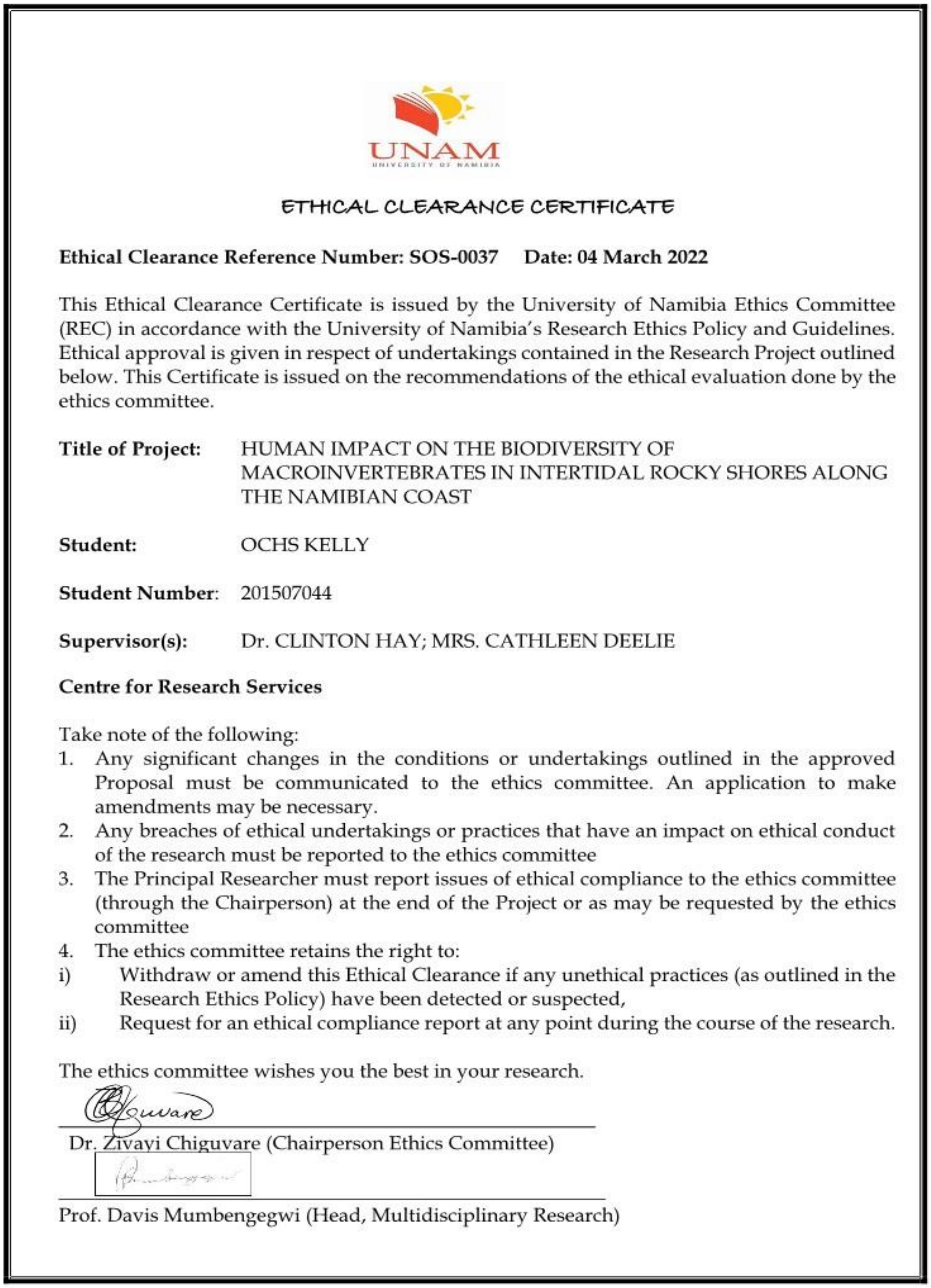
Appendices

Appendix 1: Research Project Ethical Clearance Certificate



UNAM
UNIVERSITY OF NAMIBIA

ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: SOS-0037 Date: 04 March 2022

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:	HUMAN IMPACT ON THE BIODIVERSITY OF MACROINVERTEBRATES IN INTERTIDAL ROCKY SHORES ALONG THE NAMIBIAN COAST
Student:	OCHS KELLY
Student Number:	201507044
Supervisor(s):	Dr. CLINTON HAY; MRS. CATHLEEN DEELIE

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:

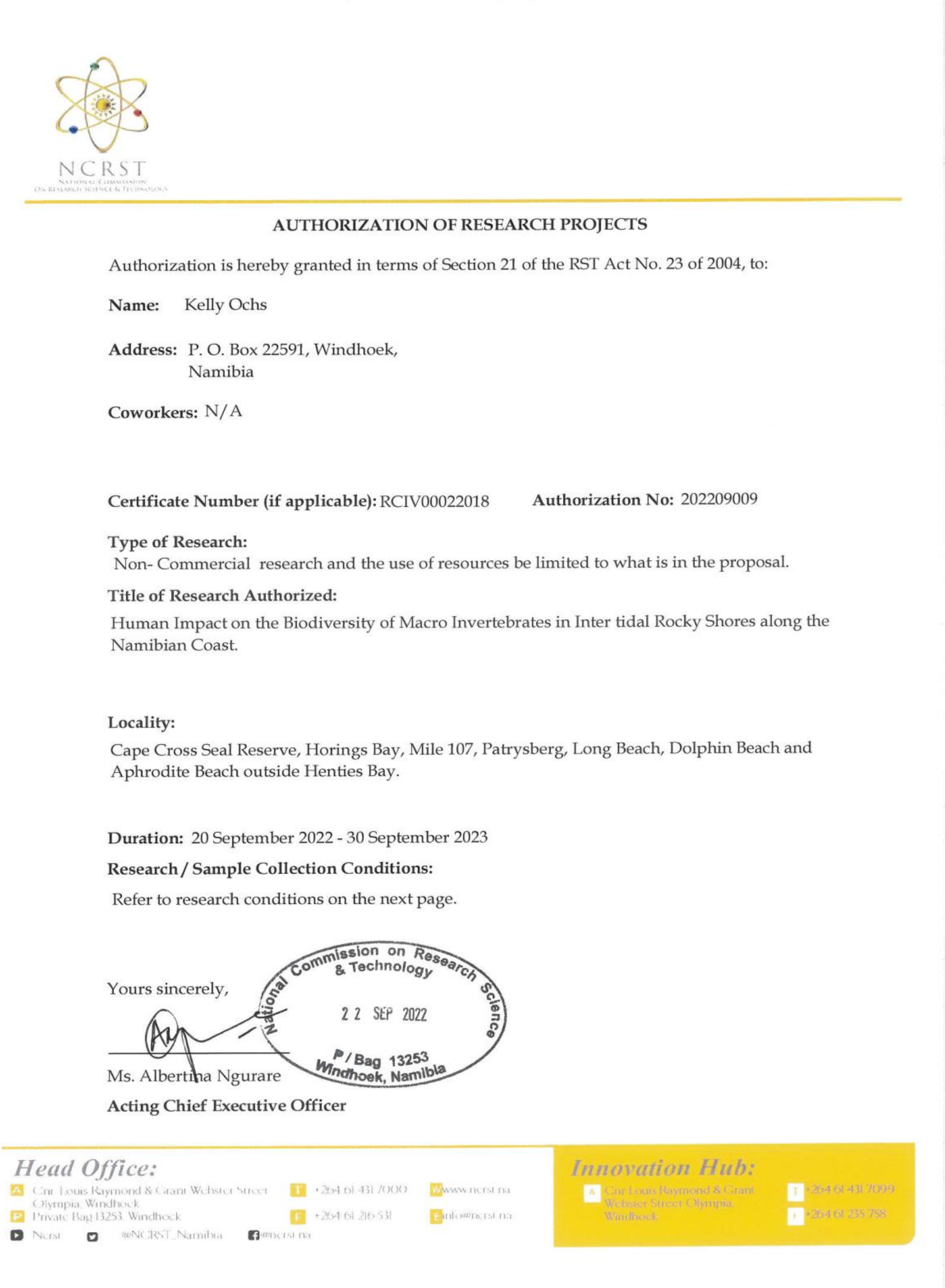
i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,
ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

Dr. Zivayi Chiguvare (Chairperson Ethics Committee)

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

Appendix 2: Research Permit by National Commission on Research Science & Technology (NCRST)



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: Kelly Ochs

Address: P. O. Box 22591, Windhoek,
Namibia

Coworkers: N/A

Certificate Number (if applicable): RCIV00022018 **Authorization No:** 202209009

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

Title of Research Authorized:
Human Impact on the Biodiversity of Macro Invertebrates in Inter tidal Rocky Shores along the Namibian Coast.

Locality:
Cape Cross Seal Reserve, Horings Bay, Mile 107, Patrysberg, Long Beach, Dolphin Beach and Aphrodite Beach outside Henties Bay.

Duration: 20 September 2022 - 30 September 2023

Research / Sample Collection Conditions:
Refer to research conditions on the next page.

Yours sincerely,

22 SEP 2022
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Windhoek, Namibia

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Appendix 3: ANOSIM Test of Species abundance in different sites in March and June

Tests for differences between unordered Site groups		
March	Sample statistic (R):	0.587
	Significance level of sample statistic:	0.10%
June	Sample statistic (R):	0.618
	Significance level of sample statistic:	0.10%

Appendix 4: Pairwise Test of Species abundance among paired sites in March

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
PB, AB	0.504	0.1	24310	999	0
PB, DB	0.558	0.1	24310	999	0
PB, LB	0.652	0.1	24310	999	0
PB, M4	0.398	0.1	24310	999	0
PB, BA	0.742	0.1	24310	999	0
AB, DB	0.55	0.1	24310	999	0
AB, LB	0.434	0.1	24310	999	0
AB, M4	0.376	0.1	24310	999	0
AB, BA	0.666	0.1	24310	999	0
DB, LB	0.262	0.1	24310	999	0
DB, M4	0.473	0.1	24310	999	0
DB, BA	1	0.1	24310	999	0
LB, M4	0.323	0.4	24310	999	3
LB, BA	0.939	0.1	24310	999	0
M4, BA	0.929	0.2	24310	999	1

Appendix 5: Pairwise Test of Species abundance among paired sites in June

Groups	R Statistic	Significance Level %	Possible Permutations	Actual Permutations	Number >= Observed
PB, AB	0.866	0.2	24310	999	1
PB, DB	0.928	0.1	24310	999	0
PB, LB	0.924	0.1	24310	999	0
PB, M4	0.648	0.1	24310	999	0
PB, BA	0.552	0.1	24310	999	0
AB, DB	0.491	0.2	24310	999	1

AB, LB	0.619	0.3	24310	999	2
AB, M4	0.444	0.1	24310	999	0
AB, BA	0.738	0.1	24310	999	0
DB, LB	0.407	0.4	24310	999	3
DB, M4	0.56	0.1	24310	999	0
DB, BA	0.758	0.1	24310	999	0
LB, M4	0.573	0.1	24310	999	0
LB, BA	0.722	0.1	24310	999	0
M4, BA	0.172	2.2	24310	999	21

Appendix 6: Statistical test values of the species sizes between control sites (PB and AB) and disturbed sites (BA, M4, LB, DB) in March and June 2022

Month	**Species**	**t**	**df**	**P**
March	*P. perna*	0.067	666	0.947
	C. meridionalis	1.775	50	0.082
	S. patagonicus	4.806	17	0.001
	M. galloprovincialis	2.057	186	0.041
	S. granularis	2.536	192	0.012
	S. argenvillei	6.263	63	0.001
	C. granatina	4.29	57	0.001
	O. variegata	4.884	97	0.001
June	*P. perna*	-0.159	135	0.874
	C. meridionalis	1.335	79	0.186
	S. patagonicus	8.716	148	0.001
	M. galloprovincialis	6.379	521	0.001
	S. granularis	4.398	120	0.001
	S. argenvillei	2.102	15	0.053
	C. granatina	0.527	56	0.6
	O. variegata	4.294	98	0.001

Appendix 7: Species diversity at Patrysberg (PB) in March 2022

Mar-22				
Species	**Frequency**	**Pi**	**In (Pi)**	**pi *In (pi)**
S. granularis	63	0.25403	-1.69	-0.429315
C. granatina	15	0.06048	-2.85	-0.172379
A. reynaudi	8	0.03226	-3.54	-0.114194
S. argenvillei	4	0.01613	-2.41	-0.038871
P. perna	75	0.30242	-1.33	-0.402218
S. patagonicus	11	0.04435	-4.01	-0.177863
O. variegata	35	0.14113	-1.55	-0.21875
C. meridionalis	5	0.02016	-3.54	-0.071371
C. dentatus	10	0.04032	-3.32	-0.133871
M. galloprovincialis	4	0.01613	-4.24	-0.068387
L. spinispiraefera	3	0.0121	-4.53	-0.054798
R. frauenfeldii	6	0.02419	-3.83	-0.092661
D. tenuis	6	0.02419	-3.83	-0.092661
P. chabrus	3	0.0121	-4.53	-0.054798
	248			**-2.122137**
				H **= 2.12**

Appendix 8: Species diversity at Afrodite Beach (AB) in March 2022

Mar-22				
Species	**Frequency**	**Pi**	**In (Pi)**	**pi *In (pi)**
P. perna	114	0.53271	-0.72	-0.383551
S. granularis	16	0.07477	-1.83	-0.136822
M. galloprovincialis	5	0.02336	-2.33	-0.054439
L. spinispiraefera	3	0.01402	-4.66	-0.065327
S. argenvillei	4	0.01869	-3.28	-0.061308
R. frauenfeldii	17	0.07944	-2.93	-0.232757
O. variegata	2	0.00935	-4.38	-0.040935
C. granatina	15	0.07009	-2.82	-0.197664
C. meridionalis	29	0.13551	-2.93	-0.397056
P. chabrus	1	0.00467	-5.76	-0.026916
A. reynaudi	1	0.00467	-5.76	-0.026916
A. africana	5	0.02336	-4.15	-0.096963
C. dentatus	2	0.00935	-5.07	-0.047383
	214			**-1.768037**
				H **= 1.77**

Appendix 9: Species diversity at Dolphin Beach (DB) in March 2022

Mar-22				
Species	**Frequency**	**Pi**	***In* (Pi)**	***pi *In* (pi)**
S. patagonicus	21	0.07447	-2.55	-0.189894
M. galloprovincialis	91	0.3227	-1.16	-0.374326
C. dentatus	11	0.03901	-3.24	-0.126383
P. perna	112	0.39716	-0.93	-0.369362
O. variegata	3	0.01064	-4.54	-0.048298
S. granularis	37	0.13121	-1.95	-0.255851
C. granatina	1	0.00355	-5.64	-0.02
O. fragilis	6	0.02128	-3.85	-0.081915
	282			**-1.466028**
				***H* = 1.47**

Appendix 10: Species diversity at Long Beach (LB) in March 2022

Mar-22				
Species	**Frequency**	**Pi**	***In* (Pi)**	***pi *In* (pi)**
P. perna	113	0.48918	-0.66	-0.322857
M. galloprovincialis	57	0.24675	-1.32	-0.325714
S. granularis	23	0.09957	-2.56	-0.254892
C. dentatus	5	0.02165	-3.84	-0.083117
O. variegata	12	0.05195	-3.15	-0.163636
S. argenvillei	4	0.01732	-5.45	-0.094372
C. meridionalis	1	0.00433	-5.45	-0.023593
A. knysnaensis	7	0.0303	-3.51	-0.106364
S. capensis	1	0.00433	-5.45	-0.023593
R. frauenfeldii	7	0.0303	-3.51	-0.106364
C. granatina	1	0.00433	-5.45	-0.023593
	231			**-1.528095**
				***H* = 1.53**

Appendix 11: Species diversity at Mile 4 (M4) in March 2022

Mar-22				
Species	**Frequency**	**Pi**	***In*** **(Pi)**	***pi *In*** **(pi)**
P. perna	144	0.51064	-0.65	-0.331915
S. granularis	56	0.19858	-1.81	-0.359433
M. galloprovincialis	28	0.09929	-2.31	-0.229362
L. spinispiraefera	3	0.01064	-4.64	-0.049362
R. frauenfeldii	17	0.06028	-2.91	-0.175426
O. variegata	4	0.01418	-4.36	-0.061844
C. granatina	13	0.0461	-3.1	-0.142908
C. meridionalis	12	0.04255	-3.26	-0.138723
P. chabrus	1	0.00355	-5.74	-0.020355
A. africana	2	0.00709	-5.05	-0.035816
C. dentatus	2	0.00709	-5.05	-0.035816
	282			**-1.580957**
				H **= 1.58**

Appendix 12: Species diversity at Badewanne (BA) in March 2022

Mar-22				
Species	**Frequency**	**Pi**	***In*** **(Pi)**	***pi *In*** **(pi)**
C. meridionalis	6	0.02105	-4.31	-0.09074
P. perna	118	0.41404	-1.02	-0.42232
C. granatina	30	0.10526	-2	-0.21053
S. argenvillei	53	0.18596	-1.62	-0.30126
V. corrugatus	1	0.00351	-5.7	-0.02
S. capensis	6	0.02105	-3.91	-0.08232
P. rubius	1	0.00351	-5.7	-0.02
O. variegata	45	0.15789	-1.69	-0.26684
R. frauenfeldii	10	0.03509	-3.4	-0.1193
C. dentatus	10	0.03509	-3.4	-0.1193
T. capensis	2	0.00702	-5.01	-0.03516
M. galloprovincialis	3	0.01053	-5.01	-0.05274
	285			**-1.74049**
				H **= 1.74**

Appendix 13: Species diversity at Patrysberg (PB) in June 2022

Jun-22				
Species	**Frequency**	**Pi**	**In (Pi)**	**pi *In (pi)**
P. chabrus	2	0.00568	-5.24	-0.029773
M. galloprovincialis	3	0.00852	-4.84	-0.04125
C. meridionalis	30	0.08523	-2.41	-0.205398
P. perna	84	0.23864	-1.31	-0.312614
S. granularis	41	0.11648	-2.53	-0.294688
C. dentatus	19	0.05398	-2.99	-0.161392
O. variegata	43	0.12216	-2.27	-0.277301
C. granatina	20	0.05682	-2.72	-0.154545
S. argenvillei	7	0.01989	-2.94	-0.058466
S. patagonicus	13	0.03693	-3.3	-0.121875
O. wahlbergii	14	0.03977	-3.3	-0.13125
A. knysnaensis	9	0.02557	-3.74	-0.095625
C. miniata	8	0.02273	-3.86	-0.087727
L. spinispiraefera	9	0.02557	-3.74	-0.095625
V. corrugatus	4	0.01136	-4.55	-0.051705
R. frauenfeldii	9	0.02557	-3.74	-0.095625
T. capensis	5	0.0142	-4.33	-0.061506
Anaspidea spp.	1	0.00284	-5.93	-0.016847
D. tenuis	4	0.01136	-4.55	-0.051705
S. capensis	15	0.04261	-3.23	-0.137642
A. stellifera	1	0.00284	-5.93	-0.016847
A. reynaudi	11	0.03125	3.54	0.110625
	352			**-2.388778**
				***H* = 2.39**

Appendix 14: Species diversity at Afrodite Beach (AB) in June 2022

Jun-22				
Species	**Frequency**	**Pi**	***In*** **(Pi)**	***pi *In*** **(pi)**
P. perna	81	0.24771	-1.45	-0.359174
L. spinispiraefera	4	0.01223	-4.57	-0.055902
M. galloprovincialis	73	0.22324	-1.37	-0.305841
O. fragilis	8	0.02446	-3.88	-0.094924
R. frauenfeldii	23	0.07034	-2.83	-0.199052
O. wahlbergii	24	0.07339	-2.78	-0.204037
S. patagonicus	35	0.10703	-2.01	-0.215138
C. miniata	2	0.00612	-5.27	-0.032232
C. meridionalis	31	0.0948	-2.35	-0.222783
S. granularis	2	0.00604	-5.11	-0.03087
S. argenvillei	2	0.00612	-4.17	-0.025505
C. dentatus	4	0.01223	-4.57	-0.055902
D. tenuis	19	0.0581	-3.02	-0.175474
P. chabrus	6	0.01835	-4.17	-0.076514
V. corrugatus	13	0.03976	-3.4	-0.135168
	327			**-2.188515**
				H **= 2.19**

Appendix 15: Species diversity at Dolphin Beach (DB) in June 2022

Jun-22				
Species	**Frequency**	**Pi**	***In*** **(Pi)**	***pi *In*** **(pi)**
P. perna	29	0.09236	-2.4	-0.221656
C. meridionalis	16	0.05096	-2.88	-0.146752
M. galloprovincialis	193	0.61465	-0.48	-0.295032
O. wahlbergii	9	0.02866	-3.57	-0.102325
P. chabrus	3	0.00955	-4.67	-0.044618
A. reynaudi	5	0.01592	-4.16	-0.066242
S. patagonicus	9	0.02866	-3.69	-0.105764
S. granularis	18	0.05732	-2.64	-0.151338
S. argenvillei	5	0.01592	-4.14	-0.06592
C. dentatus	15	0.04777	-3.06	-0.146178
L. spinispiraefera	1	0.00318	-5.77	-0.018376
R. frauenfeldii	10	0.03185	-3.47	-0.11051
V. corrugatus	1	0.00318	-5.77	-0.018376
	314			**-1.493086**
				H **= 1.49**

Appendix 16: Species diversity at Long Beach (LB) in June 2022

Jun-22				
Species	**Frequency**	**Pi**	***In* (Pi)**	***pi *In* (pi)**
S. argenvillei	3	0.00746	-6	-0.044776
P. perna	48	0.1194	-2.13	-0.254328
M. galloprovincialis	164	0.40796	-0.9	-0.367164
S. patagonicus	85	0.21144	-1.55	-0.327736
A. reynaudi	34	0.08458	-2.48	-0.209751
O. wahlbergii	5	0.01244	-4.39	-0.054602
C. granatina	7	0.01741	-3.81	-0.066343
A. knysnaensis	7	0.01741	-4.06	-0.070697
O. variegata	13	0.03234	-3.44	-0.111244
C. dentatus	19	0.04726	-3.06	-0.144627
C. miniata	1	0.00249	-6	-0.014925
R. frauenfeldii	5	0.01244	-4.39	-0.054602
S. granularis	11	0.02736	-3.44	-0.094129
	402			**-1.814925**
				***H* = 1.81**

Appendix 17: Species diversity at Mile 4 (M4) in June 2022

Jun-22				
Species	**Frequency**	**Pi**	***In* (Pi)**	***pi *In* (pi)**
P. perna	138	0.44089	-0.81	-0.357125
M. galloprovincialis	60	0.19169	-1.65	-0.316294
C. miniata	4	0.01278	-4.38	-0.055974
S. granularis	26	0.08307	-2.5	-0.207668
C. granatina	12	0.03834	-3.2	-0.122684
R. frauenfeldii	37	0.11821	-2.15	-0.254153
C. dentatus	13	0.04153	-3.2	-0.132907
S. patagonicus	12	0.03834	-3.28	-0.125751
O. variegata	11	0.03514	-3.36	-0.118083
	313			**-1.690639**
				***H* = 1.69**

Appendix 18: Species diversity at Badewanne (BA) in June 2022

Jun-22				
Species	**Frequency**	**Pi**	***In* (Pi)**	***pi *In* (pi)**
P. perna	80	0.34783	-1.13	-0.39304
C. granatina	20	0.08696	-2.14	-0.18609
M. galloprovincialis	33	0.14348	-2.01	-0.28839
S. granularis	24	0.10435	-2.11	-0.22017
O. variegata	33	0.14348	-1.95	-0.27978
R. frauenfeldii	24	0.10435	-2.33	-0.24313
A. reynaudi	4	0.01739	-4.12	-0.07165
B. cincta	1	0.00435	-5.51	-0.02396
S. patagonicus	1	0.00435	-5.51	-0.02396
C. miniata	2	0.0087	-4.82	-0.04191
C. meridionalis	4	0.01739	-4.12	-0.07165
P. chabrus	1	0.00435	-5.51	-0.02396
C. dentatus	3	0.01304	-4.41	-0.05752
	230			**-1.92522**
				***H* =1.93**

Appendix 19: Statistical test values of the species diversity between control sites (PB and AB) and disturbed sites (BA, M4, LB, DB) in March and June 2022

	Z	**P**
March	-2.905	0.002
June	-3.373	<0.001