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Spatial and Temporal Variations in Abundance and Composition of Benthic Macrofauna Associated With Seagrass Beds in Abu Dhabi

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College of Science

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SPATIAL AND TEMPORAL VARIATIONS IN ABUNDANCE AND COMPOSITION OF BENTHIC MACROFAUNA ASSOCIATED WITH SEAGRASS BEDS IN ABU DHABI

Maitha Mohamed Al Hameli

This thesis submitted in partial fulfilment of the requirements for the degree of
Master of Science in Environmental Sciences

Under the Supervision of Professor Waleed Hamza

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Declaration of Original Work

I, Maitha Mohmad Al Hameli, the undersigned, a graduate student at the United Arab Emirates University (UAEU), and the author of this thesis entitled "*Spatial and Temporal Variations in Abundance and Composition of Benthic Macrofauna Associated with Seagrass Beds in Abu Dhabi.*", hereby, solemnly declare that this thesis is my own original research work that has been done and prepared by me under the supervision of Professor Waleed Hamza in the College of Science at UAEU. This work has not previously been presented or published, or formed the basis for the award of any academic degree, diploma or a similar title at this or any other university. Any materials borrowed from other sources (whether published or unpublished) and relied upon or included in my thesis have been properly cited and acknowledged in accordance with appropriate academic conventions. I further declare that there is no potential conflict of interest with respect to the research, data collection, authorship, presentation and/or publication of this thesis.

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Abstract

This study compared the seasonal variations of macrofaunal communities found within the seagrass beds of protected areas and non-protected areas in Abu Dhabi. The study took into consideration the spatial and temporal differences of the sites and seasons as well as other environmental factors, like trace metals concentrations, water temperature, sediment composition, salinity and pH. The main objective and aim of this study is to investigate changes in the community structure of macrofauna with changes in location and seasons. Environmental parameters and biological samples were collected in-situ and analyzed at UAEU labs from both sites, during both seasons (winter and summer). All data have analyzed according to standardized techniques. The results showed that there was a temporal and spatial difference in the macrofaunal communities. Some of the findings showed that the Non-protected area has a slightly higher diversity, due to the increase of Polychaeta populations, than in the protected area, which highlights the need of better management plans for all seagrass beds, in and out of protected areas. The study has also shown that, until no enough studies have carried out on seagrass in Abu Dhabi. Moreover, it shed light on the species diversity within the seagrass community with both spatial and temporal variations.

Keywords: Seagrass, Macrofauna, Protected Area, Non-Protected Area.

Title and Abstract (in Arabic)

دراسة الاختلافات الموسمية في وفرة وتكوين الكائنات القاعية المتواجدة في الحشائش البحرية وفقاً لموقعها في مياة أبو ظبي الساحلية

الملخص

هذه الدراسة تهدف الى مقارنة مجتمعات الكائنات القاعية (المكاروفونا) الموجودة في الحشائش البحرية داخل مناطق المحمية والمناطق الغير محمية في أبو ظبي بين فصلي الصيف والشتاء. وتأخذ الدراسة في الاعتبار الاختلافات المكانية والموسمية للمواقع وكذلك العوامل الأخرى، مثل درجة حرارة المياه، المعادن النادرة، وتكوين التربة، والملوحة ودرجة الحموضة. والهدف الرئيسي من هذه الأطروحة هو محاولة فهم التغيير في بنية مجتمعات الكائنات القاعية (المكاروفونا) نتيجة التغير في الموقع ودرجة الحرارة. حيث تم جمع البيانات والعينات البيولوجية من موقع الدراسة، كما تم تحليل بعضها في مختبرات جامعة الإمارات العربية المتحدة من كلا الموقعين وخلال كلا الموسمين. تم فرز و تحليل جميع البيانات والعينات التي تم جمعها من المواقع ومقارنتها. و أظهرت نتائج الدراسة وجود فرق في مجتمعات الكائنات القاعية (المكاروفونا) مع اختلاف موقعها و درجات الحرارة. كما أظهرت النتائج أن المنطقة غير المحمية لديها تنوع أعلى في الديدان متعددة القشور نوعاً ما مقارنةً بالمنطقة المحمية، مما يبرز أهمية إيجاد برامج صون وإدارة متخصصة لقاع الحشائش البحرية، داخل وخارج المناطق المحمية. كما ألقت الدراسة بعض الضوء على الأنواع الموجودة في مجتمع الأعشاب البحرية، وكيف تختلف مجتمعات الكائنات القاعية (المكاروفونا) مع اختلاف التوزيع المكاني والتغير في المواسم ودرجات الحرارة. حيث أوضحت الدراسة نقص في البيانات حول الحشائش البحرية في أبو ظبي وأنه لم يتم إجراء دراسات كافية عليها.

مفاهيم البحث الرئيسية: الكائنات القاعية، المكاروفونا، الحشائش البحرية، المنطقة غير المحمية، المنطقة المحمية.

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Dedication

To all who that supported me through my program

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List of Abbreviations

EAD	Environment Agency Abu Dhabi
NPA	Non-Protected Area
PA	Protected Area
UAEU	United Arab Emirates University

Chapter 1: Introduction

1.1 Overview

Seagrasses are valuable habitats, providing important ecological and economic components of coastal ecosystems worldwide. Seagrasses are a functional group of about 60 species of underwater marine flowering plants (Green & Short, 2003). Thousands more associated marine plant and animal species utilize seagrass habitat. They provide habitat for fish and shellfish and nursery areas to the larger ocean, and performing important physical functions of filtering coastal waters, dissipating wave energy and anchoring sediments (Green & Short, 2003). Seagrasses often occur in proximity to, and are ecologically linked with, coral reefs, mangroves, salt marshes, bivalve reefs and other marine habitats. Seagrasses are the primary food of manatees, dugongs and green sea turtles (Green & Short, 2003).

The abundant plant material of seagrass beds forms an integral part of many food webs. The complex structure of the seagrass bed is important, providing shelter and cover. Thus, despite the relatively small number of seagrass species, a vast array of other species can be found within seagrass ecosystems (Green & Short, 2003). It is clear that, despite the relative paucity of seagrass species, as a habitat these communities are in fact highly diverse. There are many thousands of species recorded living in association with seagrass communities, although only a small proportion of these are strictly confined to seagrass ecosystems (Green & Short, 2003).

Seagrass are a major source of photosynthetic primary production, providing the energy base for an often-complex ecosystem (Hogarth, 2007). The rhizomal root system stabilizes the sediment, while the densely growing leaves reduces current velocity and encourage the settling of further partials from suspension (Hogarth, 2007). Moreover, the three-dimensional structure of the vegetation, with its network of roots and rhizomes and often-dense canopy, offers hiding places that protect against predation and provides substrate for attachment (Hemminga & Duarte, 2000). The fauna of seagrass meadows are heterogeneous assemblage of animals belonging to a variety of taxa, with many different ecological characteristics (Hemminga & Duarte, 2000).

Seagrass leaves often acquire a rich and diverse growth of bacteria, fungi and algae, ranging from single cell to thalli a few centimeters long, as well as a range of sessile animals (Hogarth, 2007). Bivalve molluscs particularly mussels and clams- may be quite abundant within seagrass meadows, with some attached to rhizomes or leaves, and the majority burrowing in the sediment, where they may protected against excavating predators by the rhizome mat. Gastropods molluscs may be herbivores, detritus feeders, or predators. Many species browse the epiphytic flora on seagrass leaves, rather than the less nutritious leaves themselves (Hogarth, 2007). Gastropods find various food source in seagrass beds (Hemminga & Duarte, 2000). Seagrass meadows have diverse crustacean fauna, including amphipods, isopods, shrimps, crabs, copepods, and ostracods. Seagrass meadows also provide nursery habitats from juvenile crabs and penaeid shrimps, which spend their adult lives elsewhere. Sea urchins can be extremely abundant in seagrass beds, where they eat epiphytes, fresh leaves, detritus, or a combination of these. The other important echinoderms in seagrass are the holothurian sea cucumber, which ingests sediment and extract seagrass detritus and other organic matter from it (Hogarth, 2007).

The fish fauna of seagrass can be of a considerable diversity. The occurrence of more than 100 species associated with seagrass beds in a certain region is no exception (Hemminga & Duarte, 2000).

There are only three seagrass species in the gulf. The Arabian Gulf characterized by large seasonal temperature variation. The area is very hot for many months of the year. A few rivers drain into the Gulf. There is little rainfall and very little freshwater runoff. In addition, the evaporation from the Gulf waters leads to salinities averaging 40 psu, but which exceeds 70 psu in Gulf of Salwah. The only three species of seagrass that can tolerate such extreme conditions are *Halodule uninervis, Halophila ovalis* and *Halophila stipulacea* (Green & Short 2003; Phillips & Milchakova, 2003).

Seagrass habitats are recognized and designated as critical marine resources in the Gulf, sustaining high primary production, harboring high biodiversity of associated species (Sheppard et al., 2010; Jones et al., 2014; Erftemeijer & Shuail, 2012).

Very few studies on seagrasses in the Gulf have been produced reporting density, biomass and primary production values (Basson et al., 1977; Erftemeijer & Shuail, 2012). These studies, suggested that primary production from seagrass and shallow water benthic algae might be of greater importance in the Gulf than that from phytoplankton. Seagrass are major source of detrital food webs, which provide food for many marine organisms (Erftemeijer & Shuail, 2012). The species diversity of benthic fauna associated with seagrass beds in the Gulf have been reported between 530 (Basson et al., 1977) and 835 species (Coles & McCain 1990; Erftemeijer & Shuail, 2012).

Due to the actual fast and vast development along the coastal areas of almost all countries surrounding the Gulf, many anthropogenic pollutants have discharged into its basin (Halpern et al., 2008; Sheppard et al., 2010). Such pollutants either chemical or physical have for sure influenced the water quality and consequently stressed the seagrass beds found along the Gulf coastal area in general and along Abu

Dhabi seabed habitats in particular. Recently, the Abu Dhabi coastal authorities have established marine protected areas to safeguard endangered species such as dugong population along Abu Dhabi coastal areas. These protected areas has great areas of seagrasses in which different microbenthic fauna are associated.

Due to the lack of information about the different macrobenthic fauna communities associated with seagrass beds in protected areas compared with its community composition out of such areas; the present study was developed to study both spatial and temporal variations of benthic macrofauna in both protected and non-protected areas in Abu Dhabi. The study also aimed to quantify macrobenthic fauna species associated with seagrass bed in both habitats. Moreover, it aimed to analyze seawater and bottom sediment characteristics of the seagrass meadows in both areas and finally to compare seagrass vitality in relation to environmental parameters.

1.2 Literature Review

Seagrasses are aquatic flowering plants (angiosperms), the only species of flowering plant to grow under the sea. They occur around estuaries and in the sea. In contrary to their name, seagrasses are not related to the terrestrial true grasses (Hartog & Kuo, 2010). Their historical and evolutionally phylogeny asserts that seagrass evolved in the past million centuries from earthly plants (Short et al., 2007). Evolution process thus conferred seagrass beneficial modifications that make them suitable to thrive in submerged ocean regions hence spend their entire lifecycle underwater. They evolved from among many species whose leaves were long, narrow and grew by rhizomes extensions and often sprout along seagrass meadows which bear a resemblance to grassland (Short et al., 2007).

Seagrass is classified into class monocotyledonae alongside other plants that have leaves and bear flowers and seeds. Seagrass is further classified under the order Alismatales. In the Alismatales order seagrass is the only plant with flower and grows fully submerged in marine water (Hartog & Kuo, 2010). An archetypal feature of plants classified under the Alismatales is that mature seeds lack an endosperm. They exist as genetically diverse species, almost 72 species in the world which are classified into major four families grounded on similar characteristics. The four families include Posidoniaceae, Hydrocharitacea, Cymodoceaceae and Zosteraceae (Olsen et al., 2016).

The seagrass is described as an ecological engineer that adjusts the conditions around them in order to satisfy their own needs. For example, they possess strong roots and long leaves that aid in calming water, reduce the nutrient level hence mitigate algae overgrowth and trap sediments suspended in water to enhance water clarity thus overall optimal growth conditions (Warren et al., 2001). At optimal condition, the seagrass has been found to cover a dense sea floor resulting in an ecosystem known as seagrass meadows. The seagrass meadows can be either monospecific which comprise of a single species such as in temperate zones with *Zostera marina* in Northern Atlantic or mixed beds which encompass a variety of species, especially in tropical beds (Short, et al., 2007). The meadows vary in size and density from small coverings that are a square a meter to large surfaces that cover more than 10,000 square meters (Tanaji et al., 2019). Their flowering nature is of short duration in a year and is dependent on the season. They have a diverse geographical distribution in the world and hence the ecosystem thus they range from tropics to the north and south poles (Grey & Moffler, 1987).

Despite their wide tropical distribution, and the fact that they provide high and important ecological and economical values to coastal ecosystems and communities worldwide, seagrasses beds has been overlooked and understudied, they are also poorly mapped, in comparison to other marine habitats like coral and mangroves.

Across their extended distribution, many marine creatures that utilize seagrass beds, as through photosynthetic primary production, seagrass provides the energy base for the ecosystem around it as shown in Figure 1 (Hogarth, 2007).

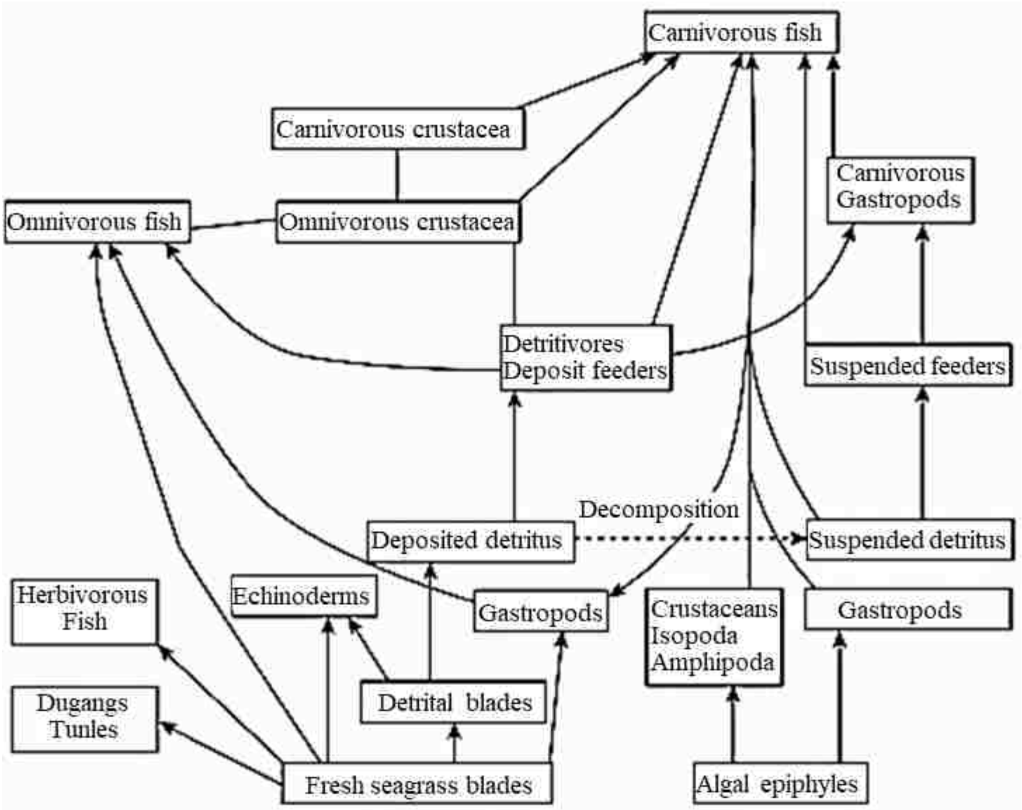

Figure 1: A general diagram showing the tropical food web with seagrass base

Fish and shellfish use grass beds as habitats and nurseries for their eggs and offspring, while other mobile marine organisms move between the seagrass beds and other marine habitat through different stages of their lifecycle, while some live their entire life on seagrass beds (Green & Short, 2003; Hogarth, 2007). Seagrasses are the primary food of manatees, dugongs and green sea turtles (Green & Short, 2003), where green turtles can consume up to 200 g of seagrass per day while 65 kgs of seagrass per day (Hogarth, 2007). Despite the ecological significance of seagrass towards food security, downplaying climate changes and supporting ecological diversity, less interest geared towards seagrass preservation. Anthropogenic activities such as dredging, land reclamation, boat striking, and fishing have been demonstrated to be harmful and presented a great threat to seagrass (Coles et al., 1987; Al-Azab et al., 2005). In fact, the rise in sea sulfide concentrations emanating from anthropogenic activities has been shown to be the leading cause of a decline in seagrass population in the affected areas. This assertion is supported by environmental scientists whose study findings show that half the total area covered by the seagrass has vanished in the past few decade (Al-Azab et al., 2005).

1.3 Importance of Seagrass

Despite the paucity of studies, the seagrass has great ecological significance to both humans, animals and other biota that surround it. Seagrasses play a very important role in the marine ecosystem, and that is because these beds do not grow in isolation but they form a crucial role by providing a highly complex ecosystem (Gullström et al., 2002). Due to their abundant availability across the globe, they play an integral part of the marine and terrestrial food web. The complex structure of the seagrass bed is important, this complexity provides shelter and protection for many organisms and despite the limited number of seagrass species; they host large variety of marine species within its ecosystems. Seagrass meadows provide a favorable environment for juvenile fish and invertebrates to conceal themselves from predators. Many fish species like coral reef fish spend their complete juvenile life stage on seagrass flats (Hartog & Kuo, 2010). There are many marine organisms that are found exclusively within the seagrass beds are belonging to seagrass ecosystems, and cannot be found anywhere else. While other organisms may utilize the seagrass beds for restricted periods during their life cycle, either as breeding areas or as nurseries, as well as feeding areas, or even as main habitat, where they settle in during their adult lives (Spalding et al., 2003). In addition to that, seagrasses are a major source of primary production, where they provide the energy base for the marine ecosystem food web through photosynthesis (Hogarth, 2007).

Moreover, the vegetation structure of the seagrass beds, and its complex network of roots and rhizomes canopy, help protects marine species against predation by offering an optimum hiding places with in the complex structure (Hemminga & Duarte, 2000).

They help in the stabilization of sediments, due to their extensive network of rhizomes and roots that, extend both vertically and horizontally. In turn this helps making the bottom of the sea stable and this mitigates coastal erosion by water currents and tidal waves. Further, this role is compounded by the long blades of seagrass which slow down the movement of water by reducing wave energy and storm surge. Seagrass acts as a source of food to living organisms both direct and indirect. Some organisms graze directly on some sea grass species such as endangered Florida manatee *trichechus manatus* and green sea turtles *chelonia mydas* and others use it indirectly. For instance, some mammals like bottlenose dolphin *tursiops* feed on organisms that reside in the seagrass (Campbell et al., 2014). Furthermore, detritus from bacteria decomposition of dead seagrass provide food for worms, crabs and filter feeders. In addition, decomposition releases nutrients such as nitrogen and phosphorus, which reabsorbed by sea grass and phytoplankton once they dissolve in water (Charpy & Sournia, 2014).

Seagrass enhances the quality of seawater by trapping suspended sediments and fine particulates thereby increasing water clarity. In absence of seagrass, windy and water currents stir sediments affecting marine animal behavior and decreasing recreational quality of marine areas. Water clarity enhances penetration of light energy, which sustains photosynthesis in the deep sea. Further, the seagrass filters nutrients which originate from land based industrial discharge and domestic run off water before these nutrients are washed into the sea and other sensitive habitats such coral reefs. They offer economic value by creating nursery grounds for commercial and recreationally valued fishery species such as gag grouper and others as well as these sites can act as wildlife and tourism attraction centers especially along with coastal areas. Sea grass helps in lowering oceanic acidification by removing excess carbon dioxide from the water column hence balancing seawater pH. This has the effect of enabling the survival of acid intolerant organisms such as molluscs. In addition, the removal of carbon dioxide helps in mitigating against climate change by downscaling the speed of carbon dioxide concentration buildup in the atmosphere (Hartog & Kuo, 2010).

1.4 The Morphology and Anatomy of the Seagrass

Just like other plants in class Monocotyledonae, seagrass has three primal parts to include leaves, stem, and roots. Further, they bear tiny flowers, fruits, and seeds. Grossly they have green leaves, which emanate from vertical branches. Seagrass leaves are unique in a way that makes them suited for the marine environment (Hartog & Kuo, 2010). They possess a basal sheath that aids in the protection of apical meristem and serve as a base for leaf development. Seagrass leaves are equipped with distal blades, which internally lined with numerous chloroplasts that trap light energy and converts water and carbon dioxide to sugars in the process of photosynthesis. Further, the leaves provide a surface area that enables disperse excess water from plant through transpiration (Hartog & Kuo, 2010).

Figure 2 highlights the similarities and the differences between certain seagrass species. Where the similarities found across all seagrass species is that the majority of the species have a rhizome, roots, and leaf blades, while neither all seagrasses have stems, nor do all seagrass species have leaf sheath and leaf scales (McKenzie, 2008).

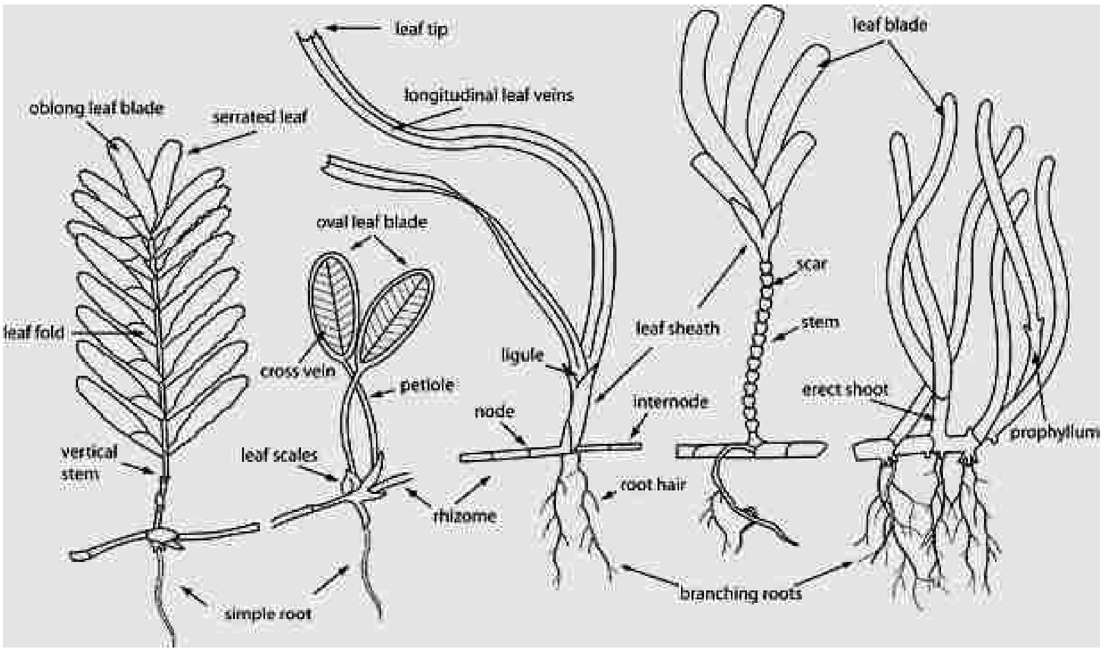

Figure 2: Seagrass anatomy

In addition to roots, seagrasses have horizontal stems called rhizomes which are usually buried in substrate either sand or mud and aid in anchoring the seagrasses making them stable and also help in nutrient absorption for seagrass physiological functions such as growth and energy provision. Rhizomes and roots are quintessential in withstanding shock and bending moments on the seagrass caused by sea waves and tides (Grey & Moffler, 1987). The roots are adventitious and emanate from the rhizomes. At the tip, seagrass roots have a distinctive root cap, which protects meristem cells, and aid in cell growth through undergoing a continuous process of cell division. All the seagrass organs have three distinct regions. First, the outermost region is the epidermis, which is a continuous layer on the surface of the whole-body plant and has a thin cuticle as its outermost layer (Hartog & Kuo, 2010). The cuticle in addition to serving a mechanical protection role, it is tailored to modulate processes of transpiration and aeration. The second region is the vascular bundle. Composed of two distinct structures: xylem, phloem, and it is an element that persevered beyond evolution. The xylem is found in both the stem and leaves and aids in the transportation of water for pivotal life process while the phloem helps in solute/food translocation. The innermost region is the parenchyma which is lined with thin walls and non-lignified collenchyma for photosynthesis and food storage (Olsen et al., 2016). Further, the parenchyma has thick lignified sclerenchyma. The essence of this feature is in laying the internal mechanical support skeleton for parenchyma tissues. The leaves and stems of seagrass are in possession of veins and air channels that aid in fluid and solute transportation and gas absorption (Hartog & Kuo, 2010).

1.5 Biological Characteristics of the Seagrass

Seagrass species are not all related, but they all have similar characteristics, and share the same biological and physical needs to survive. Being angiosperms, seagrass need the same basic requirements needed by terrestrial plants to survive. There are three basic components that seagrass like all plants, require in order to grow these three elements are light, carbon dioxide and nutrients (Larkum et al., 2006).

Each of the seagrass anatomical features is modified and adapted in a manner that enables them to perform their biological functions in their marine environment to include nutrition reproduction, growth and development as well as other biological functions. Seagrass thrives in salt or brackish water environments and various adaptation features possessed by this plant underpin this. Seagrass is classified to belong to hydrophytes which are plants adapted to grow and thrive in a water environment (Coles et al., 1987).

Seagrasses need a substrate where they can anchor their roots in and tolerable water where levels of salinity and pH will allow them to grow, in addition to temperatures that should be within their threshold (McKenzie, 2008). Seagrasses need to receive efficient amount of sunlight in order to photosynthesis, and they need it in order to get the required amount of carbon. They are commonly found along shallow regions of the coast with shallower depths since this gives them to light normally 11% of light incidence to the water surface, which help in photosynthesis. Further, concerning photosynthesis, seagrass has numerous chloroplasts in their parenchyma a feature shared by other green plants. These chloroplasts bear a green pigment, chlorophyll that traps sunlight energy, which used in the conversion of water and carbon dioxide into sugars and oxygen. The sugars provide the plant with an energy reserve to power its functions while the oxygen is aerated and exchanged with carbon dioxide, which is a raw material for photosynthesis. Seagrasses disperse off adequate amounts of oxygen. By photosynthesis, water becomes aerated and carbon dioxide levels downscaled (Grey & Moffler, 1987). The seagrass meadows represent about 10 % of ocean total carbon storage per hectare, which is as twice as the rainforest. In line with this, seagrass can sequestrate about 2 to 4 million tons of carbon dioxide annually. The removal of carbon dioxide helps buffer the marine pH thus, confers a protective function to animals that have external skeleton and shells such as molluscs, oysters and others from the effect of low pH in seawater (Campbell et al., 2014).

A little to none nutrients are absorbed from the water level and sediment pore water, the main source of nutrients for seagrass in the carbonate rich sediments, where dead marine species have started to decay and erode releasing nutrients into the soil. What is important to note is that seagrass does not take-in the nutrients solely through their roots, but also have a system of abortion through their leaves (Duarte & Hemminga, 2008).

However, unlike terrestrial plants seagrass do not have stomata that allow gas and nutrients in, what they have is a thin layer (cuticle), which allows that exchange of gasses and nutrients to take place. In addition to that, all seagrasses have airspaces called lacunae, which found in special tissues called *Aerenchyma*, within their leaf. Root and stem system also aiding in gases exchange, as well as helping seagrass to stay buoyant. The physical similarities include the rhizome (horizontal stems) and roots, and leaves, while leaf blades differ from species to species. Another important part of the of seagrasses are the Rhizomes, which are stem like horizontal pipe that acts as the main anchoring system that keeps seagrass beds in place conceiting shoots and roots together. Rhizomes also help expand the seagrass habitat through horizontal growth (Larkum et al., 2006).

Despite being submerged all (most) of the time seagrass reproduces and pollinates while they are underwater, where the male organ will release pollen which will travel through water and land on a female flower to fertilize, although rarely recorded seagrass also reproduces asexually (Duarte & Hemminga, 2008). Seagrasses species also all have similar adaptation mechanism, these adaptation mechanisms are the main reason these species are able to survive in the conditions they thrive. Seagrass is able to grow while being completely submerged, despite the lower oxygen and carbon dioxide availability in water, they also have the ability to survive in waters of high, and variable salinity, their anchoring mechanism mentioned earlier helps seagrass root themselves in the substrate withstanding water movements and currents. Seagrass has evolved and adopted a pollination mechanism while being submerged, and they have a competing ability against other marine species (Short et al., 2007).

1.6 Seagrass Distribution

Seagrass beds are generally found across shallow sheltered waters with bottom types that allow the anchoring of the roots (Short et al., 2007). There are a number of conditions that effect the occurrence and the distribution of seagrass across the world. The conditions include the availability and penetration of sun light through the water column, being a plant, sunlight is important for these species to survive, and the penetration of an adequate amount of light is crucial form their availability. Deeper seabeds that have little to no sun light and high hydrostatic pressure on the plants are less attractive beds for the seagrass to grow on. Proper tide and water movement are also crucial for the seagrass meadows where the water movement helps in the pollination and seagrass distribution. Salinity of the water also plays an important role where studies had shown the difference in communities between waters of low salinity versus waters of high salinity. The salinity effects the distribution, seagrass species compositions and reproduction while temperature effects the individual species and their thermal tolerance, effecting the type of species that occur around the area (Short et al., 2007).

The global seagrass coverage has estimated to range between 300,000 km^2 to 600,000 km^2 and is found in all continents with the exception of Antarctica (Charpy & Sournia, 2014). Shallow areas on the continental shelf of all continents except for Antarctica, under water area of lands surrounding each continent to create relatively shallow water known as a shelf sea. The shelf sea approximately covers 125,000 km^2 around world shore and 600,000 km^2 of shallow oceans thus giving a crude estimate of seagrass coverage (Short et al., 2007). Seagrasses mostly prefer places, which are situated adjacent to estuaries, bays and coastal waters from shallow regions down to depths of 50 to 60 meters where waves are limited while permeation of light energy and nutrients level is high. The depth of 50 to 60 meters is further dependent on tides, wave action, clarity of water and low salt concentration where seagrass can thrive (Coles et al., 1987).

Globally, sea grass species inhabit diverse environments ranging from mud areas to rock areas and they cover regions along the coast from tropical to temperate regions (Short et al., 2007). Most seagrass species are densely populated at tropic regions where temperatures are high, unlike temperate regions where temperatures are relatively low (Short et al., 2007). However, some species such as *Halophila ovalis*and, *Syringodium isoetifolium*can inhabit both tropical and temperate regions. Further, seagrass beds are densely populated in some regions (Figure 3), where they form seagrass meadows that cover large space areas. The four common water meadows in the world include the following: Indo-pacific, Central-America, Sea around Japan and Australia, and Mediterranean Sea (Coles et al., 1987). However, only four species of the world 60 species exist European waters (Green & Short, 2003). The distribution of seagrass is limited to few miles offshore; this is linked to permeation of light energy, which decreases with increasing water depth. Different species thrive well in distinct and specific zones ranging from fast high, which are 1 to 3 meters, and mid intertidal zone to subtidal zone as deep as 58 meters. Fast high and mid intertidal zone is mostly situated below mangrove vegetables and support species like *Halodule wrightii* and *Cymodocea rotundata* on more stable substrates with some sand. Fast high and mid intertidal zone also supports some flora such as seaweed like *chondria* and *hypnea*. The second zone is the mid and low intertidal zone, which is uncovered as tides move in and out, where climax vegetation such as, *Thalassia hemprichii* mainly dominate it. The subtidal zone is found deep under water and is dominated by *Syringodium isoetifolium* which have tough cylindrical leaves and thus tolerant to low light conditions. Other species that grow in these regions include *Halophila stipulacea* and *Halodule uninervis* (Paul & Dawood, 2012).

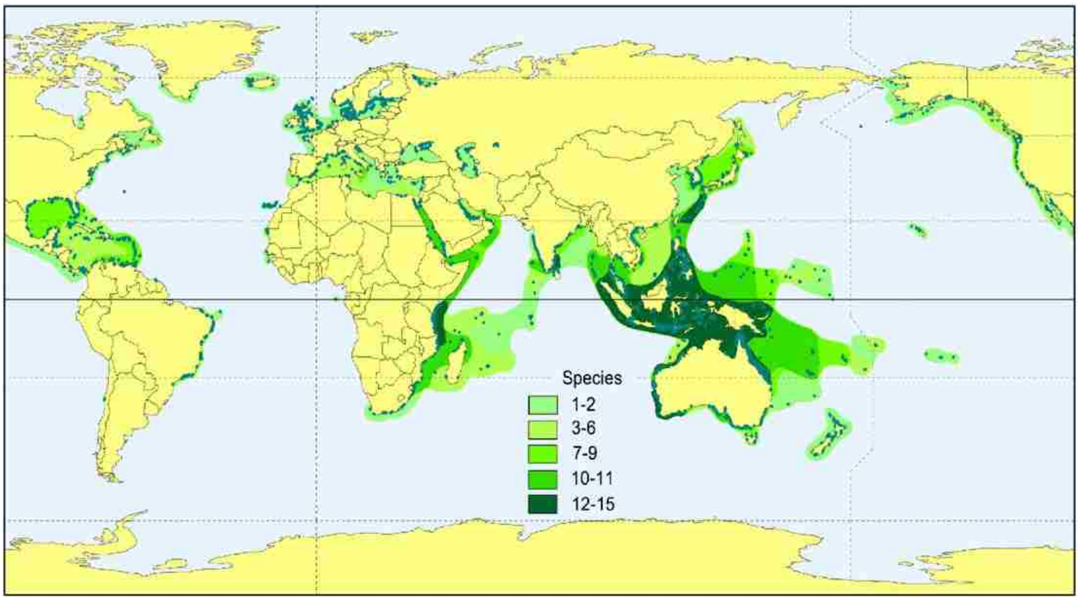

Figure 3: Global seagrass diversity and distribution
Note: Shades of green indicate numbers of species reported for an area; blue points and polygons indicate documented reports of seagrass occurrence.

Lowest diversity of seagrass is found in the Temperate North Atlantic with 5 recorded species found around estuaries and lagoons, followed by the Mediterranean with 9 species, while the Tropical Atlantic has a larger diversity of 10 species found on back reefs and shallow clear waters. The higher diversity meadows are found in the Temperate north Pacific with 15 species found around estuaries, lagoons and costal zones, followed by the Temperate Southern Ocean where extensive meadows are found with diversity that is low to high totaling to 18 species. The Tropical Indo-pacific is considered to have the highest and most divers seagrass with 24 species (Short et al., 2007).

1.7 Associated Flora and Fauna

Since seagrasses live their entire life cycle within the marine environment, they are considered a highly productive ecosystem. Seagrasses sustain and support different kinds of biota throughout their ranger. The biota found in association with seagrass include plants, animals and living organisms, which thrive in the same conditions and regions, occupied by seagrass. They may coexist with each other, or some maybe dependent on other for existence. The vast fauna associated with the seagrass meadows is made up of a mix of a number of animals that in place belong to different taxa, and have many different ecological characteristics (Hemminga & Duarte, 2000). Many species take shelter in the different structure of the seagrass beds, where infauna species live within the sediments, while epifauna species live on the stems and leaves, and lastly the mobile species known as nektonic species, which move freely around the seagrass beds. Starting with the single cell organisms and small thalis that differ in sizes and structure are found on the seagrass leaves like bacteria, algae and fungi, and dissolved organic matter that is released from decayed seagrass blades (Price et al., 1993), as well as a diverse number of sessile organisms that also live on seagrass leaves (Hogarth, 2007). Bivalve, especially mussels are found with in seagrass meadows in abundant numbers. They are usually found attached to rhizomes or to the leaves, or burrowing themselves within the sediment, where they seek protection under the rhizome from predators that excavate them. Gastropods are also found in high numbers within the seagrass meadows, especially molluscs which happen to be herbivores, detritus feeders, and also predators find various food source in seagrass beds (Hemminga & Duarte, 2000; Hogarth, 2007).

Seagrass meadows also host a population of crustaceans, these include, but not limited to, amphipods, isopods, shrimps, crabs, copepods, and ostracods. It also acts as nursery grounds and safe havens for juvenile crabs and penaeid shrimps, which, when they reach their adult lives spend it elsewhere away from the seagrass beds (Coles et al., 1987; Hogarth, 2007). Sea urchins also utilize seagrass meadows and are found in high numbers, that is because they find epiphytes, fresh leaves and detritus, which are a main source of food for these sea urchins. Another important echinoderm that is found within the seagrass meadows are the holothurian sea cucumber, which feed by ingesting the sediment around the seagrass and extracting organic matter from the sediment (Hogarth, 2007).

The fish fauna found associated with seagrass meadows are of a relatively high and considerable diversity where it has been recorded that 746 fish species utilize seagrass meadows in the Indo-Pacific, 486 in Australasia, 222 in the North East Pacific, 313 in the Caribbean, and 297 in the North Atlantic (Unsworth et al., 2018).

A study of the trophic ecology of the fish fauna of vegetated and un-vegetated habitat at 14 sites along the southern Australian coast showed that the estimated production of crustaceans was much higher in the seagrass habitat than in the un-vegetated sites in nearly all cases (Edgar & Shaw, 1995). That also believed to be the reason behind the high fish density that was found at the seagrass (Hogarth, 2007). Research has also highlighted the nursery role that these seagrass beds play where juvenile specimens of fish were often dominating the population of the fish communities in seagrass meadows (Hogarth, 2007). Larger fauna also utilize seagrass, beds for grazing like Dugongs and Green Turtles

1.8 Seagrass of the Arabian Gulf

The Arabian Gulf encompasses parts of Arabian Sea ecoregion and is a representative of Tropical Indo-Pacific Ocean. The region experiences extreme environmental conditions with seasonal temperature variation ranging from winter to summer with a temperature range of 15 to 36 degrees Celsius (Al-Ghadban et al., 1998). Further, the seasonal variations with concomitant evaporation variations trigger changes in water salinity which sometimes exceed 43 psu and go up to a range of 70-80 psu in the tidal pools and lagoons. The seagrass meadows extend on a surface of 7000 square kilometers along the coastal water of the United Arab Emirates, Bahrain, and Qatar (Paul & Dawood, 2012). The greatest area of the seagrass in the region is situated off the coast of United Arab Emirates and is between Bahrain and Qatar with the surface area of 5500 and 1000 square kilometers respectively (Paul & Dawood, 2012).

The characteristics of the Arabian Gulf determine the seagrass species that occurs within its waters. The large seasonal temperature variation in seawater temperature, due to the high atmospheric temperatures and long sunny summer days as well as the long summer period. It’s high salinity due to the lack of freshwater input, and the little rain water runoff that occurs around the gulf, in addition to the high evaporation rate that leads to average salinity of 40 psu, and that can reach up 70 psu in the Gulf of Salwah. Due to these harsh conditions seagrass in the Arabian Gulf encompasses only opportunistic species of seagrass, which are capable of tolerating extreme environmental conditions such as extreme low or high temperatures and varying salinity. The only three opportunistic seagrass species that thrive in these harsh areas include the following: *Halodule uninervis, Halophila stipulacea,* and *Halophila* *ovalis* and they live close to the limit of their environmental tolerance (Price et al., 1993).

The importance of these seagrass beds has been recognized within the region and labeled as critical marine resources. It is well known that these meadows help sustain high primary production, and have ecological value whereby a variety of food sources and feeding grounds for several species of living organisms and in turn hosting a high biodiversity of species (Sheppard et al., 2010; Jones et al., 2014; Erftemeijer & Shuail, 2012). They further aid controlling climate change through their ability to sequester carbon whereby they store carbon resulting to a total biomass ranging from 0.03 to 1.13 mg C per hectares. The region sustains second largest population approximately 5,800 dugongs *dugong dugon* that feed almost exclusively on seagrass and other marine species (Salma et al., 1991).

It is also highlighted that the extensive root systems of these large seagrass meadows play a critical role when it comes to the stabilization sea beds that are close to shore protecting the shoreline from wave action and other erosion (Jones et al., 2014; Erftemeijer & Shuail, 2012).

Despite their recognized importance, only a few numbers of studies have been conducted around seagrasses in the Arabian Gulf, which reported the density of seagrass community, the associated biomass and the primary production values of these habitats (Basson et al., 1977; Erftemeijer & Shuail, 2012). Coles and McCain's study managed to identify a total of 834 species associated with seagrass and sand/silt substrate at seagrass beds in Saudi Arabia (Coles & McCain, 1990). The species diversity of benthic fauna associated with seagrass beds in the Gulf have been reported between 530 (Basson et al., 1977) and 835 species (Coles & McCain, 1990; Erftemeijer & Shuail, 2012).

Surprisingly and despite the extreme conditions found in the water of Abu Dhabi, the western areas where dense seagrass meadows are found with extensive growth (Phillips et al., 2004). Water at the coast of Abu Dhabi demonstrated marked seasonal variation in physical, chemical and biological features (Wehbeh et al., 2003). Seasonal surface temperature may range from 13.5^{o} to 36^{o} for areas of water in shores and between 17^{o} and to 34^{o} Celsius for water areas off shore. Overall, the seawater temperatures exceed 34^{o} Celsius in some and a minimum temperature of 16^{o} Celsius has recorded in winter. On the other hand, salinity ranges from 50 to 70 psu in shallow areas (Warren et al., 2001).

In Abu Dhabi, the extensive seagrass meadows sustain world second largest dugong population (Environment Agency - Abu Dhabi, 2014) and over 7488 sea turtles, inducing green turtle (Environment Agency - Abu Dhabi, 2016). Seagrass meadows in Abu Dhabi cover large areas of shallow water with a depth of fewer than 10 meters. The marine habitat of Abu Dhabi involves a subtidal benthic substrate, which encompasses areas of more than 10% cover of rooted vascular seagrass species (Coles et al., 1987). The seagrass species found in Abu Dhabi are similar to those three main opportunistic seagrass species aforementioned in the Arabian Gulf. However, environmental scientists have discovered the fourth species *Syringodium isoetifolium* (Kenworthy et al., 1993) but little is known about how the species tolerate the harsh environmental condition of this region. Among the three-common species, *Halodule uninervis* is the most densely populated species in the waters of Abu Dhabi with highest density situated at the North of Abu Dhabi highland around Al Sammaliah Island (Wehbeh et al., 2003).

The seagrass of Abu Dhabi is of great significance to the surrounding living organism and human beings. For instance, it is a direct source of food for dugongs, green turtles and a habitat for fish and invertebrates especially as a refuge from predators for juvenile fish. Seagrass is also regarded as a ‘blue carbon sink’ at the coast and marine habitat due to its ability to sequester and store carbon dioxide thus modifying environment and climate of the locale (Campbell et al., 2014).

In conclusion, seagrass is a highly adapted yet very significant element of climate control. However, in the recent decade, human activities have had significant impact on marine life and threaten to deprive planet earth such a treasured element. Thus, there is a need to conduct further research that will inform policy formulation to undo the damage. In such spirit and sheer force of scientific inquisition ecological balance and climate, preservation agenda can be attained.

Chapter 2: Methods

2.1 Area of Study

The study was conducted across the coast of Abu Dhabi, were two sites were selected to collect the data and get samples. The sites were selected in and out of the protected areas of Abu Dhabi. The first site (unprotected), Halat Al Bahrani (24^o 23.987’N 54^o 15.101’E) which is a busy area with heavy boat traffic, seagrass is abundant (Figure 4).

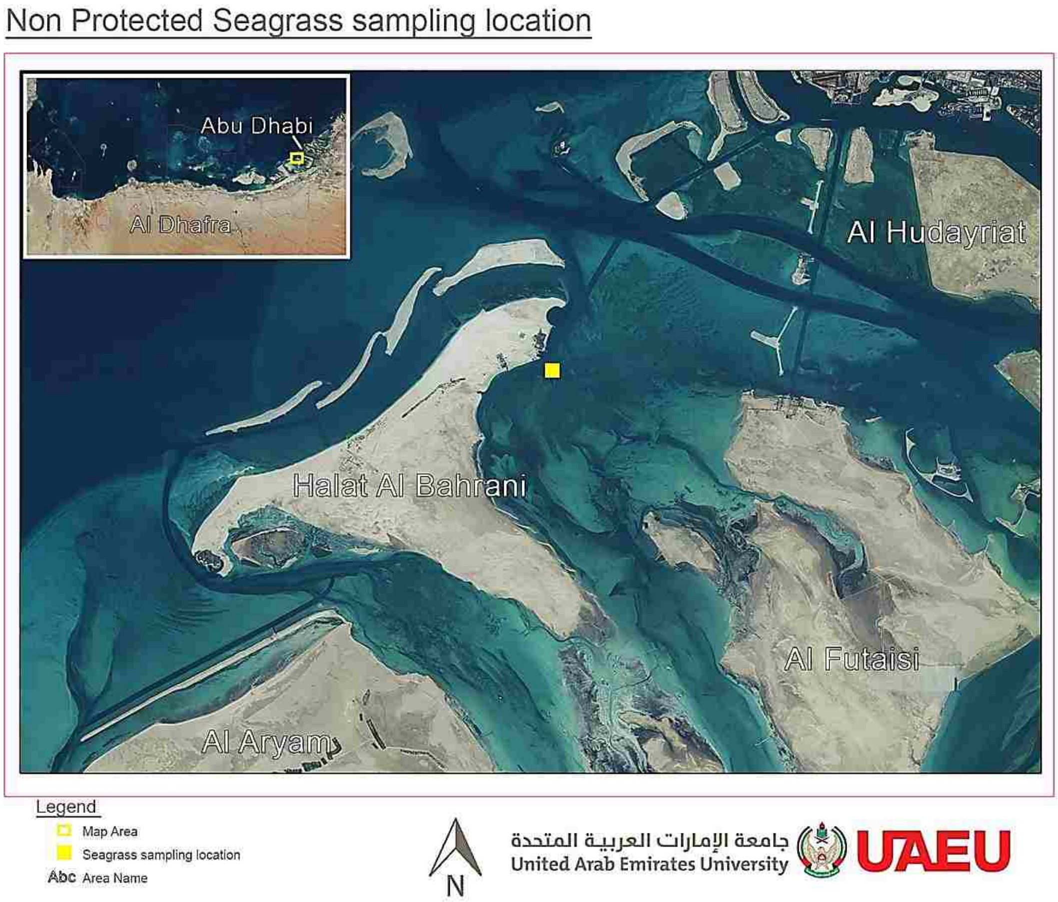

Figure 4: Map of none protected site showing sampling location

The second site falls within the Marawah Protected Area, North of Um Amim Island (24^o 16.632’N 53^o 23.121’E) where boat traffic is extremely light, and the seagrass bed is protected due to its unique location in the protected area boundaries (Figure 5).

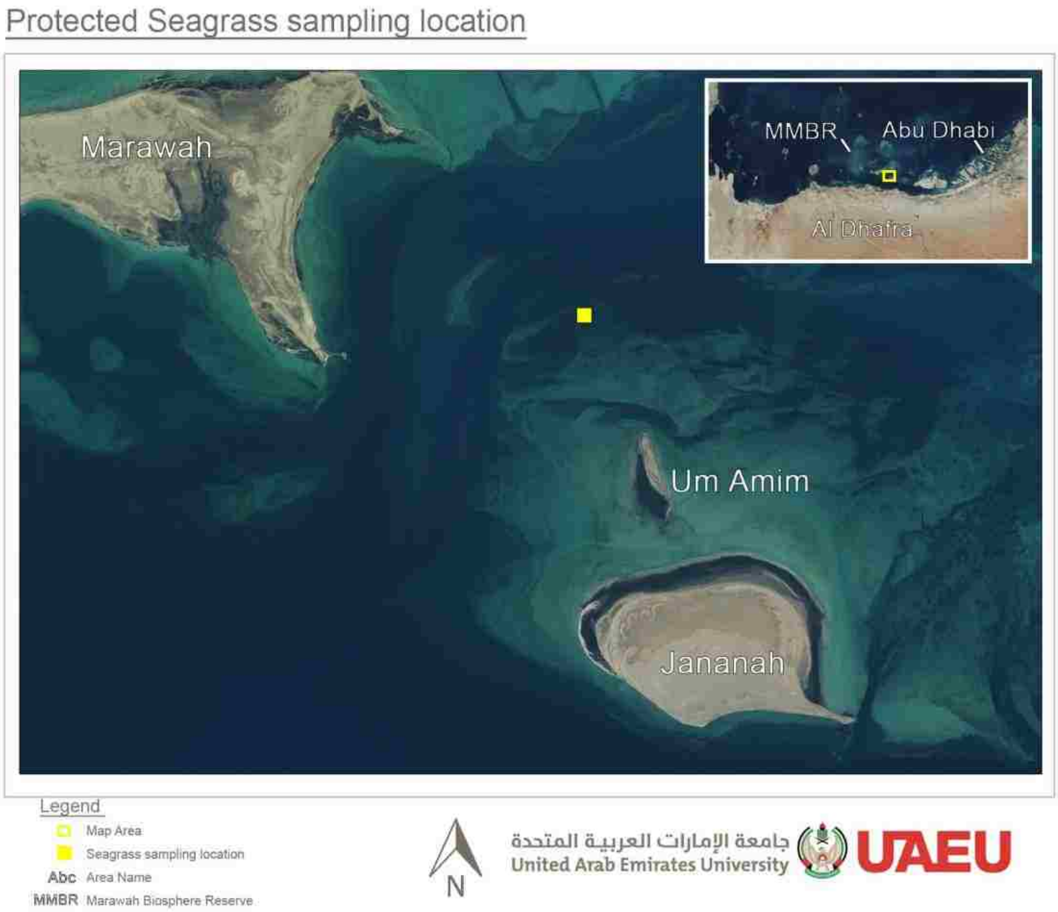

Figure 5: Map of protected area site showing sampling location

These two sites where selected by the use of satellite imagery and ground trothing. First, by using the Environment Agency- Abu Dhabi’s EnviroProtal (Figure 6) a habitat map was obtained, and seagrass sites where highlighted as potential study sites. After the sites where highlighted remotely, ground truthing the sites was crucial to find which sites where more accessible and can reflect the environment of the non-protected areas as well as the protected areas.

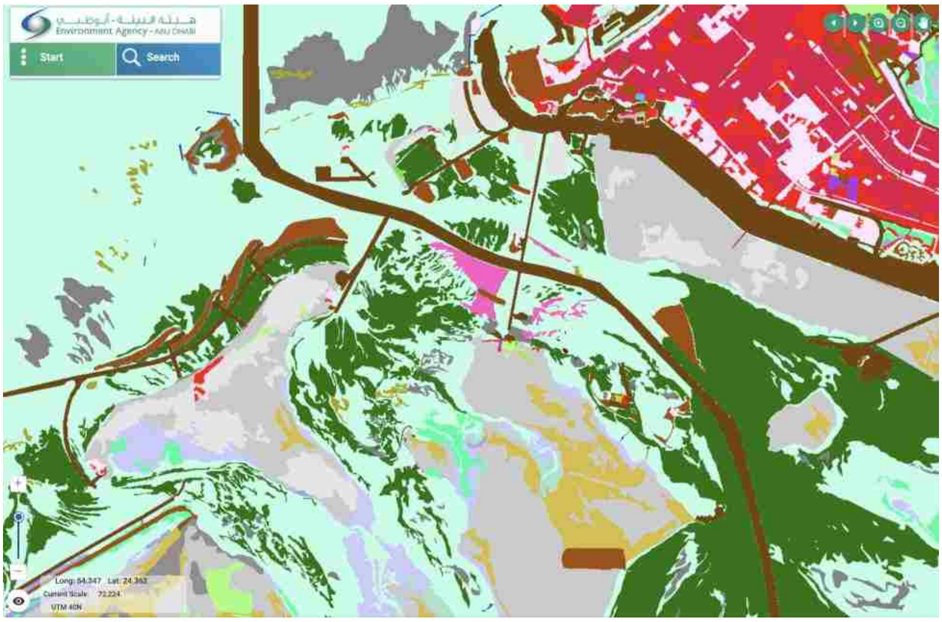

Figure 6: Screen shot of enviro-portal showing habitat layering

2.2 Data Collection

All data collection took place at the selected site. A trip during summer to the Non-protected site and the site within the Protected Area was launched to collect the summer samples and data during the month of September 2017. The samples and data for the winter season were collected during January 2018.

2.3 Environmental Parameters

A number of Environmental parameters where recorded at the field, where the parameters where collected in situ in the sampling area. The hydrolab MS5 and the Hydrolab surveyor HL were used to collect the following environmental parameters; surface water temperature, water salinity, pH and dissolved oxygen. The Suunto EON Steel Dive Compute was used to record depth and bottom temperature during each dive.

2.4 Water Analysis

Water Samples were collected at the sampling areas, kept in coolers, before moving them to UAEU lab for trace metal analysis.

2.5 Sediment and Seagrass Samples

The sediment samples were collected across three 15 meters line transect, laid 15 meters apart. Figure 7 shows the 15 meter line transects, where data is collected at every 5 meters. The transects were laid perpendicular to the shoreline parallel to each other moving from the North to the South.

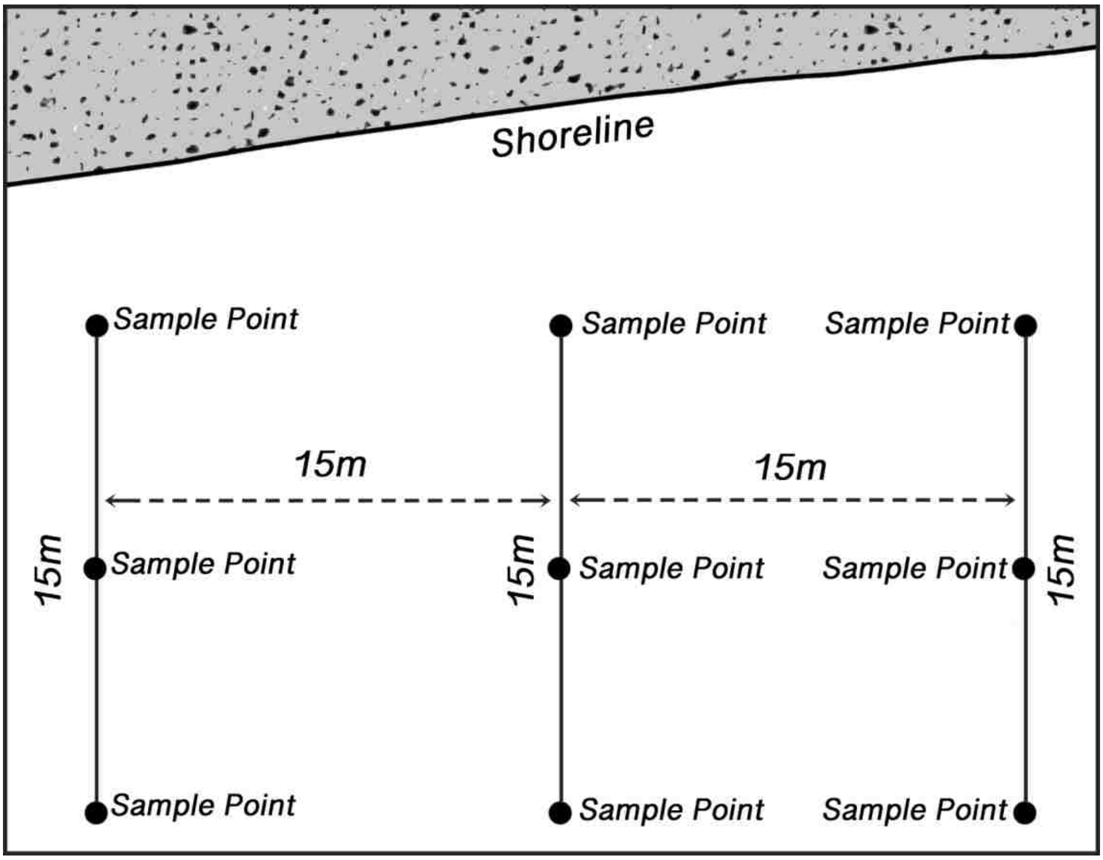

Figure 7: Three parallel 15 meter Line transects and sample points

In addition to the sediment and seagrass samples that were collected across the transect, Photographs of the seagrass bed were taken using photo quadrats. Using scuba, a diver would go down with the 1m x 1m photo quadrat and swim along the laid transect recording an image every 5 meters to determine the seagrass cover for the area.

Using a van veen grab, shown in Figure 8, core size of 250 cm² (3.14 L) at the sampled plots, total of 9 samples were collected, and placed in airtight containers on ice, and moved to the labs in United Arab Emirates University, Al Ain, for separation and sorting.

Figure 8: Van Veen grab

At the lab, the samples were sorted, where the seagrass was separated from the sediments and the large living organisms were picked up by hand. The smaller living organisms where separated from the sediment sample using a 1 mm sieve to retain the macrofauna.

Sediment samples are then dried in room temperature and hand shaken, and a sample of 100 g is and put through a sieve tower with sieve sizes 2.00 mm, 1.00 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.062 mm, and <0.062 mm representing the sediment types gravel, very coarse sand, coarse sand, medium sand, fine sand, very fine sand and mud respectively. Samples retained in each sieve was then weight and recorded.

2.6 Biological Data

Biological organisms were separated in to two main components, the first component is the seagrass and the second component is the macrofauna organisms.

The seagrass data is collected in the field, and in the laboratory. In the field the seagrass percentage cover is recorded using photo quadrates, where a 1m x 1m quadrat was laid on the line transect and a photo was taken at every 5 meters across all 3 transect 15 m transect lines. Wet weight and dry weight of the samples were collected in the laboratory by using of balance and oven to dry the seagrass samples at 45^{o}C.

All organisms collected during the sieving process were transferred to appropriately labeled containers reflecting the sample number, season, and site and fixated using a 4% formaldehyde solution. A total of 18 samples per season where collected from both sites where kept separate. Collected biota were transferred to Nautica Environmental Associates LLC labs for species identification and population count. Biota were kept in 4% formaldehyde for 3 days for fixation then was moved to a 70% alcohol solution for conservation through the identification process.

In the laboratory, the supernatant liquid was poured into a large container for subsequent neutralization with sodium metabisulphite. Each infauna sample was then emptied into a 0.5 mm, sieve and thoroughly rinsed in a sink under a running tap for 5 to 10 minutes to remove all formalin.

The samples were then placed onto a plastic tray with a few millimeters of clean water. All infaunal specimens were identified and put into a labelled container containing 50 to 70% ethanol.

The extracted specimens were examined by an experienced invertebrate specialist under a binocular light microscope with magnification of up to x90, in the NEA laboratory. Each specimen was identified to the lowest practicable taxonomic level. The numbers of each taxon in each sample were recorded and entered into a spreadsheet, with a column for each sample number, and a row for each taxon, in taxonomic sequence, with total numbers of each sample and each taxon.

Data was recorded to show taxon recorded in each sample, season, and site and were reflected in tables and graphs whenever appropriate.

2.7 Statistical Analysis

The statistical analysis was carried out using the latest PAST statistical package version 3.22. The package was used to compare between the data collected at the two locations and the two seasons. It was also used to find the correlation and regression between the environmental parameters and the biomass in both location during the different seasons. Species richness and diversity indices were also calculated using the tools available within the PAST statistical package.

Chapter 3: Results

3.1 Environmental Parameters Results

The average of the environmental parameters collected at both sites during the two seasons are shown in the Table 1.

Table 1: Collected parameters

Location	Season	Surface Temp (ºC)	Bottom Temp (ºC)	Salinity (ppt)	pH	Dissolved Oxygen (mg/L)
Protected Area	Summer	34.78	34.76	44.21	8.01	4.77
	Winter	22.53	21.95	46.15	8.07	5.20
Non-Protected Area	Summer	33.32	33.22	47.38	8.08	5.01
	Winter	20.25	20.01	44.06	8.07	5.40

The differences in temperature between the seasons is obvious with a change of almost 12ºC in winter in the protected area 13ºC in the none protected area. While the salinity increased in the winter in the protected area by about 2 ppt, it decreased in the non-protected area by 3 ppt, but the over-all salinity out of the protected area was higher. The difference in pH during the seasons and location was very small, but it did increase in the protected are 0.06 points. On average, the change in dissolved oxygen was also little where it increased less than 0.50 mg in both sites.

3.2 Sediment Samples

The results of the sieved sediment samples, shown in Tables 2 and 3, reflecting the findings per sample, per site during both seasons.

Table 2: Grain size analyses of bottom sediments collected during summer season at the protected area (PA) and non-protected area (NPA)

	Gravel		**Coarse Sand**		**Medium Sand**	**Fine Sand**		**Mud**
Sample / Sieve size	4mm	2mm	1mm	0.500 mm	0.250 mm	0.125 mm	0.063 mm	<0.062 mm
Summer Sample - PA								
PA-S1- SEDIMENT	3.30	8.90	12.60	23.30	26.60	9.30	10.50	5.50
PA-S2- SEDIMENT	6.00	3.40	9.00	28.30	31.20	8.30	12.20	1.60
PA-S3- SEDIMENT	0.00	3.60	13.00	29.10	31.50	9.70	6.80	6.30
PA-S4- SEDIMENT	0.90	35.00	47.10	15.40	1.60	0.00	0.00	0.00
PA-S5- SEDIMENT	3.90	10.80	16.80	32.80	24.40	5.80	3.40	2.10
PA-S6- SEDIMENT	5.20	11.50	15.70	33.20	21.50	5.40	6.20	1.30
PA-S7- SEDIMENT	5.10	17.40	13.70	30.00	26.20	4.20	2.10	1.30
PA-S8- SEDIMENT	1.60	7.00	10.80	30.20	34.50	8.30	4.60	3.00
PA-S9- SEDIMENT	1.80	11.50	21.80	28.20	19.90	7.40	6.20	3.20
Percentage	15.21%		45.66%		24.15%	12.26%		2.70%
Summer Samples - NPA								
NPA-S1-SEDIMENT	0.00	3.70	10.50	13.70	29.60	31.80	9.60	1.10
NPA-S2-SEDIMENT	0.00	2.80	11.30	14.00	27.65	32.85	11.40	0.00
NPA-S3-SEDIMENT	0.00	13.30	12.60	18.90	38.30	14.80	2.10	0.00
NPA-S4-SEDIMENT	2.30	6.60	12.70	26.30	34.10	9.00	4.80	4.20
NPA-S5-SEDIMENT	0.00	5.30	15.60	25.10	26.70	20.20	5.80	1.30
NPA-S6-SEDIMENT	0.10	8.00	14.10	15.70	23.60	28.90	6.90	2.70
NPA-S7-SEDIMENT	0.00	2.10	17.20	22.40	25.70	25.10	5.20	2.30
NPA-S8-SEDIMENT	0.40	5.00	11.00	16.00	25.20	33.10	6.60	2.70
NPA-S9-SEDIMENT	0.00	4.70	14.10	13.70	23.60	31.70	10.50	1.70
Percentage	6.03%		31.65%		28.27%	32.26%		1.78%

Table 2 shows the detailed composition of the sediments within the protected and non-protected areas during summer season. Detailed gravel size, coarse sand, medium sand, fine sand and mud composition are shown based on a 100 mm sample.

Figure 9 diagram shows the sediment composition and differences within the protected area.

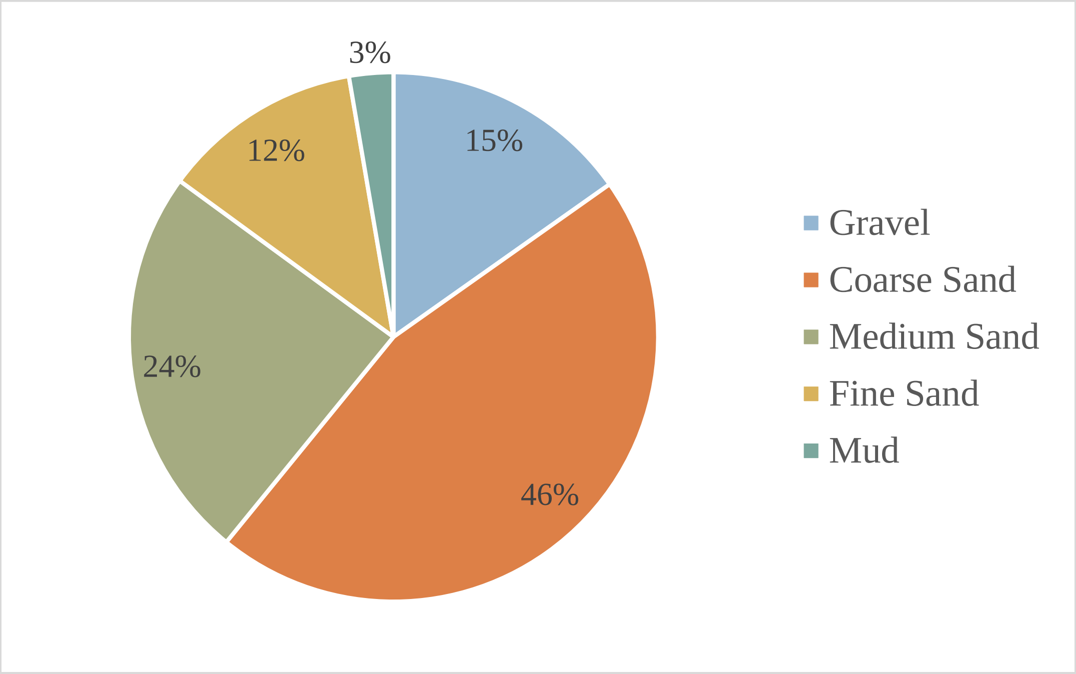

Figure 9: Summer sediment samples composition in the protected area

The collected samples were mainly made up of coarse sand with 45.66% of the overall collected sediments, followed by medium sand that made up 24% of the sample, then gravel at 15.21% where fine sand was 12.26% and the least was mud at 2.70%. The findings of the Non-Protected Area are diagramed in Figure 10.

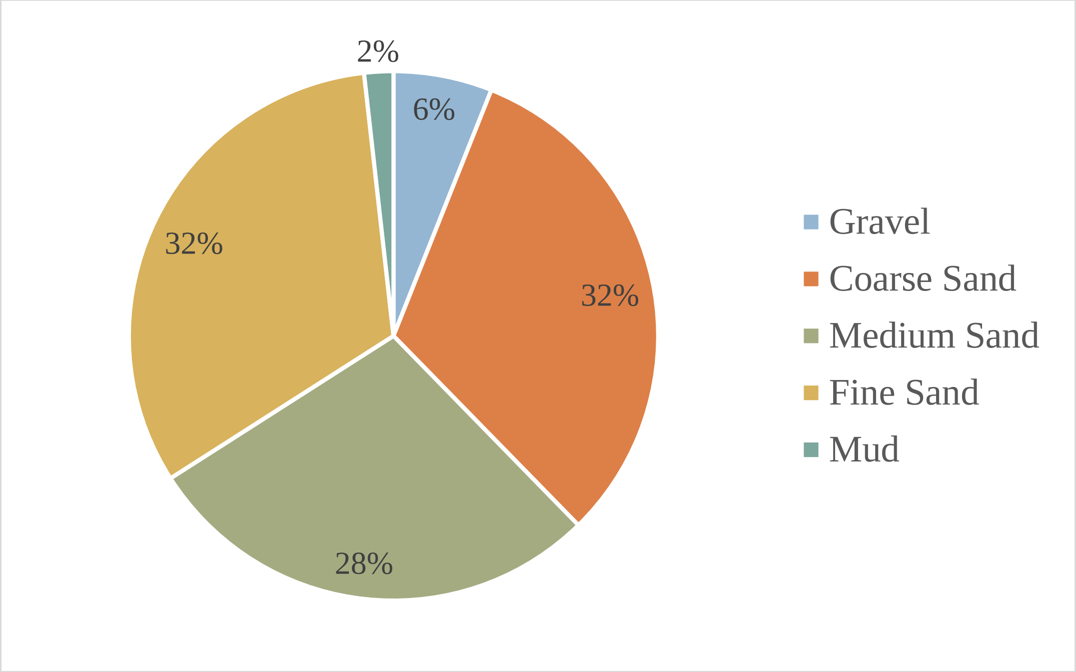

Figure 10: Summer sediment samples composition in the non protected area

The samples from the non-protected area where mainly made up of fine sand and coarse sand, at 32.26% and 31.65% respectively. Medium sand made up 28.27% of the sediment composition, while gravel only made up 6.03% and mud was only 1.78% of the sample.

When compared side by side, the difference in the sediment composition at each area, as reflected in Figure 11.

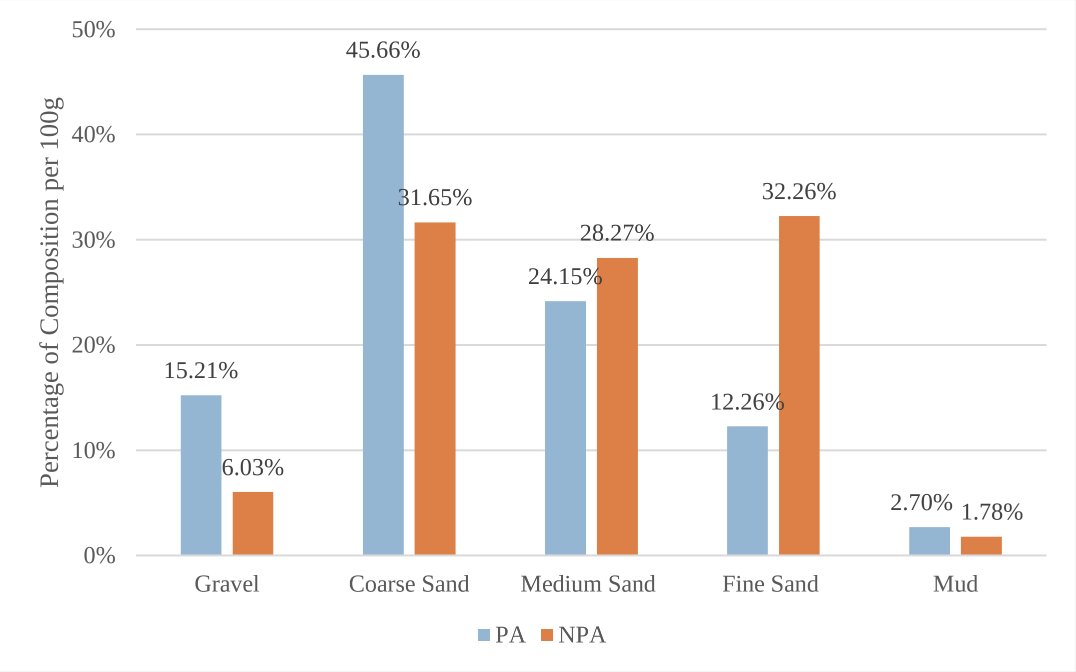

Figure 11: Sites comparison of summer sediment samples grain sizes composition

The difference between the sites are very clear, where the Protected Area sediment was mainly coarse sand, while the Non-Protected Area the sediment composition was more evenly distributed between all three sand sizes, fine sand and coarse sand, followed by medium sand. Moreover, in the protected area, the sediment sample was composed of more gravel than in the non-protected area. Fine sand was relatively less in the protected area in comparison to the non-protected area.

Table 3 reflects the composition of the sediment sample collected within the protected and non-protected areas during winter. Showing detailed gravel size, coarse sand, medium sand, fine sand and mud composition are shown based on a 100 mm sample.

Table 3: Grain size analyses of bottom sediments collected during winter season at the protected area (PA) and non-protected area (NPA)

	Gravel		**Coarse Sand**		**Medium Sand**	**Fine sand**		**Mud**
Sample / Sieve size	**4mm**	**2mm**	**1mm**	**0.500mm**	**0.250mm**	**0.125mm**	**0.063mm**	**<0.062mm**
Winter Samples - PA								
PA-W1- SEDIMENT	0.00	3.50	13.10	32.20	26.30	11.20	8.90	4.80
PA-W2- SEDIMENT	1.90	3.90	15.70	23.90	31.30	10.30	9.60	3.40
PA-W3- SEDIMENT	0.00	2.80	13.60	27.90	28.10	8.30	10.90	8.40
PA-W4- SEDIMENT	3.30	13.50	11.20	24.90	28.30	11.40	7.40	0.00
PA-W5- SEDIMENT	4.30	8.40	12.60	24.30	28.90	9.30	6.90	5.30
PA-W6- SEDIMENT	2.80	5.40	14.40	33.60	25.60	9.10	6.70	2.40
PA-W7- SEDIMENT	1.40	3.90	15.20	28.90	38.90	6.80	4.90	0.00
PA-W8- SEDIMENT	2.30	4.70	12.30	31.40	29.40	11.20	7.50	1.20
PA-W9-SEDIMENT	7.20	4.30	10.40	31.90	27.10	13.90	4.20	1.00
Percentages	8.18%		41.99%		29.32%	17.61%		2.94%
Summer Samples - NPA								
NPA-W1-SEDIMENT	0.10	4.20	12.70	15.80	26.10	29.90	11.20	0.00
NPA-W2-SEDIMENT	0.00	8.40	12.40	15.20	25.90	31.90	6.20	0.00
NPA-W3-SEDIMENT	2.30	2.40	11.20	11.20	27.30	31.90	12.40	1.30
NPA-W4-SEDIMENT	0.00	6.70	7.70	11.90	28.90	29.20	13.90	1.70
NPA-W5-SEDIMENT	1.20	2.40	10.70	17.40	28.80	31.30	5.90	2.30
NPA-W6-SEDIMENT	0.00	2.50	5.90	19.60	32.10	33.70	2.10	4.10
NPA-W7-SEDIMENT	0.00	7.90	12.90	15.80	33.60	23.60	2.30	3.90
NPA-W8-SEDIMENT	0.00	2.60	14.60	21.30	26.40	27.60	6.40	1.10
NPA-W9-SEDIMENT	0.00	8.40	12.00	14.80	25.40	29.10	10.30	0.00
	5.46%		27.01%		28.27%	37.65%		1.60%

Figure 12 clearly shows the sediment composition and differences within the Protected Area.

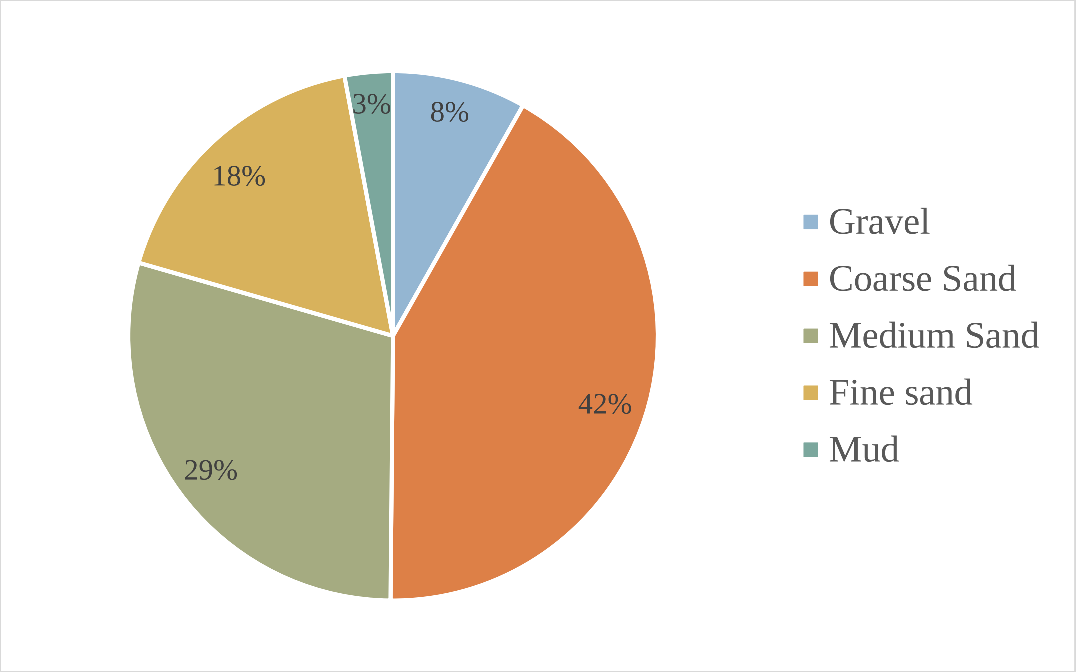

Figure 12: Winter sediment samples composition protected area

The samples from the Protected Area where mainly made up of coarse sand at 41.99% of the sediment composition, followed by Medium Sand at 29.32% of the sample, while fine sand was only 17.61% of the sample. Gravel made up 8.18% while mud was only found to be 2.94% of the sediment composition. The overall composition during the two season is very similar, where the sediment composition was mainly coarse sand, followed by medium sand, fine sand, gravel and mud. The percentage of the grain sizes found during both seasons was very similar too. The findings of the Non-Protected Area are diagramed clearly Figure 13.

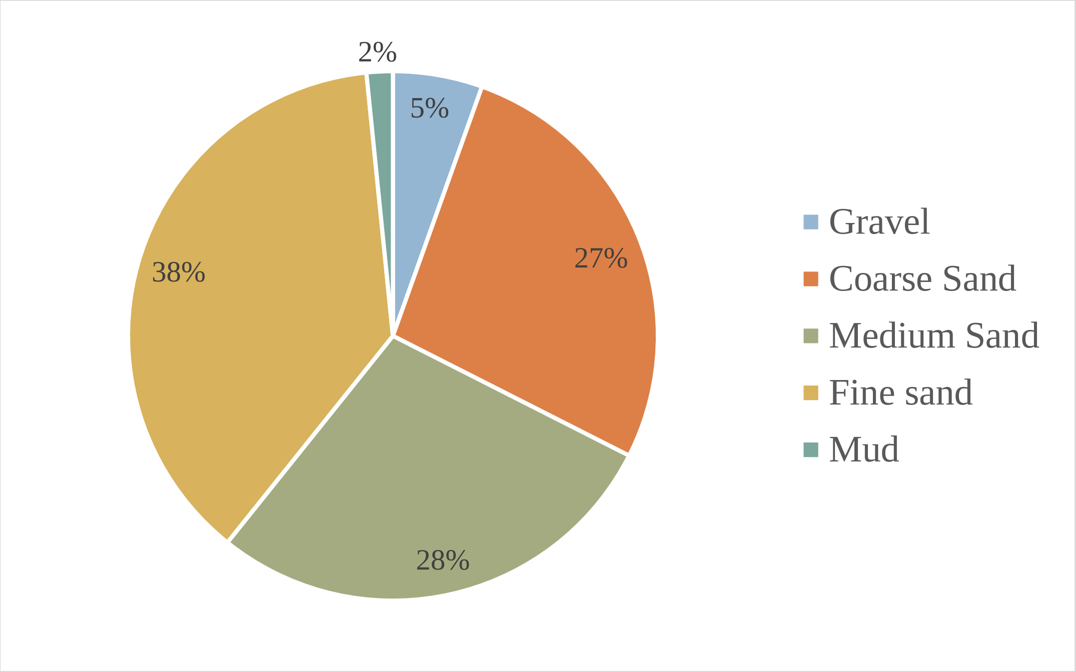

Figure 13: Winter sediment samples composition non protected area

The samples from the Non-Protected Area where more evenly distributed between fine sand at 37.65% and Medium sand at 28.27% and coarse sand at 27.01%, while Gravel and mud made up smaller portion of the sediment composition where gravel was at 5.46% and mud was only 1.60% of the sample. When compared to the summer season sediment composition, overall, during both seasons the sediment sample composition very similar.

When compared side by side, the difference in the winter sediment composition at each area, are reflected in Figure 14.

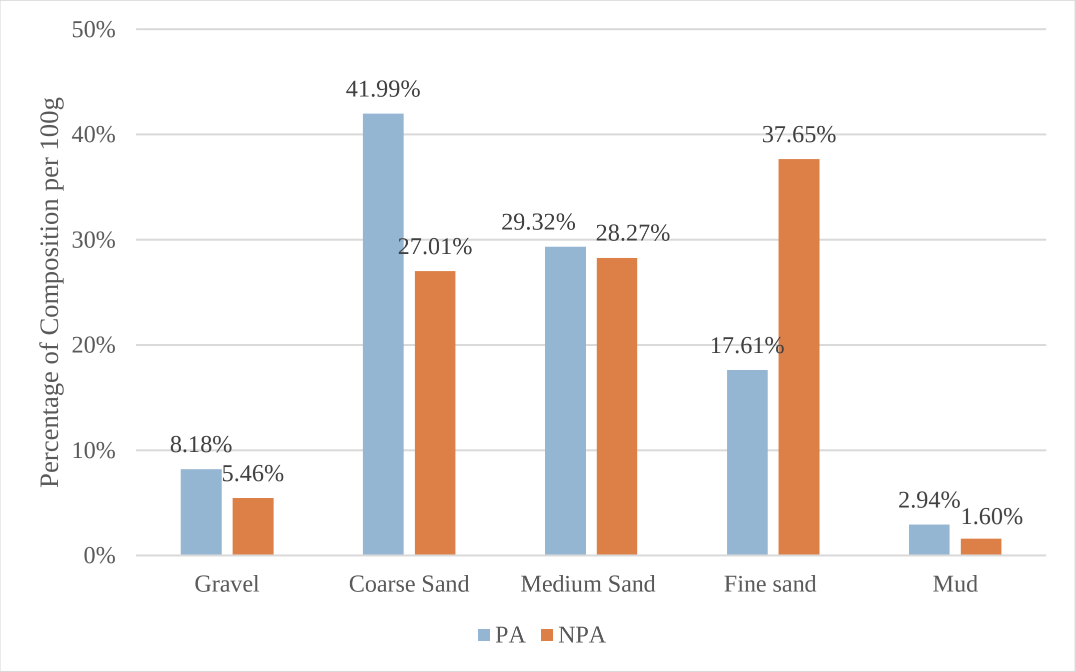

Figure 14: Comparison between PA and NPA grain sizes composition (winter)

The difference between the sites show in the chart above, just like the samples collected during summer, the sediment collected during winter shows that the Protected Area sediment was mainly coarse sand, while the Non-Protected Area the sediment composition was more evenly distributed between all three sand sizes, mainly fine sand and medium sand, followed by coarse sand. During winter, the percentage of gravel found in both sites was fairly similar with a difference of 2.72 & while fine sand was still relatively less in the protected area in compression to the non-protected area, just like in the summer sediment sample.

3.3 Water Analysis

On average the difference between the eighteen elements tested was minimum as reflected in Table 4 and Table 5. Table 6 shows only the trace metals analyzed in the water samples collected.

Table 4: PA water analysis - summer and winter results

Sample ID			**PA 1**	**PA 2**	**PA 3**	**PA 4**	**PA 5**	**PA 6**	**PA 7**	**PA 8**
Mg/ l (ppm)	**Winter**	**Ca**	605.1	604.5	608.1	563.3	562.7	562.3	578.8	562.2
	Summer	**Ca**	567	563.3	582.3	564.4	570.6	568.1	567.6	548.3
	Winter	**K**	608.9	613.6	615.4	576	586.3	583.1	587.8	577.4
	Summer	**K**	468.6	455.3	490.8	460.5	481.7	477.4	472.5	448.5
	Winter	**Mg**	1795.3	1840.5	1837.4	1739	1728.4	1769.7	1752.3	1765.4
	Summer	**Mg**	1802.3	1764.4	1838.8	1766.5	1804	1798.6	1787	1746.9
	Winter	**Na**	12530.7	12594.2	12531.6	12059.7	12228.4	12296.6	12300	12253.9
	Summer	**Na**	11509	11358.8	11693.6	11372.3	11552.3	11588	11462.1	11110.6
	Winter	**S**	1327.7	1324.3	1369.2	1250.2	1279	1257.6	1307.5	1244.3
	Summer	**S**	1378.8	1331.1	1384.8	1348.6	1368.7	1383.3	1359.3	1321.3
	Winter	**Al**	<0.010	0.016	0.017	<0.010	0.02	<0.010	0.011	0.016
	Summer	**Al**	0.009	0.02	<0.010	0.023	0.024	0.018	0.013	<0.010
	Winter	**As**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Summer	**As**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Winter	**Cd**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Summer	**Cd**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Winter	**Co**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Summer	**Co**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Winter	**Cr**	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Summer	**Cr**	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Winter	**Cu**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Summer	**Cu**	0.016	0.012	0.013	0.012	0.013	0.011	0.012	0.012
	Winter	**Fe**	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
	Summer	**Fe**	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
	Winter	**Mn**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Summer	**Mn**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Winter	**Mo**	0.009	0.007	0.01	0.01	0.008	0.009	0.01	0.007
	Summer	**Mo**	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018
	Winter	**Ni**	<0.002	0.002	<0.002	0.003	0.004	0.003	<0.002	<0.002
	Summer	**Ni**	0.004	<0.002	<0.002	0.005	0.002	0.002	0.003	0.003
	Winter	**P**	0.013	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
	Summer	**P**	0.023	<0.010	0.024	0.021	0.019	0.016	0.016	0.019
	Winter	**PBS**	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
	Summer	**Pb**	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
	Winter	**Sr**	3.32	3.08	3.07	3.07	3.19	3.31	3.4	3.19
	Summer	**Sr**	4.155	3.986	4.137	4.083	4.166	4.044	4.08	4.259
	Winter	**V**	0.001	0.002	0.002	0.002	0.002	0.002	0.001	0.002
	Summer	**V**	0.003	0.002	0.003	0.003	0.003	0.003	0.004	0.003
	Winter	**Zn**	0.001	0.001	0.004	0.001	0.001	0.003	0.002	0.005
	Summer	**Zn**	0.005	0.004	0.003	<0.001	0.004	0.005	<0.001	0.002

Table 5: NPA water analysis - summer and winter results

Sample ID			**NPA 1**	**NPA 2**	**NPA 3**	**NPA 4**	**NPA 5**	**NPA 6**	**NPA 7**	**NPA 8**
Mg/ l (ppm)	**Winter**	**Ca**	568.9	572.7	548.9	565.9	546.6	548.4	542.8	535.1
	Summer	**Ca**	560.3	547.7	554.5	535.1	567	562.7	549.3	562.3
	Winter	**K**	587.8	565.7	574.8	555.3	538.1	558.4	549.7	546.6
	Summer	**K**	464.4	444.4	454.9	432.3	461.6	448.8	448.8	467.5
	Winter	**Mg**	1762.8	1703	1721.6	1704.9	1638.7	1681.7	1688.9	1642
	Summer	**Mg**	1760.5	1736.2	1761.1	1682	1773.3	1777.1	1738.2	1790.8
	Winter	**Na**	12152.1	11771.3	11877.6	11807	11427.8	11862.6	11760.1	11724.5
	Summer	**Na**	11379.8	11134.2	11202.2	10784.1	11435.7	11339.2	11181.1	11393.7
	Winter	**S**	1233.2	1212.3	1188.9	1219.5	1176.8	1208.8	1176.9	1175.8
	Summer	**S**	1301.1	1270.6	1299.4	1256.9	1352.5	1325.4	1309.5	1350
	Winter	**Al**	<0.010	0.013	<0.010	<0.010	<0.010	0.01	<0.010	0.012
	Summer	**Al**	<0.010	0.023	0.017	0.018	0.022	<0.010	0.014	0.016
	Winter	**As**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Summer	**As**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Winter	**Cd**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Summer	**Cd**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Winter	**Co**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Summer	**Co**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Winter	**Cr**	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Summer	**Cr**	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
	Winter	**Cu**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Summer	**Cu**	0.01	0.012	0.009	0.012	0.015	0.011	0.013	0.013
	Winter	**Fe**	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
	Summer	**Fe**	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
	Winter	**Mn**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Summer	**Mn**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Winter	**Mo**	0.037	0.013	0.013	0.012	0.01	0.009	0.01	0.007
	Summer	**Mo**	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018	<0.018
	Winter	**Ni**	0.003	0.002	0.004	<0.002	<0.002	0.002	0.002	<0.002
	Summer	**Ni**	0.002	<0.002	0.003	0.004	0.005	0.005	0.002	0.002
	Winter	**P**	0.01	0.01	0.02	0.028	<0.010	<0.010	0.01	0.01
	Summer	**P**	<0.010	0.017	<0.010	0.024	0.011	0.01	<0.010	0.014
	Winter	**PBS**	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
	Summer	**Pb**	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
	Winter	**Sr**	3.74	3.49	3.35	3.24	3.31	3.22	3.16	3.13
	Summer	**Sr**	3.684	3.731	3.574	3.772	3.818	3.558	3.688	3.726
	Winter	**V**	0.002	0.001	0.002	0.002	0.001	0.001	0.002	0.001
	Summer	**V**	0.002	0.003	0.003	0.002	0.003	0.002	0.001	0.003
	Winter	**Zn**	0.002	0.001	0.003	0.001	0.001	0.001	0.001	0.001
	Summer	**Zn**	0.008	0.004	0.006	0.007	<0.001	0.003	0.005	0.002

Table 6: PA and NPA water sample trace metal - summer and winter results

Sample ID			**PA 1**	**PA 2**	**PA 3**	**PA 4**	**PA 5**	**PA 6**	**PA 7**	**PA 8**	**Average**
Mg/ l (ppm)	**Winter**	**S**	1327.7	1324.3	1369.2	1250.2	1279	1257.6	1307.5	1244.3	1294.975
	Summer	**S**	1378.8	1331.1	1384.8	1348.6	1368.7	1383.3	1359.3	1321.3	1359.488
	Winter	**Al**	<0.010	0.016	0.017	<0.010	0.02	<0.010	0.011	0.016	0.016
	Summer	**Al**	0.009	0.02	<0.010	0.023	0.024	0.018	0.013	<0.010	0.018
	Winter	**As**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Summer	**As**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Winter	**Cd**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Summer	**Cd**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Winter	**Co**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Summer	**Co**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Winter	**Cu**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Summer	**Cu**	0.016	0.012	0.013	0.012	0.013	0.011	0.012	0.012	0.013
	Winter	**Fe**	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
	Summer	**Fe**	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
	Winter	**Mn**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Summer	**Mn**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Winter	**Pb**	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
	Summer	**Pb**	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
	Winter	**Zn**	0.001	0.001	0.004	0.001	0.001	0.003	0.002	0.005	0.002
	Summer	**Zn**	0.005	0.004	0.003	<0.001	0.004	0.005	<0.001	0.002	0.004
Sample ID			**NPA 1**	**NPA 2**	**NPA 3**	**NPA 4**	**NPA 5**	**NPA 6**	**NPA 7**	**NPA 8**	**Average**
Mg/ l (ppm)	**Winter**	**S**	1233.2	1212.3	1188.9	1219.5	1176.8	1208.8	1176.9	1175.8	1199.025
	Summer	**S**	1301.1	1270.6	1299.4	1256.9	1352.5	1325.4	1309.5	1350	1308.175
	Winter	**Al**	<0.010	0.013	<0.010	<0.010	<0.010	0.01	<0.010	0.012	0.012
	Summer	**Al**	<0.010	0.023	0.017	0.018	0.022	<0.010	0.014	0.016	0.018
	Winter	**As**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Summer	**As**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Winter	**Cd**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Summer	**Cd**	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	Winter	**Co**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Sumer	**Co**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Winter	**Cu**	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003
	Summer	**Cu**	0.01	0.012	0.009	0.012	0.015	0.011	0.013	0.013	0.012
	Winter	**Fe**	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
	Summer	**Fe**	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017	<0.017
	Winter	**Mn**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Summer	**Mn**	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009	<0.009
	Winter	**Pb**	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
	Summer	**Pb**	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
	Winter	**Zn**	0.002	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001
	Summer	**Zn**	0.008	0.004	0.006	0.007	<0.001	0.003	0.005	0.002	0.005

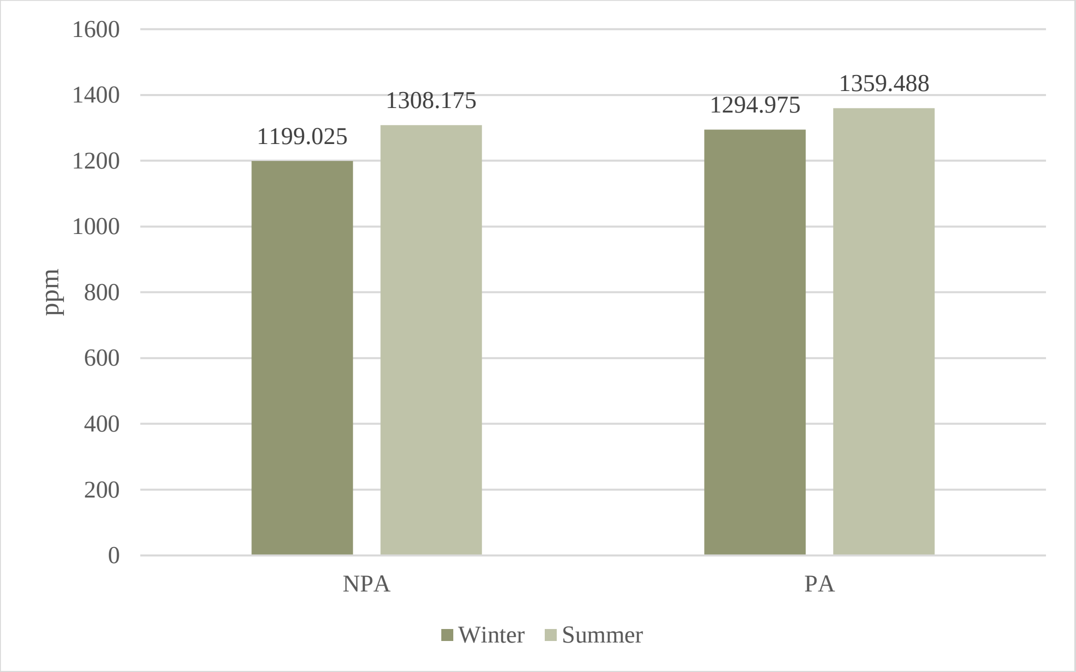

Figure 15: Sulphur concentration in NPA vs PA during winter and summer

Figure 15 shows the trace metals found in the water samples collected at the sites during both seasons. Most trace metals tested were not detected at elevated numbers nor was there a significant difference between the two locations and seasons. Sulphur was the only trace metal detected during both seasons and at both sites. Where the average Sulphur detected during winter was at 1199.025 ppm, and increased during summer + 109.15 ppm to 1308.175 ppm, while in the Protected area the Sulphur detected was at 1299.975 increasing during summer 64.50 ppm to 1359.488 ppm.

3.4 Biological Data

The calculated seagrass covers of each photo quadrate in both sites during the different seasons shown in Table 7. The data in Table 7 indicates that the total cover of seagrass during summer was > 80% at both sites, compared to the winter values where the seagrass coverage reduced to 67% in the protected area and 53 % at the non-protected area. Showing a change of - 14% and in the PA and - 29% in the NPA.

Table 7: Seagrass percentage cover at both protected and non-protected areas during the different seasons

		Seagrass Percentage Coverage									Total
Season	Site	1	2	3	4	5	6	7	8	9	
Summer	PA	98%	95%	85%	80%	65%	70%	85%	65%	85%	81%
	NPA	95%	80%	90%	95%	65%	75%	80%	70%	85%	82%
Winter	PA	45%	35%	75%	50%	70%	80%	90%	80%	75%	67%
	NPA	65%	75%	65%	55%	60%	40%	35%	45%	40%	53%

As per Table 7, seagrass percentage cover is high during the summer season where overall, the percentage cover is > 80% in both sites. The change in the density is obvious during the winter where in the non-protected area seagrass coverage was 53%, while in the Protected Area it was 67%. Figure 16 shows the seasonal variation in the seagrass coverage at both sites.

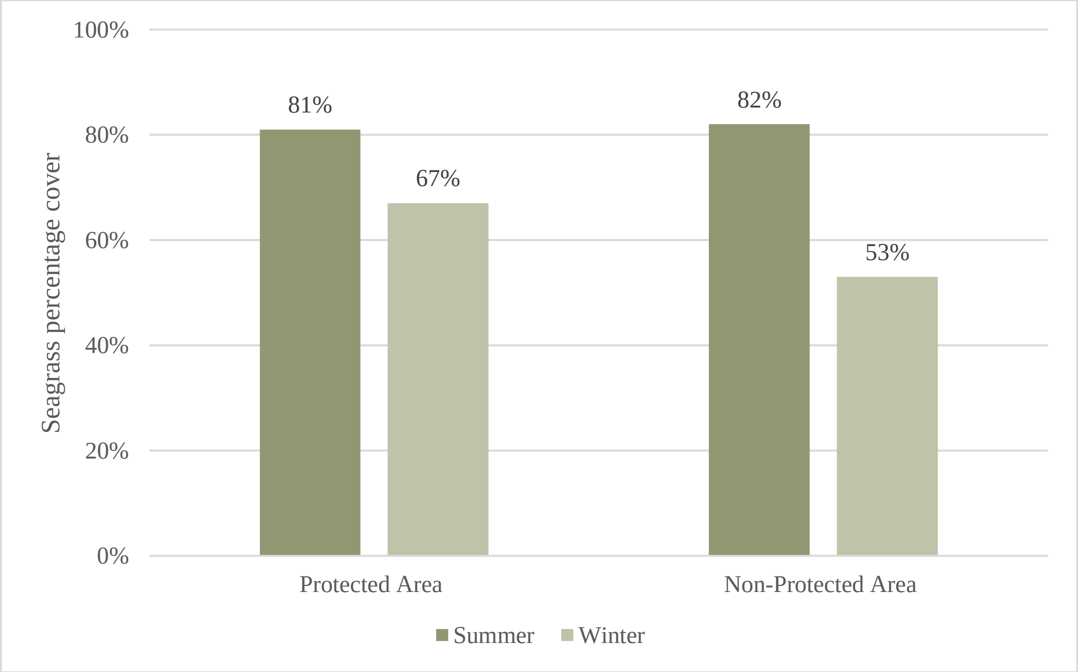

Figure 16: Seasonal variation in seagrass percentage cover at both PA and NPA

The biomass of the seagrass has calculated using the wet weight and the dry weight of the seagrass samples are illustrated in Table 8.

Table 8: Seagrass wet weight and dry weight at different seasons in both the protected and the non-protected areas

	Protected Area										
Season	Weight (g)	1	2	3	4	5	6	7	8	9	Total	Moisture %
Summer Samples	Wet Weight	74.426	75.12	62.22	72.37	63.48	83.25	49.76	84.07	53.77	618.47	25%
	Dry Weight	10.414	9.586	7.94	12.41	10.9	7.187	10.85	4.473	82.9	156.67	
Winter Samples	Wet Weight	31	16.5	16.55	28.06	22.8	33.45	16.02	15.16	28.62	208.16	17%
	Dry Weight	5	2.03	2.47	5.14	3.94	6.22	2.8	2.35	5.18	35.13	
	Non-Protected Area											
Season	Weight (g)	1	2	3	4	5	6	7	8	9	Total	
Summer Samples	Wet Weight	41.399	51.14	22.27	12.77	41.36	72.91	96.8	90.64	93.95	523.25	15%
	Dry Weight	6.907	9.373	3.858	1.735	5.314	12.82	15.04	12.37	10.3	77.72	
Winter Samples	Wet Weight	40.31	34.05	29.26	37	39.2	33.85	25.07	33.78	32.26	304.78	14%
	Dry Weight	5.57	4.36	3.996	4.9	5.238	4.09	4.47	5.14	4.02	41.78	

The data in Table 8 shows that there is a higher biomass weight for seagrass during summer season than in winter, where the summer samples in the protected area weight 618.47 g, while during the winter the seagrass weight was 208.16 g with a change of - 410.31 g. On the other hand, the dry weight in the protected areas was 156.67 g during summer while, during winter the seagrass weight was 35.13 g. with a difference of - 121.54 g in weight. However, in the NPA the summer wet weight was 523.25 g, while in winter the seagrass wet weight was 304.78 g with a difference of - 218.47 g and the dry weight was 77.72 g during summer and changed to 41.78 g with a difference of - 35.94 g.

The moister content was highest during summer in the Protected area, where there was a 25% moister in the samples and during winter it was 17%. However, there was no significant change in moister in the NPA with 15% during summer, and 14% during winter.

Wet weight and dry weight results, and their seasonal variation is reflected in Figure 17.

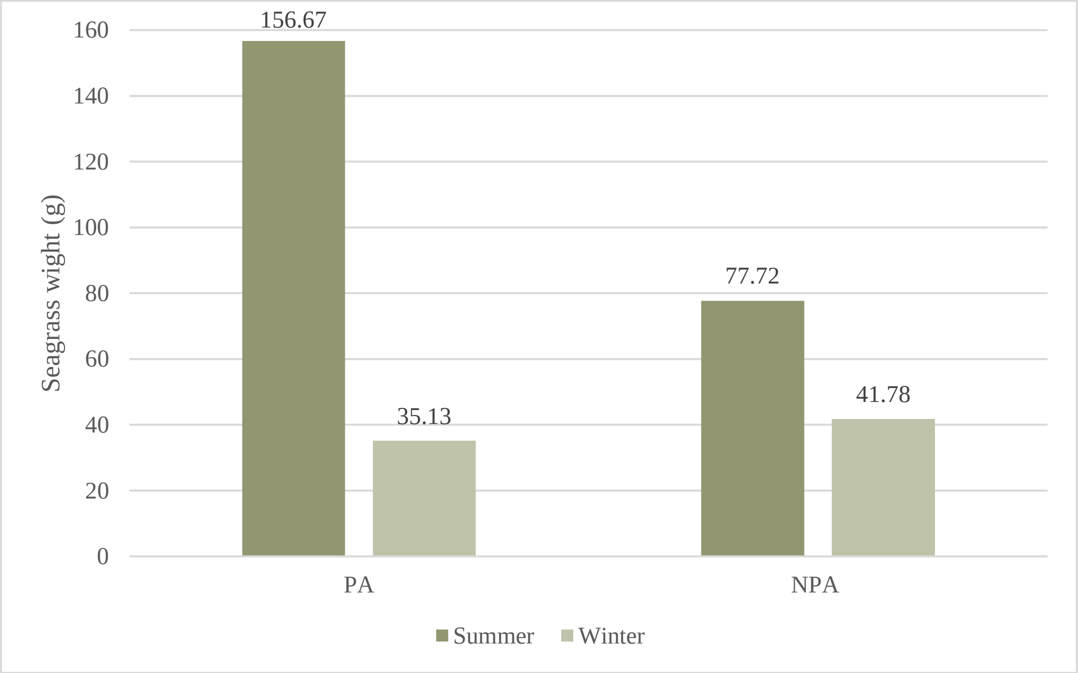

Figure 17: Seasonal variation in seagrass dry weight at PA and NPA

Figure 17 shows a very similar pattern to the seagrass coverage, where there is a change between the seasons, where winter has a lower seagrass biomass in comparison to summer.

The Seagrass species recorded at each site per season were *Halodule uninervis*, *Halophila stipulacea* and *Halophila ovalis* reflected in Figures 18-22.

Figure 18: *Halodule uninervis* and *Halophila ovalis* at the NPA during summer

Figure 19: *Halodule uninervis* and *Halophila stipulacea* at the NPA during summer

Figure 20: *Halodule uninervis and Halophila stipulacea* at the MPA during summer

Figure 21: *Halodule uninervis* and *Halophila ovalis* at the MPA during summer

During the Summer Survey all three seagrass species where found at both the Protected and nonprotected site with the obvious domination of *Halodule uninervis*

Figure 22: *Halodule uninervis* and *Halophila ovalis* at the MPA during winter.

During the winter, the *Halophila stipulacea* was not reordered in both sites, but with sparse *Halophila ovalis* recorded.

All the macrofauna data was tabulated per sample per site for each season listing the species, genus and class in Tables 9-12.

Table 9 shows 89 individuals from 9 different classes and 19 different species that have been identified in the summer samples. Where, the majority of the identified individuals were belonging to Gastropoda, followed by Polychatea. The species diversity was higher amongst Gastropodas and Bivalvias, with 5 identified species for each class, in compression to the other recorded species that have counts of 2 and 1 species per class. Figure 23 shows the different classes and species densities within the protected area during the summer season.

Table 9: Macro-fauna densities recorded in samples collected during summer season at the protected area

Class	**Genus/species**	**Summer Protected area (PA) Sample**									**Total**	**Class Total**	**Species Count**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
Sipunculidea	Phascolion sp.	1	0	0	0	0	0	0	0	0	1	1	1
Polychaeta	Onuphidae	1	3	3	1	0	2	4	0	0	14	19	2
	Serpulidae	2	0	0	0	0	3	0	0	0	5		
Isopoda	Sphaeromatidae	0	0	0	0	0	1	0	2	0	3	3	1
Malacostraca	Clibanarius sp.	0	0	6	0	3	1	0	1	0	11	12	2
	Medaeus sp.	0	0	0	0	0	1	0	0	0	1		
Gastropoda	Phasianella solida	0	0	0	0	1	0	0	0	0	1	35	5
	Bothropoma munda	1	0	0	0	1	1	0	2	0	5		
	Smaragdia souverbiana	1	0	0	0	0	0	0	0	0	1		
	Rhinoclavis kochi	2	0	3	0	5	15	1	0	0	26		
	Mitrella blanda	0	0	2	0	0	0	0	0	0	2		
Bivalvia	Solamen vaillantii	0	0	0	0	0	1	0	0	0	1	12	5
	Pterelectroma zebra	0	0	0	0	0	1	0	0	0	1		
	Pillucina vietnamica	0	0	0	1	0	2	0	2	2	7		
	Dosinia ceylonica	0	0	0	0	0	0	0	0	1	1		
	Corbula sulculosa	0	0	0	1	0	0	0	1	0	2		
Asteroidea	Aquilonastra burtoni	1	1	0	1	0	0	0	2	0	5	5	1
Ophiuroidea	Ophionereis dubia	0	0	1	0	0	0	0	0	0	1	1	1
Osteichthyes	Gobiidae	0	0	0	0	0	0	0	1	0	1	1	1

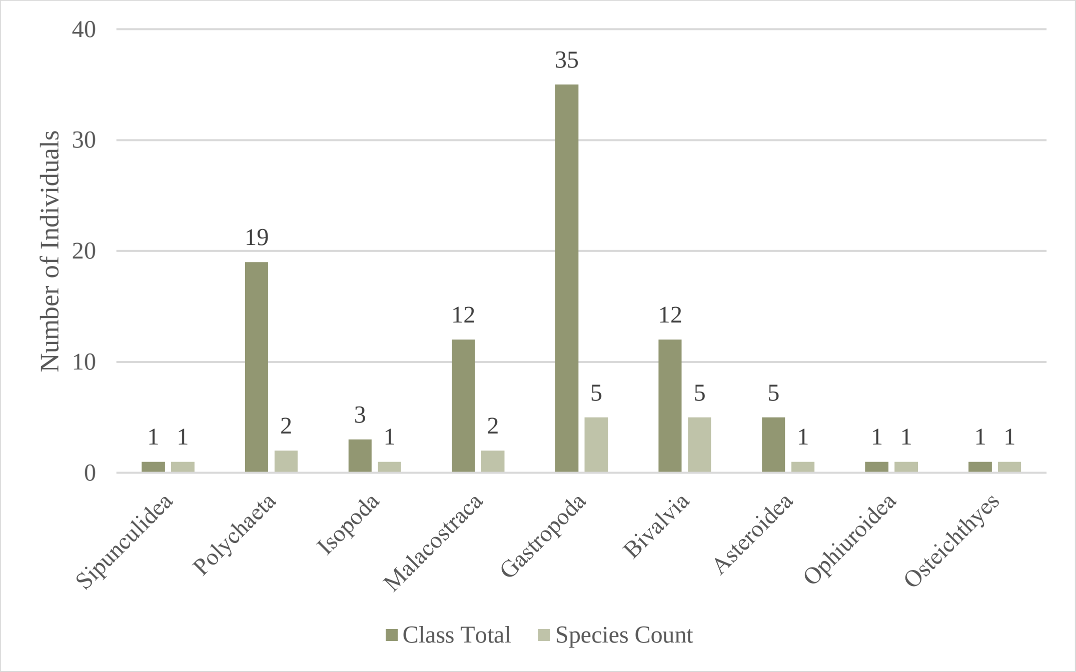

Figure 23: Macrofauna identified classes and the species densities within each class in the protected area during summer

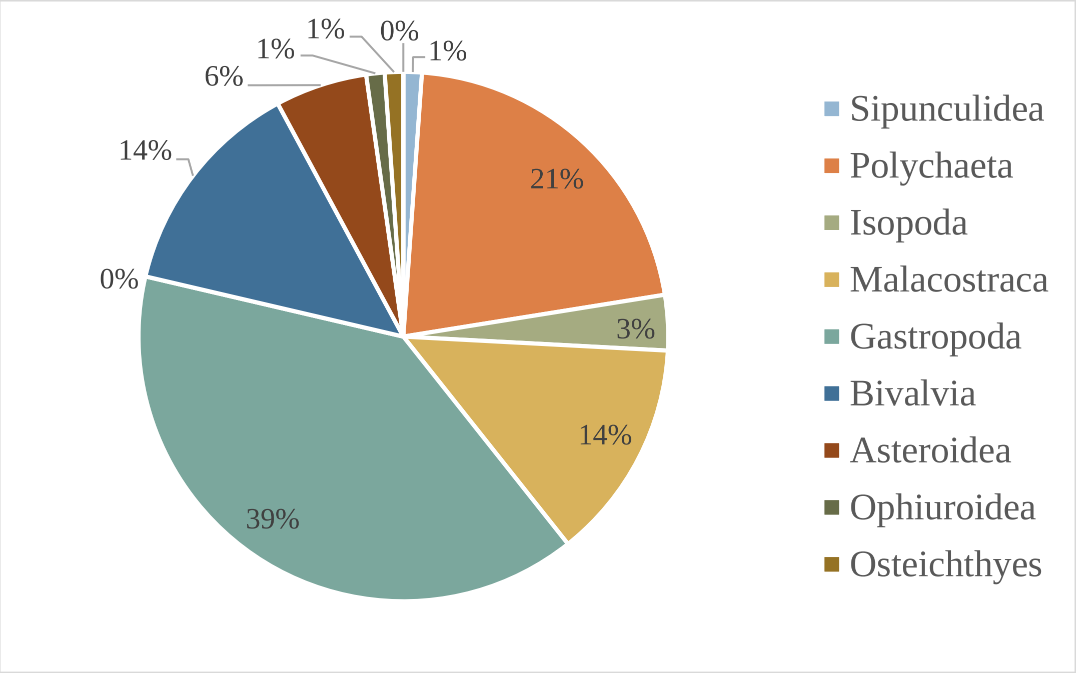

Figure 24: Macro faun class distribution in protected area summer

Figure 24 draws an overall view on the class distribution. On the other hand, the identified species of Macrofauna and their classes during winter are shown in Table 10.

Table 10: Macro-fauna densities recorded in samples collected during winter season at the protected area

Class	**Genus/species**	**Winter Protected area (PA) Sample**									**Total**	**Class Total**	**Species count**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
Sipunculidea	Phascolion sp.	0	0	1	1	1	0	0	0	2	5	5	1
Polychaeta	Nereididae	0	0	0	0	2	0	1	0	0	3	19	9
	Glycera sp.	0	0	0	0	1	0	1	0	0	2		
	Lumbrineridae	0	1	0	0	0	0	1	0	0	2		
	Oenonidae	0	0	0	0	0	0	1	0	1	2		
	Orbiniidae	0	0	0	0	2	0	1	0	0	3		
	Onuphidae	0	1	0	0	0	0	1	1	0	3		
	Phyllochaetopterus sp.	0	0	0	0	0	0	0	1	0	1		
	Ampharetidae	0	1	0	0	0	0	0	0	1	2		
	Owenia fusiformis	0	0	0	0	0	0	1	0	0	1		
Malacostraca	Bodotriidae	0	0	0	0	1	0	0	0	0	1	6	5
	Apseudidae	0	0	0	0	0	0	1	0	0	1		
	Ampeliscidae	0	0	0	0	0	0	1	0	0	1		
	Orchomene sp.	0	0	0	1	0	0	1	0	0	2		
	Anthuridae	0	0	1	0	0	0	0	0	0	1		
Gastropoda	Rhinoclavis kochi	0	0	1	9	0	2	0	0	0	12	13	2
	Mitrella blanda	0	0	0	0	0	1	0	0	0	1		
Bivalvia	Modiolus cf. barbatus	0	0	0	0	0	0	1	0	0	1	2	2
	Tellina methoria	0	0	0	0	0	0	0	1	0	1		
Ophiuroidea	Ophiodermatidae	0	0	0	0	0	1	0	0	0	1	1	1

Table 10 shows a decline in the number of individuals where the total identified individuals were only 46 that belongs to 6 different classes and 20 different species. Polychaeta was dominant during winter with 19 individuals, followed by Gastropoda, while the Polychaeta had the highest species diversity with 9 identified species, followed by Malacostraca with 5 different species. Osteichthyes, Isopoda and Asteroidea disappeared during the winter season.

Figure 25 reflects the class totals and the species diversity found in the protected area during the winter survey.

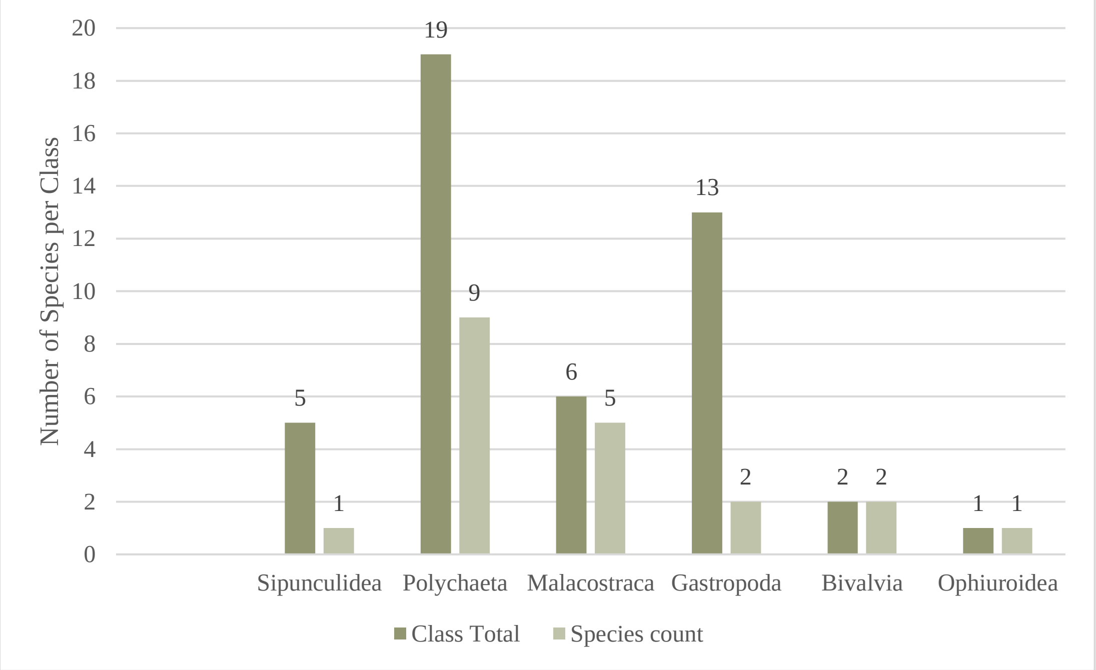

Figure 25: Macrofauna identified classes and the species densities within each class in the protected area during winter

The figure shows that not all classes had a high biodiversity, where Sipunculidea, was made of only one specie, and Gastropoda was only reflected in two specie, Polychaeta had a higher biodiversity with 9 different species.

The pie chart, shown in Figure 26, draws an overall view on the class distribution in the Protected Area during winter

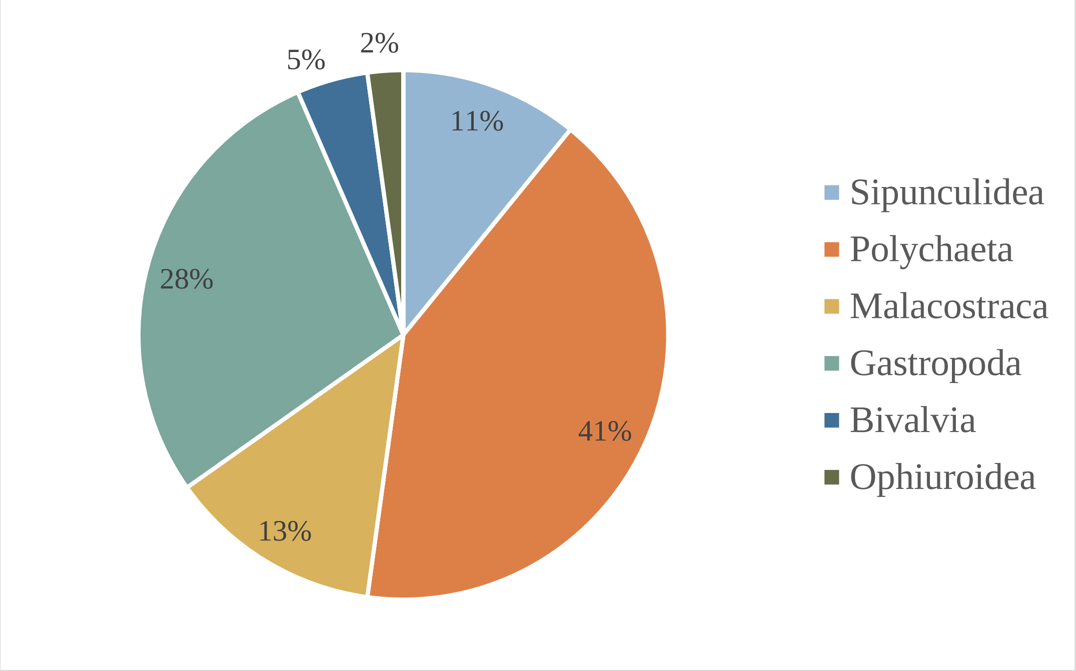

Figure 26: Macrofauna class distribution in protected area winter

Figure 27 reflects the difference in class total population between the seasons in the protected area.

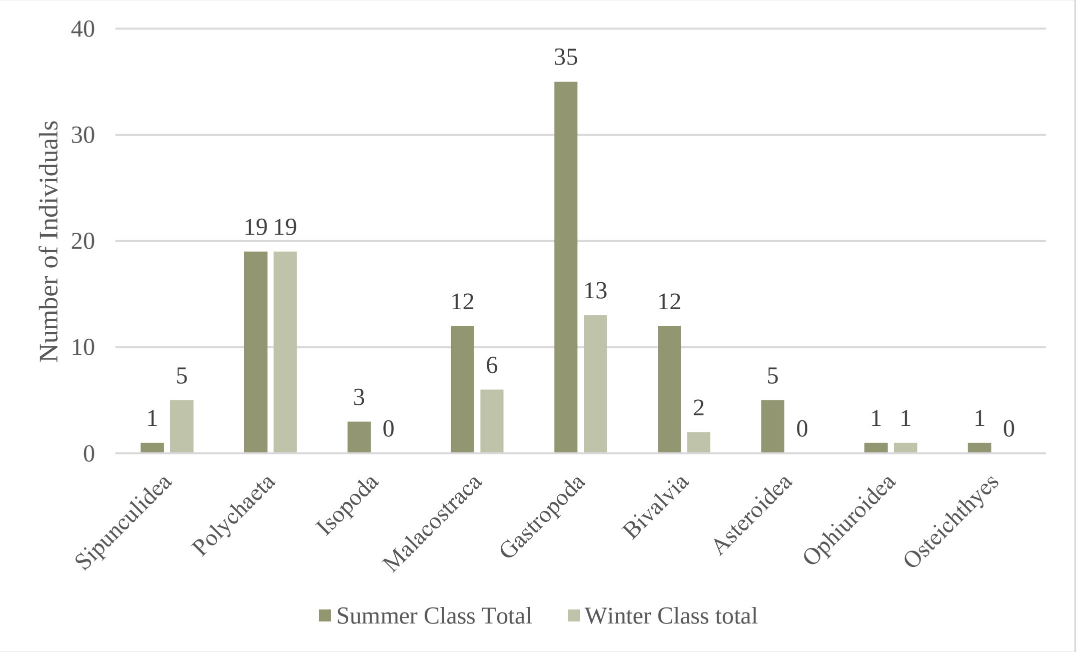

Figure 27: Classes populations of Macrofauna at both summer and winter seasons in the protected area

Where it is clearly noticed that there is a decrease across most classes in population in winter compared with summer, where the summer samples had a higher number of Isopoda, Malacostraca, Gastrapoda, Bivalvia, Asterodiea and Osteichthyes. The class population of Polychaeta and Ophiuroidea stayed similar between the seasons. On the other hand, Sipunculidea increased in class population during winter.

The species richness also varied between the two seasons in the protected area as shown in Figure 28.

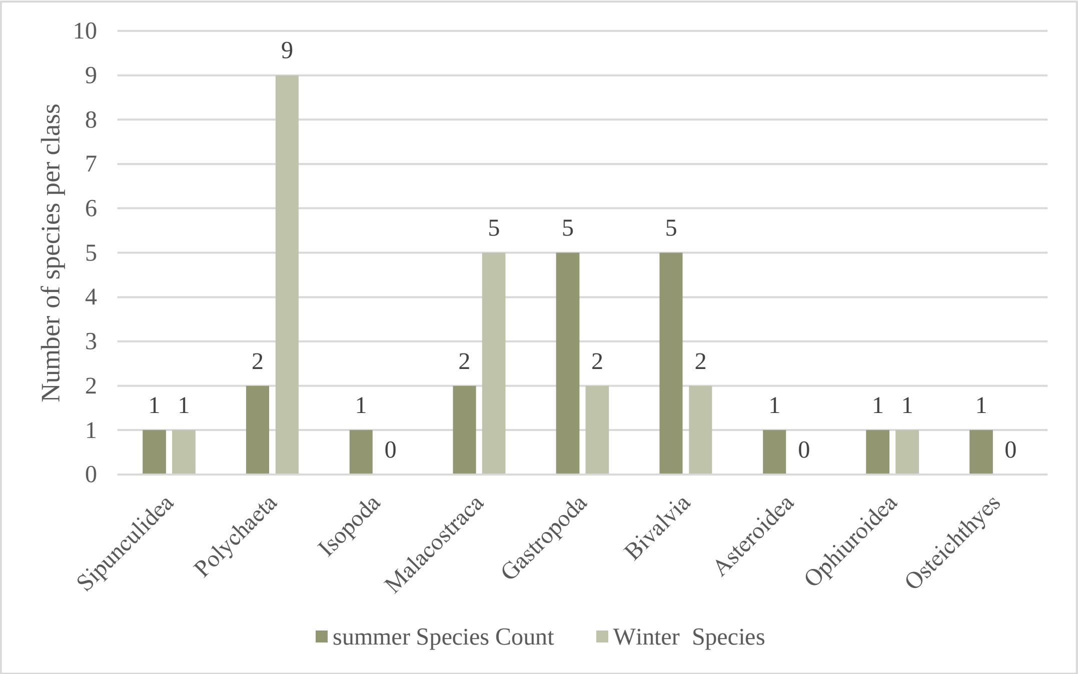

Figure 28: Species richness at both summer and winter in the protected area

The variations in polycheata class species composition at the protected area during both summer and winter are shown in Figure 29.

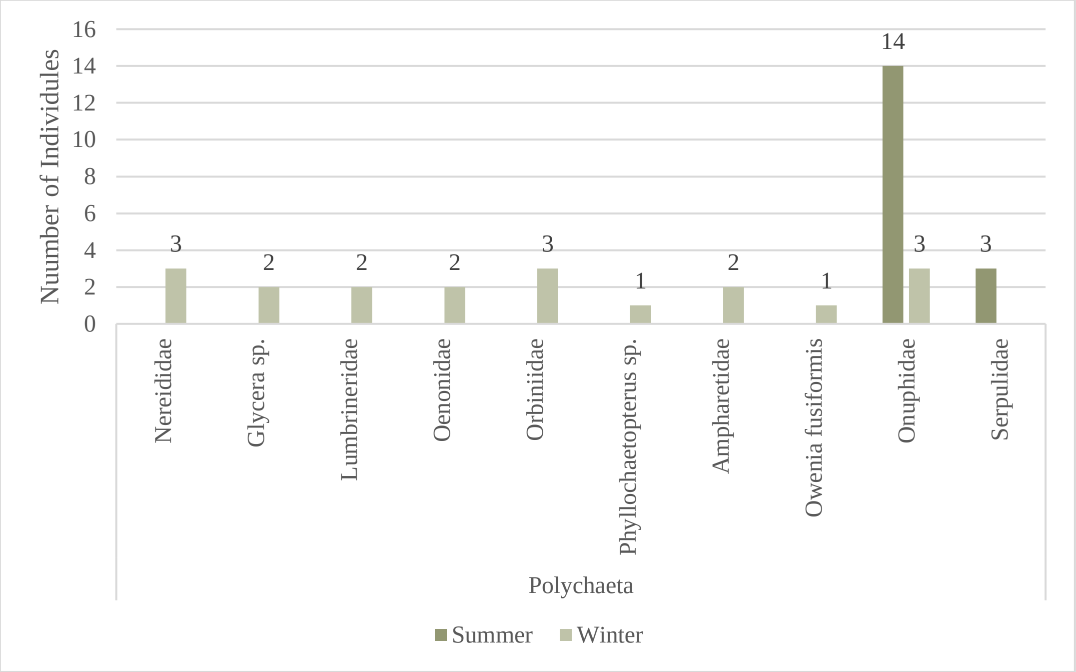

Figure 29: Seasonal variations of Polychaeta species composition in the protected area

The total of polychaeta count was constant between the two seasons, Figure 29 highlights the high diversity during winter with low count in each species, where the highest count was at 3 for three species during winter. However, in summer it showes a lower diversity, but with a high count of only *Onuphidae* sp., with 14 idevidules, followed by *Serpulidae sp.* with 3.

The same is reflected when the data of the Malacostraca is graphed in Figure 30.

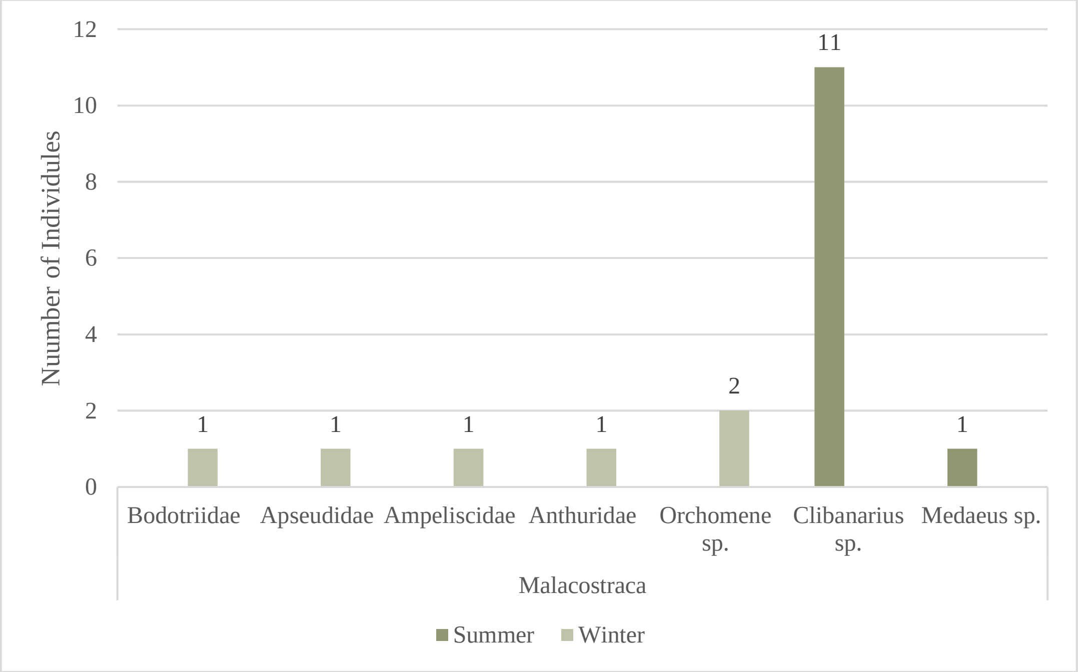

Figure 30: Seasonal variations of Malacostraca species composition in the protected area

Figure 30 reflects a higher species composition and diversity during winter where 5 species have been recorded, with a lower number of individules, at an avarage of 1 individules per species, while during summer the species are limited to two, where 11 *clibanarius* sp. where recorded during summer, and 1 Medaeus sp.

On the other hand, Gastropoa and Bivalvia showed the opposite results, as reflected in Figures 31 and 32.

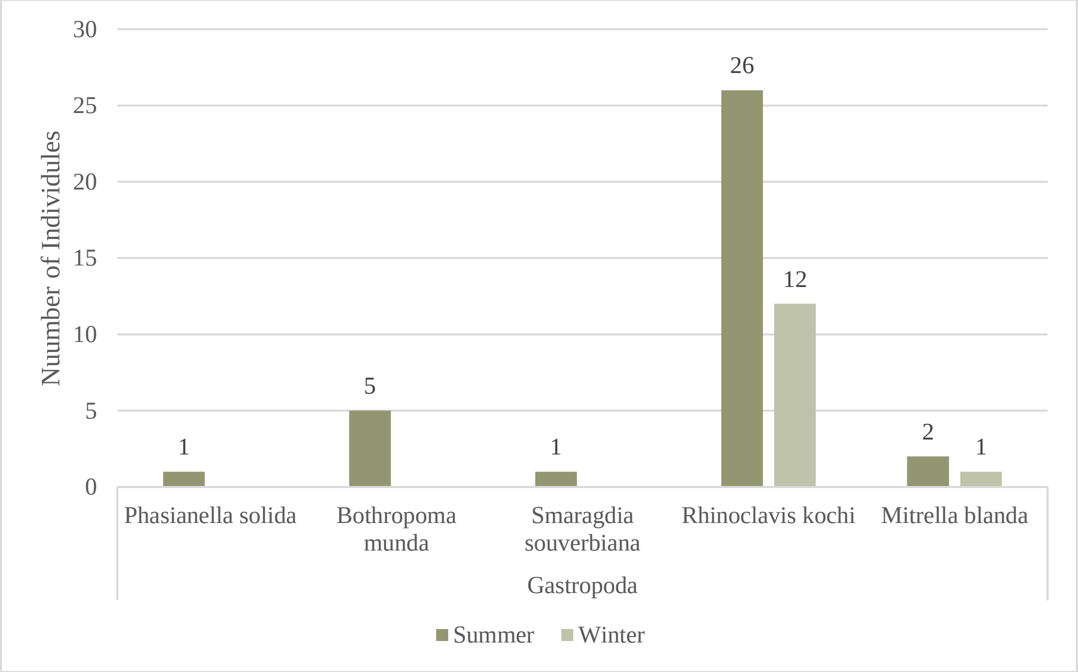

Figure 31: Seasonal variations of Gastropoda species composition in the protected area

Gastrapoda, unlike Malacostraca and Polychaeta, increase in both species diversity and individules, where during winter only two species were recordeed and a total of 13 individels where *Rhinoclavis kochi* made up 12 and *Mitrella blanda* was recored once. In summer a total of five species 36 individules where recorded with 26 *Rhinoclavis Kochi*, followed by 5 *Bathropoma munda*.

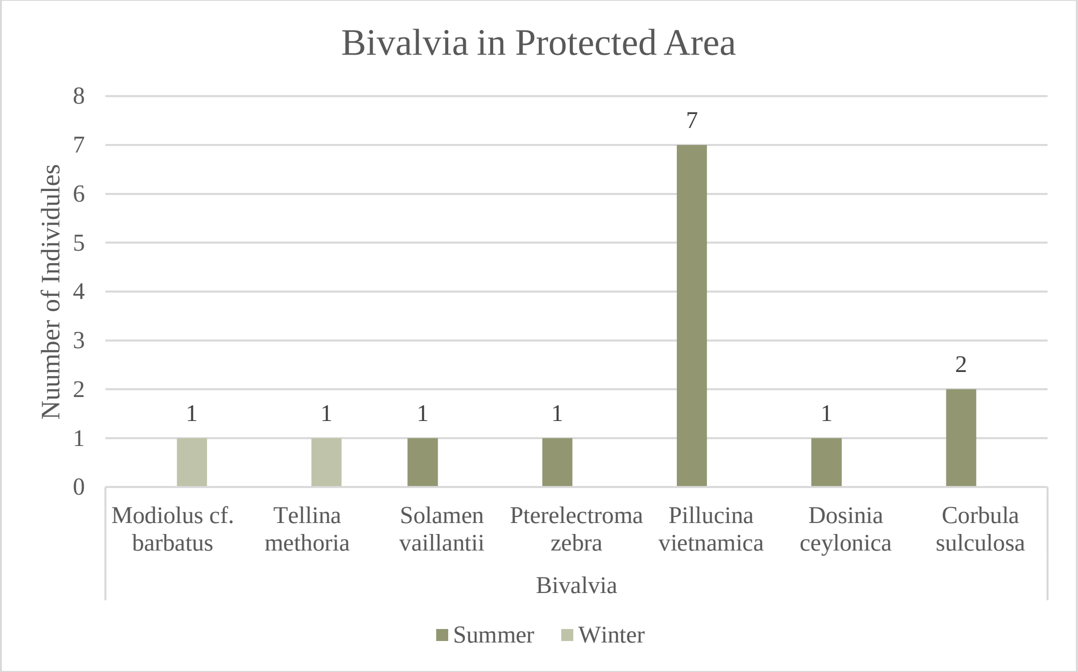

Figure 32: Seasonal variations of Bivalvia species composition in the protected area

Like Gastropoda, Bivalvia has a lower species diverity during winter, with two recorded species, and only two individules. During summer, a higher species diversity was recorder, in addition to a higher individule count, where 7 *pillucina vietnamnica* followed by 2 *corbula sulculos.*

By shifting to the Non protected area the summer Macrofauna classes and their species composition have identified. The analyses are summarized in Table 11.

Table 11: Macro-fauna densities recorded in samples collected during summer season at the non-protected area

Class	**Genus/species**	**Summer Non-Protected area (NPA) Sample**									**Total**	**Class Total**	**Species Count**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
Sipunculidea	*Phascolion sp.*	0	1	3	1	0	0	2	2	7	16	16	1
Polychaeta	*Onuphidae*	0	1	0	0	0	0	0	0	0	1	1	1
Isopoda	*Sphaeromatidae*	0	0	0	1	0	1	0	0	1	3	3	1
Malacostraca	*Diogenes avarus*	0	0	3	0	0	0	0	0	0	3	4	2
	Thalamita poissoni	0	1	0	0	0	0	0	0	0	1		
Gastropoda	Ceithiidae	0	0	0	0	0	1	0	0	0	1	1	1
Bivalvia	*Musculista senhousia*	0	0	0	0	0	1	0	0	0	1	25	7
	Musculus cf.costulatus	1	0	0	0	0	0	0	0	1	2		
	Pinctada radiata	0	0	0	0	0	1	0	0	0	1		
	Pillucina vietnamica	0	1	0	0	0	1	1	5	0	8		
	Cardiolucina semperiana	1	1	0	0	0	1	0	3	1	7		
	Tellina pinguis	0	0	0	0	0	0	0	3	0	3		
	Circe rugifera	1	0	0	0	1	0	0	0	1	3		
Asteroidea	*Aquilonastra burtoni*	0	1	0	0	0	0	0	0	0	1	1	1
Ophiuroidea	*Amphiuridae*	0	0	0	0	0	0	0	0	1	1	4	2
	Ophionereis dubia	0	0	0	0	0	0	1	2	0	3		
Ascidiacea	*Styelidae*	0	0	0	0	0	0	0	1	0	1	1	1

Table 11 reflects the summer findings in the non-protected area, where 56 individuals from 9 different classes and 17 species were identified dominated by Bivalvia, with 25 individuals, followed by Sipunculidea with 17 individuals, while

Bivalvia had the highest species biodiversity, with 7 species followed by Malacostraca and Ophiuroidea with only 2 species per class. Sipunculidea, Polychaeta, Isopoda, Gastropoda, Asteroidea and Ascidiacea had only 1 species count per class. Figure 33 reflects the identified classes and the species densities found in the non-protected area during the summer survey.

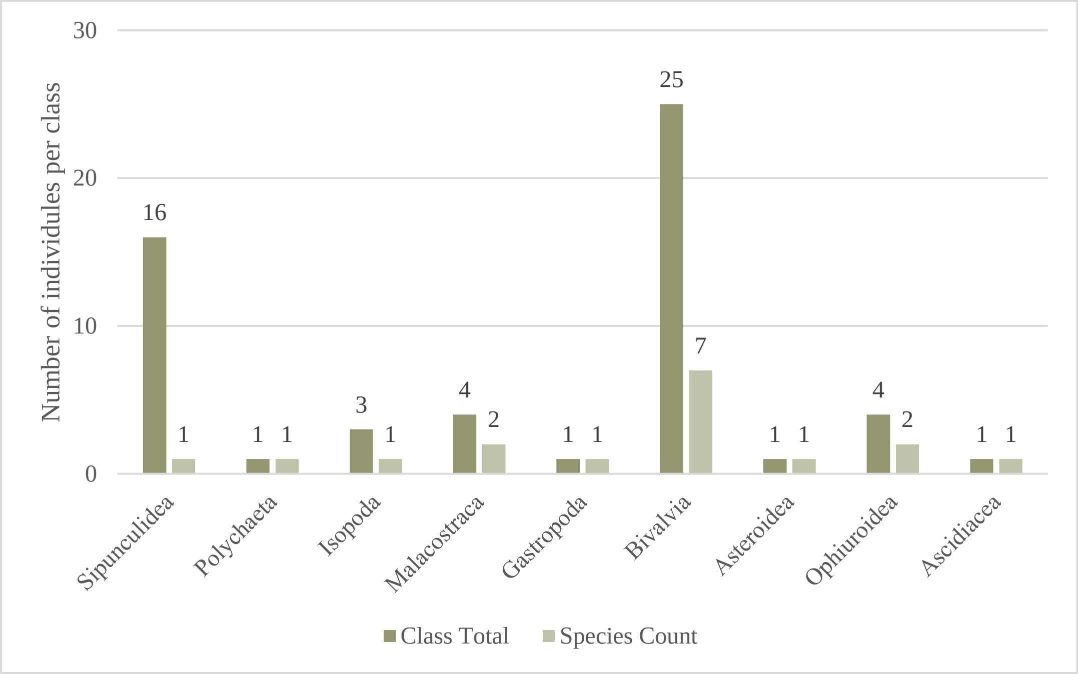

Figure 33: Macrofauna identified classes and the species richness within each class in the non-protected area during summer

The graph above puts into perspective the difference in species count and class total, where Figure 33 reflects the number of identified classes and the species composition and their counts in each class. It can be seen that despite the high number of Sipuculidea, it is only made up of one species/Genus, *Phascolion* sp., while the 25 Bivalvias where made up of 7 different species.

Table 12 shows 55 individuals from 8 different classes and 26 species. Where Polychaeta dominated with the highest number of individuals and highest species diversity with 15 individuals and 7 species, followed by Malacostraca and Bivalvia with 10 individuals and 5 species each respectively. While, Isopoda and Asteroidea disappeared while, Scaphopoda, which was not found during the summer survey appeared during winter (Figure 33).

Table 12 Winter non-protected area macro-fauna

Class	**Genus/species**	**Winter Non-Protected area (NPA) Sample**									**Total**	**Class Total**	**species count**
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**			
Sipunculidea	*Phascolion sp.*	0	1	0	1	0	1	0	1	1	5	5	1
Polychaeta	Polynoidae	0	2	1	0	0	1	0	0	1	5	15	7
	Nereididae	1	0	0	0	0	0	0	0	0	1		
	Glycera sp.	0	0	0	0	0	1	0	0	0	1		
	Onuphidae	0	1	0	0	0	0	0	0	0	1		
	Flabelligeridae	0	1	0	0	0	0	0	0	1	2		
	Terebellidae	0	0	1	0	0	1	0	2	0	4		
	Trichobranchidae	1	0	0	0	0	0	0	0	0	1		
Malacostraca	Bodotriidae	1	0	1	0	0	0	0	0	0	2	10	5
	Sphaeromatidae	0	0	0	0	0	1	1	0	0	2		
	Diogenes avarus	0	0	1	1	0	0	0	1	0	3		
	Medaeus sp.	0	0	0	1	0	0	0	0	0	1		
	Thalamita poissoni	0	1	0	0	1	0	0	0	0	2		
Gastropoda	*Phasianella solida*	0	0	0	0	0	0	0	1	0	1	4	4
	Clanculus gennesi	0	0	0	1	0	0	0	0	0	1		
	Hexaplex kuesterianus	0	0	0	1	0	0	0	0	0	1		
	Ancilla farsiana	0	0	0	0	1	0	0	0	0	1		
Scaphopoda	*Laevidentalium sp.*	0	0	0	0	0	0	0	1	0	1	1	1
Bivalvia	*Pinctada radiata*	0	1	0	0	0	0	0	0	0	1	10	5
	Pillucina vietnamica	0	0	0	0	0	0	0	5	0	5		
	Chama reflexa	0	0	0	1	0	0	0	0	0	1		
	Tellina pinguis	0	0	0	0	0	0	0	1	0	1		
	Gafrarium pectinatum	0	0	0	0	0	1	0	1	0	2		
Ophiuroidea	*Ophionereis dubia*	0	0	1	1	0	0	0	1	0	3	3	1
Ascidiacea	Styelidae	0	2	0	0	0	1	0	0	0	3	7	2
	Didemnidae	0	1	0	0	0	0	0	1	2	4		

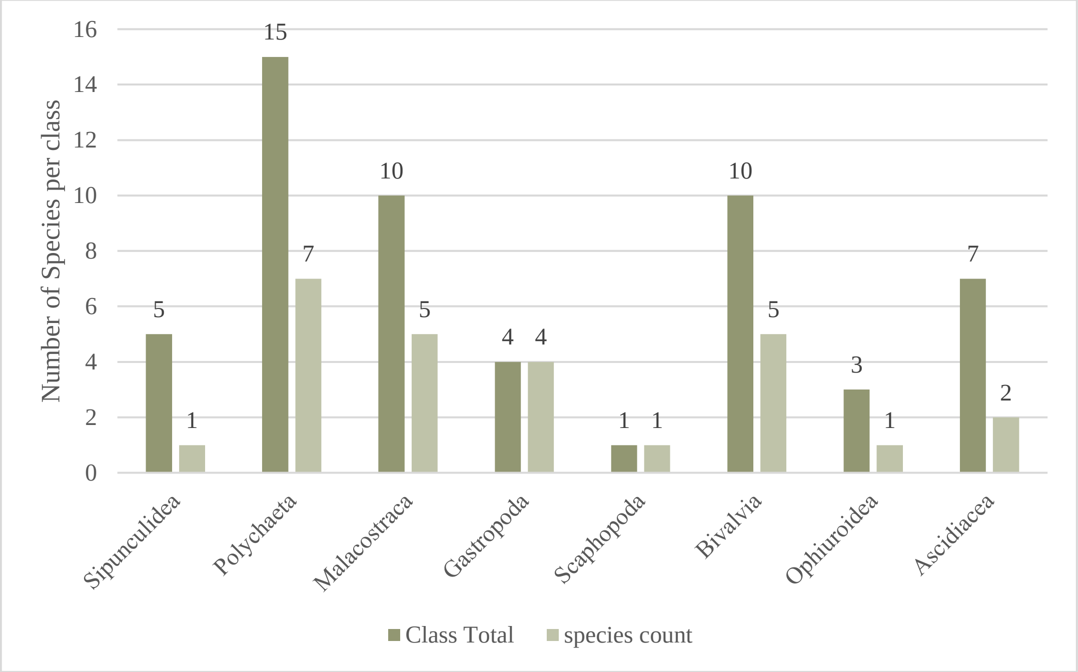

Figure 34: Macrofauna identified classes and the species richness within each class in the non- protected area during winter

Figure 34 shows the class count and the number of species in each class, where it clearly indicating that Sipunculidea, Scaphopoda, Ophilurodea and Ascidacea were low in diversity, while Polychaeta, malacostraca, Gastropoda and Bivalvia had a relatively higher diversity per class.

The difference in class count is clear per season as reflected in Figure 35. The difference in class population during the two seasons, where out of the 10 defined classes, 5 increase during summer, where Sipunculidea and Bivalvia dramatically increase in comparison to Ophiuroidea, while Isopoda and Asteroidea are absent in the winter samples. During winter, Polychaeta and Malacostraca and Ascidiacea increase dramatically in compassion with Gastropoda, in addition to the appearance of Scaphopoda in the winter sample. The species diversity is better shown in Figure 36.

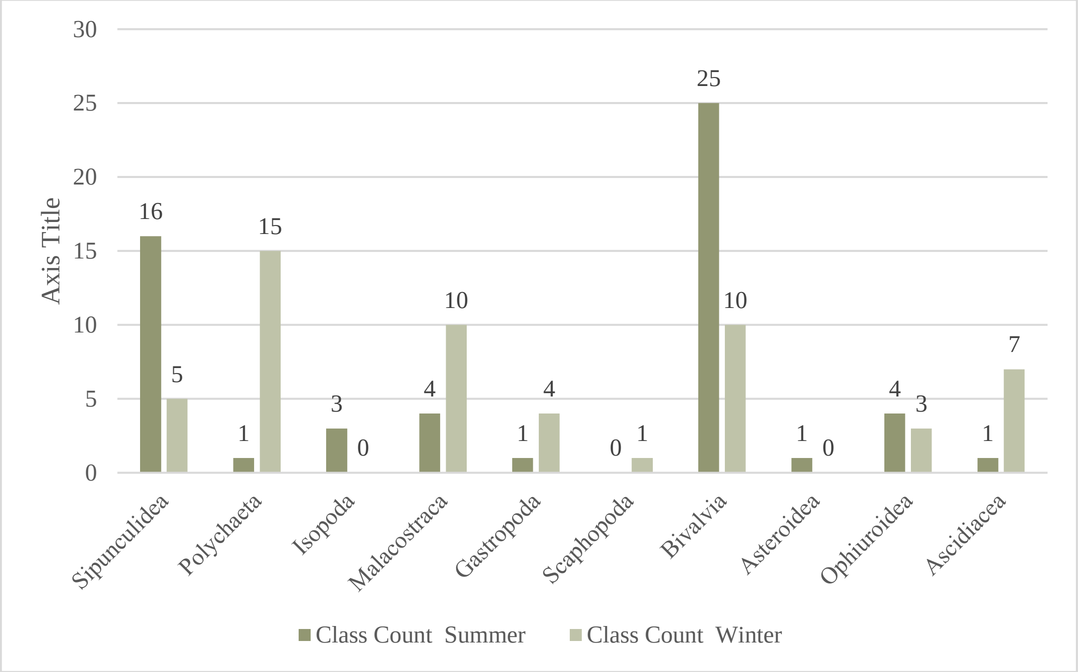

Figure 35: Identified classes at both summer and winter in the non-protected area

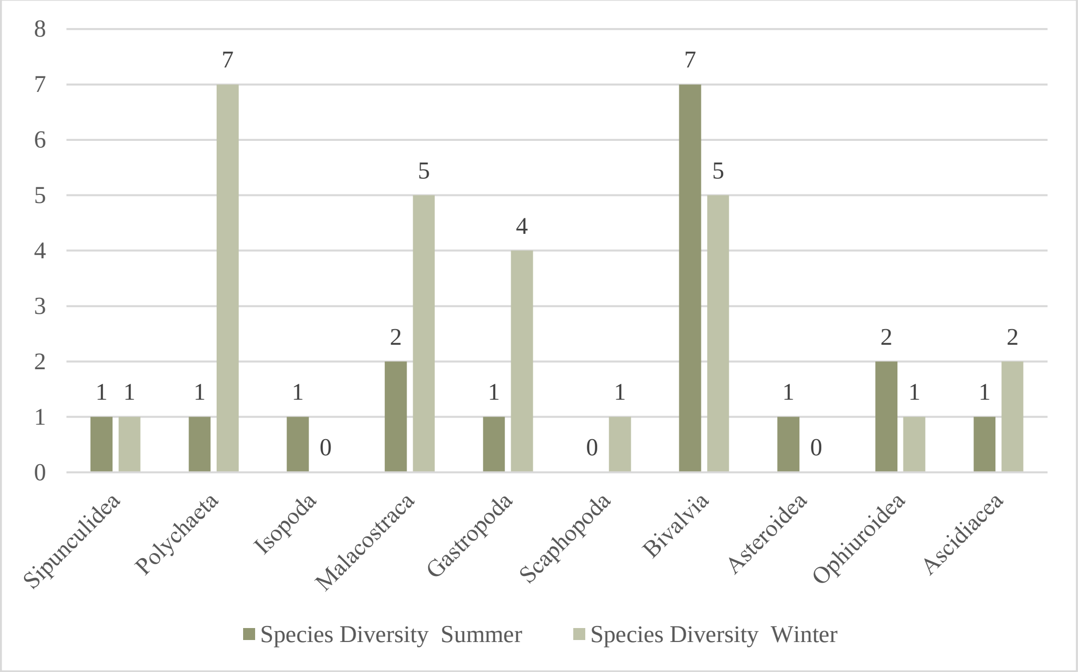

Figure 36: Species richness at both summer and winter in the non-protected area

The graph above reflects the relatively high spike in species diversity during winter in Polycheaeta, Malacostraca and Gastrapoda, whereas Ascidiacea only increases one species count. While two species of Bivalvia disappeared during winter, only one species of Ophiuroidea was absent in compression to the summer samples. Isopoda and Asteroidea are absent during winter. Sipunculidea count remains unchanged, while, Scaphopoda appears during winter with one species count.

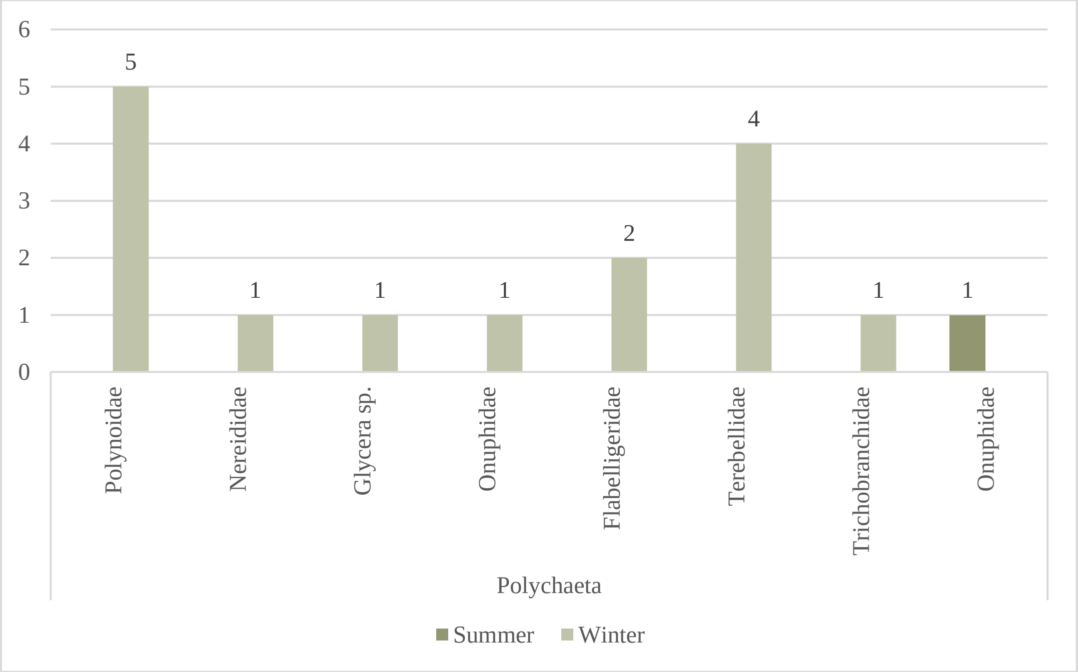

Figure 37: Seasonal variations of Polychaeta species composition in the non-protected area

Just like the protected area, the Polychaeta species composition during winter is more diverse (Figure 37), but unlike the protected area, the species count is more abundant, where the count of the Polychaetas during winter was 15 across six different species, dominated by *polynoidea*, with 5 individuals, followed by *terebllidea* with 4 individuals.

Malacostraca population in the Non-Protected Area is shown in Figure 38. It is similar to the Polychaeta trend, where the winter species composition is higher than in summer with 5 species have found during the winter season, while only two species where recorded during summer. *Diogenes avarus* count was 3 individuals in winter, followed by *Bodotriidae*, *Sphaeromatidae* and *Thalamita Poissoni* with two individuals. During summer, the only two species recorded *Diogenes avarus* with three individuals and *Thalamita Poissoni* with two recorded individuals.

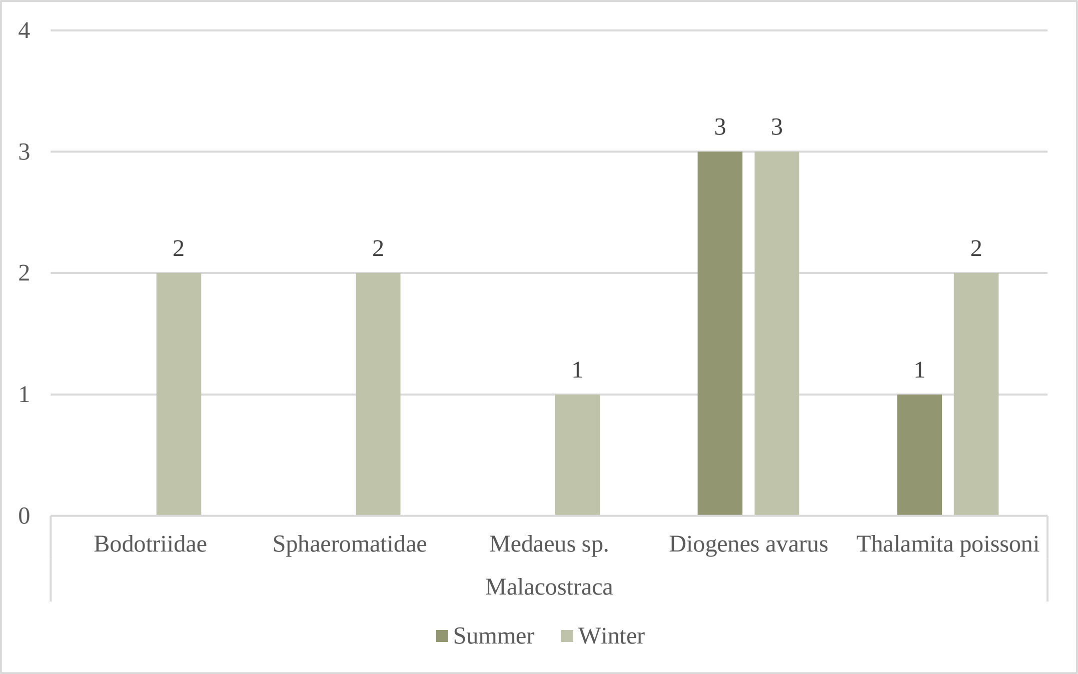

Figure 38: Seasonal variations of Malacostraca species composition in the PA

The most significant composition changes between the seasons were visible in Bivalvia as shown in Figure 39.

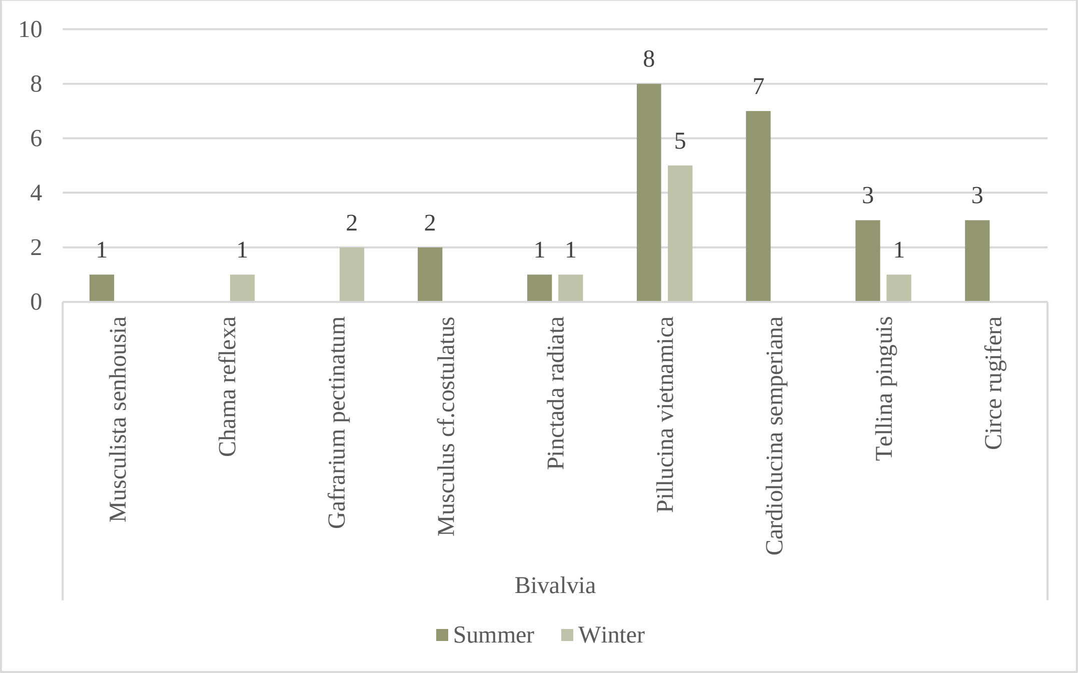

Figure 39: Seasonal variations of Bivalvia species composition in the protected area

During summer, 25 individuals from seven species have been recorded with the domination of two species, *Pillucina Vietnamica* with 8 recorded individuals and *Cardiolucina Semperiana* with 7 recorded individuals. During winter, 10 individuals from 5 recorded species dominated by *Pillucina Vietnamica*, followed by *Tellina Pinguis* and *Circe Rugifera* at 3 recorded individuals.

A comparison between macrofauna classes recorded during the present study at both protected and non- protected areas is shown in Figure 40.

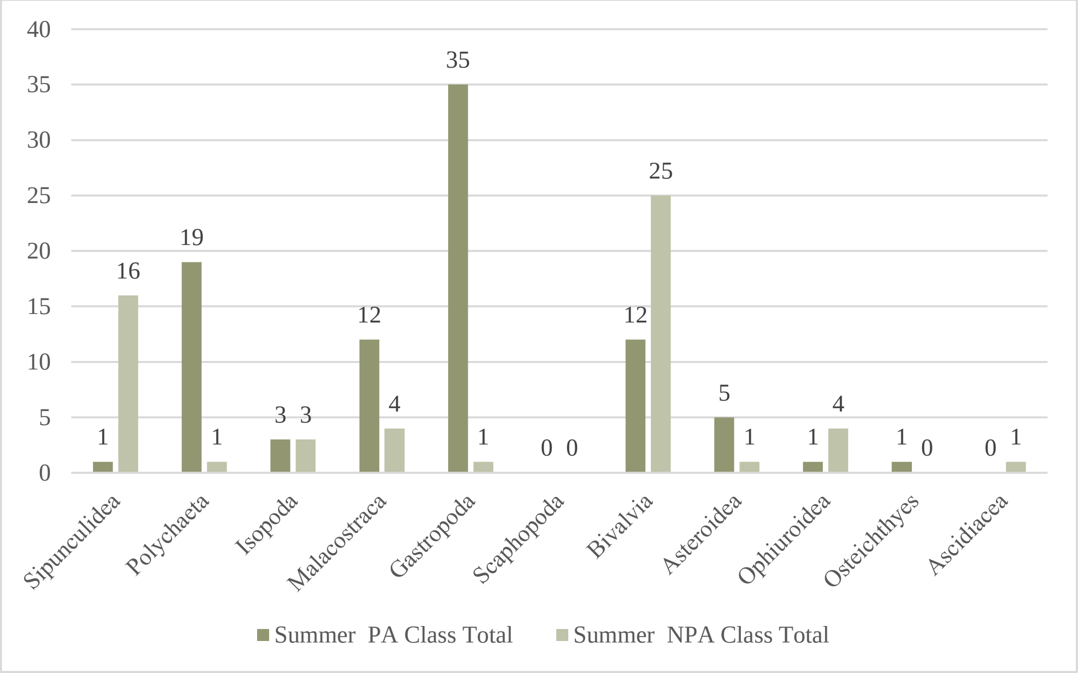

Figure 40: Comparison between the identified macrofauna classes at both protected and non-protected areas during summer season

Figure 40 reflects the class count between the two sites during Summer, where from the 11 identified classes five of the classes, Polychaeta, Malacostraca, Gastrapoda, Asteroidea and Osteichthyes are found in higher numbers in the PA than in the NPA. Sipunculidea, Bivalvia, Ophiuroidea and Ascidiacea have found to have higher counts in the NPA compared to the PA, while Scaphopoda doesn’t exist in both sites during summer.

On the other hand, Figure 41 shows the differences found in the identified classes in both protected and the non-protected sites during winter season.

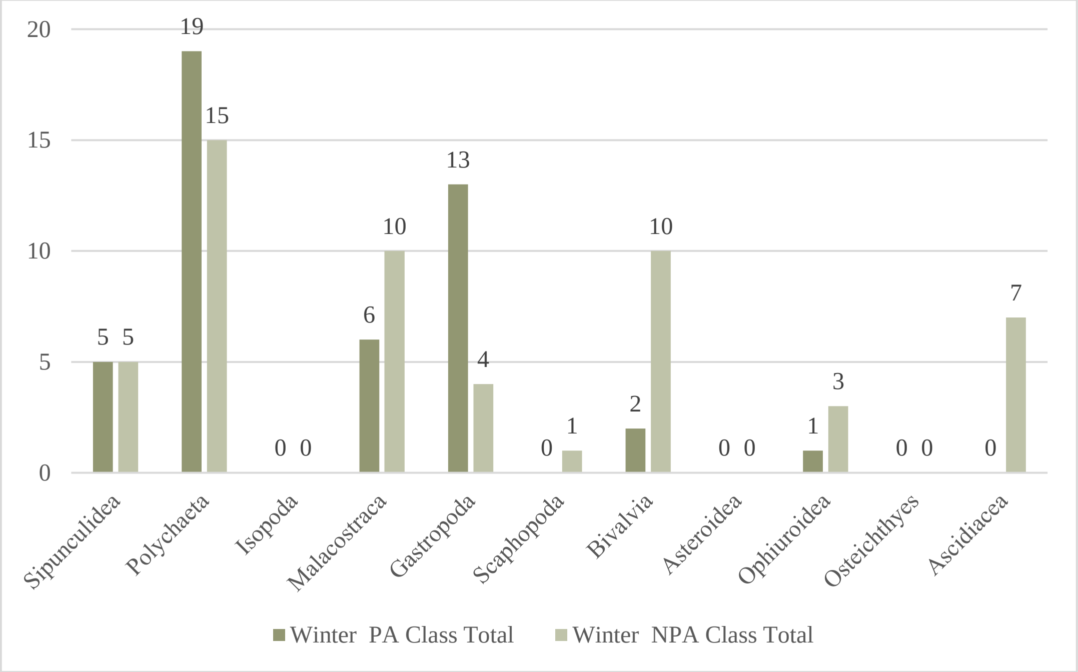

Figure 41: Comparison between the identified macrofauna classes at both protected and non-protected areas during winter season

Figure 41 reflects the absences of three classes during winter, where Isopoda, Asteroidea and Osteichthyes are not recorded in any of the winter samples in both sites. Sipunculidea class count is similar in both sites, Polychaeta and Gastropoda are more abundant in the PA, while the other identified classes were found more in the NPA, including Scaphopoda and Ascidiacea, which are only recorded in the NPA during winter.

The species diversity variations between the two sites is shown clearly in Figures 42 and 43.

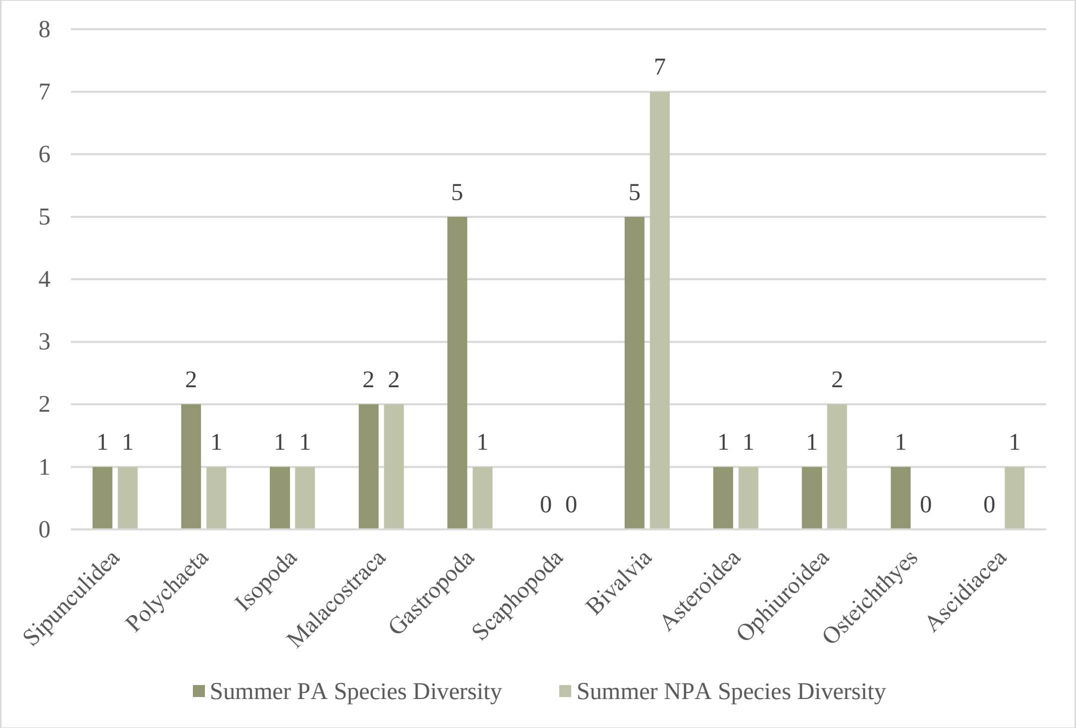

Figure 42: Species diversity PA and NPA during summer

Figure 42 compares the diversity of species between the two sites. There is a similarity between the sites' species diversity between Sipunculidea, Isopoda, Malacostraca and Asteroidea. Gastropoda is significantly higher in the protected area than in the PA, while Bivalvia is more abundant in the NPA.

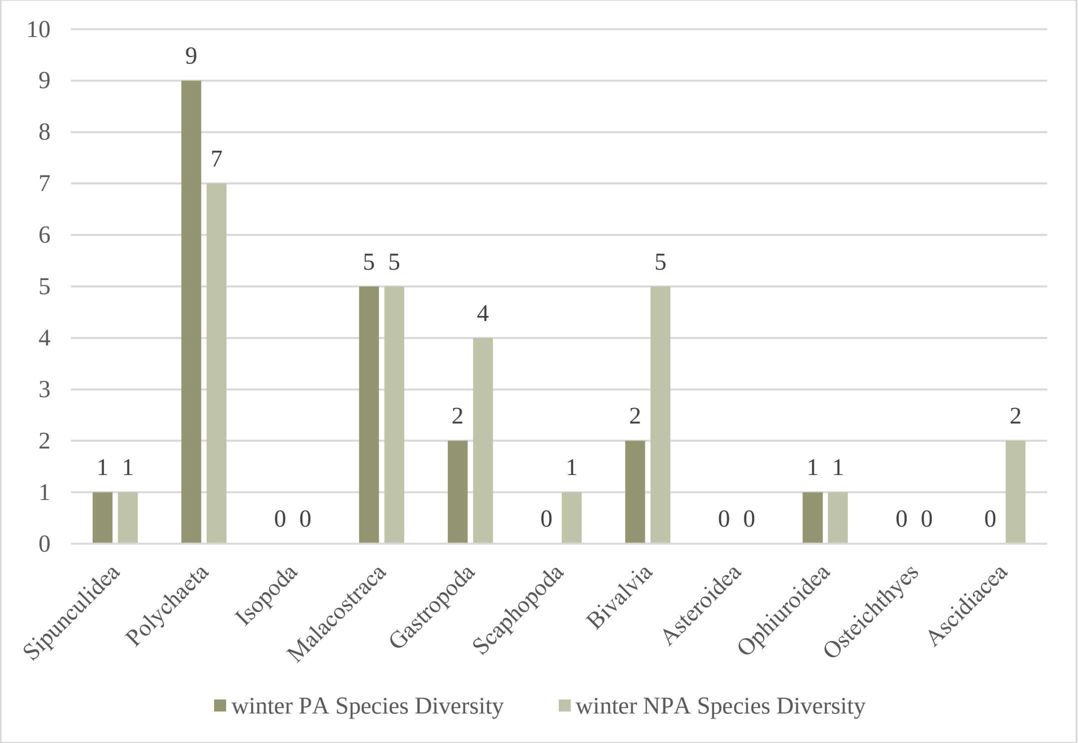

Figure 43: Species diversity PA and NPA during winter

During winter it is clear that Polychaeta and Malacostraca increased in both sites during winter. Gastropoda counts were lower in the Protected Area, and increased in the Non-Protected Area PA. Bivalvia were lower in both sites during winter (Figure 43).

3.5 Statistical Analysis

In order to find the diversity richness and evenness, Past 3.23 (Paleontological Statistic Software package for Education and data Analysis) was used. The Macrofauna Shannon Index used to determine the richness, while the Evenness was used to see the distribution amongst the species. The results for the protected area and non-protected area, shown in Figures 44 and 45, reflects the overall difference between the sites and seasons as well as the seasonal difference between the four main Classes, Polychaeta, Malacostraca, Gastropoda and Bivalvia.

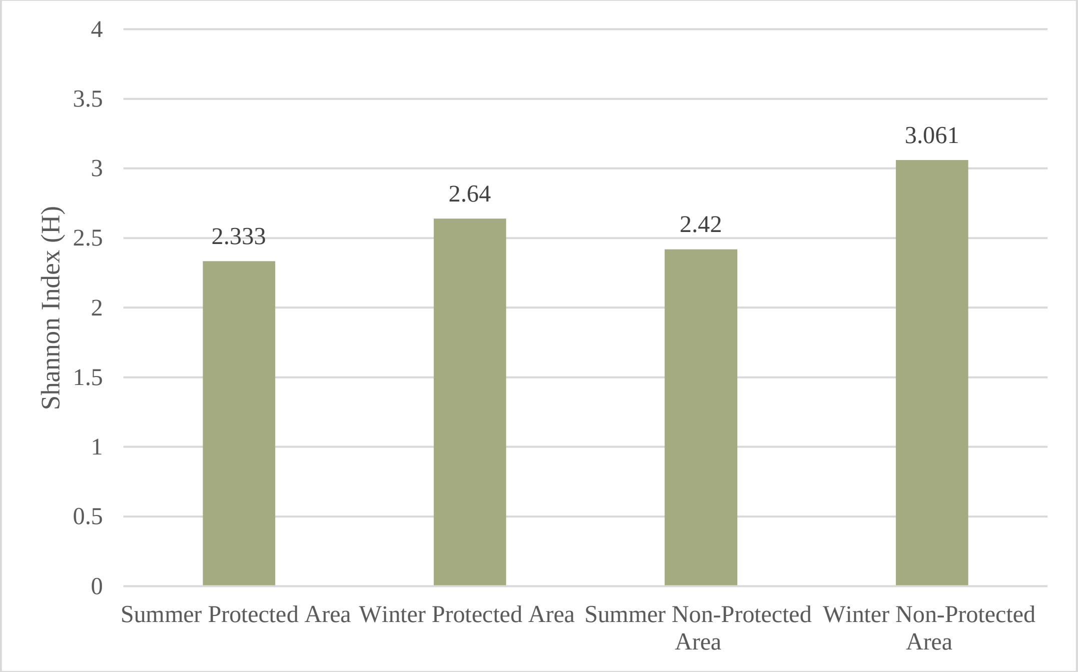

Figure 44: Overall species diversity at both sites and in both seasons

The Shannon diversity index, shown in Figure 44, gives us the measure of the diversity of the species in a given sample by taking into account the number of species within the sample and the abundance of these species. The higher the diversity index, the more the representatives of different species are there compared other samples. Accordingly, the result of Figure 44 the winter non-protected area has the highest representativeness of different kinds of species with a diversity index of 3.061, while the summer protected area has the least representativeness with an index of 2.3328.

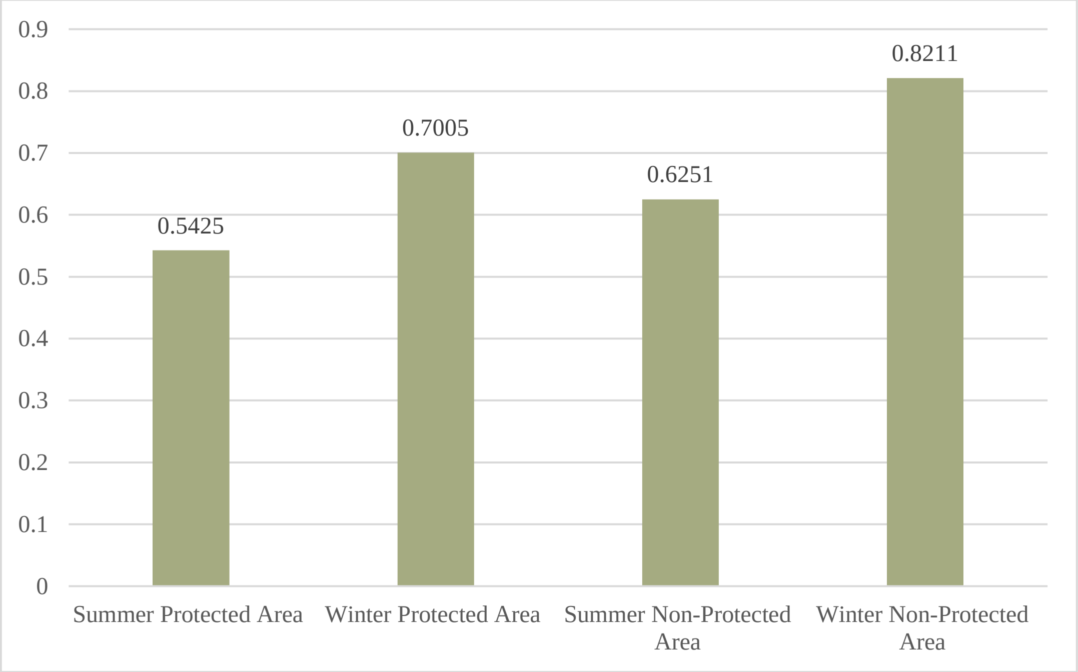

Figure 45: Overall species evenness in both sites and in both seasons

Evenness is another statistical tool that characterize different sample spaces. It measures how similar is the number of different kinds of species. An evenness of 0 suggests that the species in a sample space have extremely different numbers, while an evenness of 1 suggests that the number of each of the species in a sample space is the same. Similar to the result of diversity index, Figure 45 shows that the winter non-protected area has the highest similarity in number of each different species with an evenness of 0.8211, while the summer protected area has the lowest similarity in number of each different species with an evenness of 0.5425.

Going further, this work conducts a paired sample t-test to see if the diversity between the different sample spaces are statistically significant. The results of the test are presented in Table 14.

For macrofauna class diversity specific analysis, the resulted at the protected area at the different seasons the biodiversity during winter with Polychaeta and Malacostraca is higher than that of the diversity in summer, while in winter, the diversity of the Gastropoda and Bivalvia was relatively higher than that of the summer. The evenness in overall, higher during winter across all classes, it is highest in Bivalvia, during winter, and lowest in Gastropoda during summer (Figures 46 and 47).

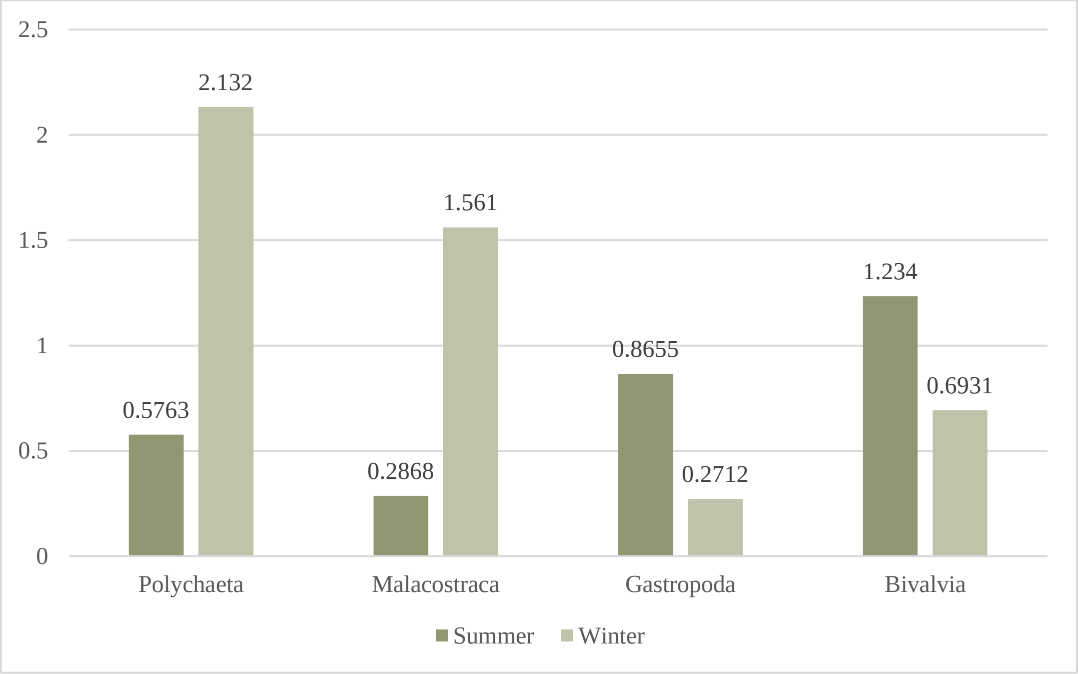

Figure 46: Macrofauna shannon index (H') at protected area

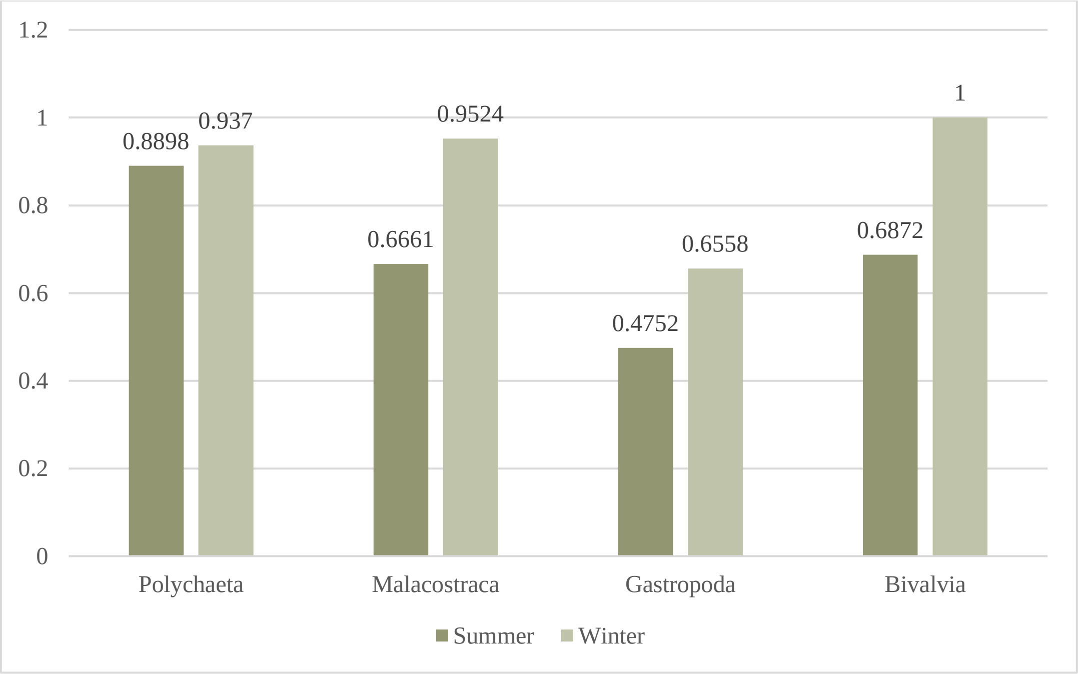

Figure 47: Macrofauna evenness _e^H/S at protected area

However, Figures 48 and 49 reflects the diversity in the Non-Protected area shows that Polychaeta, Malacostraca and Gastropoda all had a higher diversity during winter, while Bivalvia had a slightly higher diversity during summer. The evenness of the species distribution was relatively high across all classes, and during both seasons.

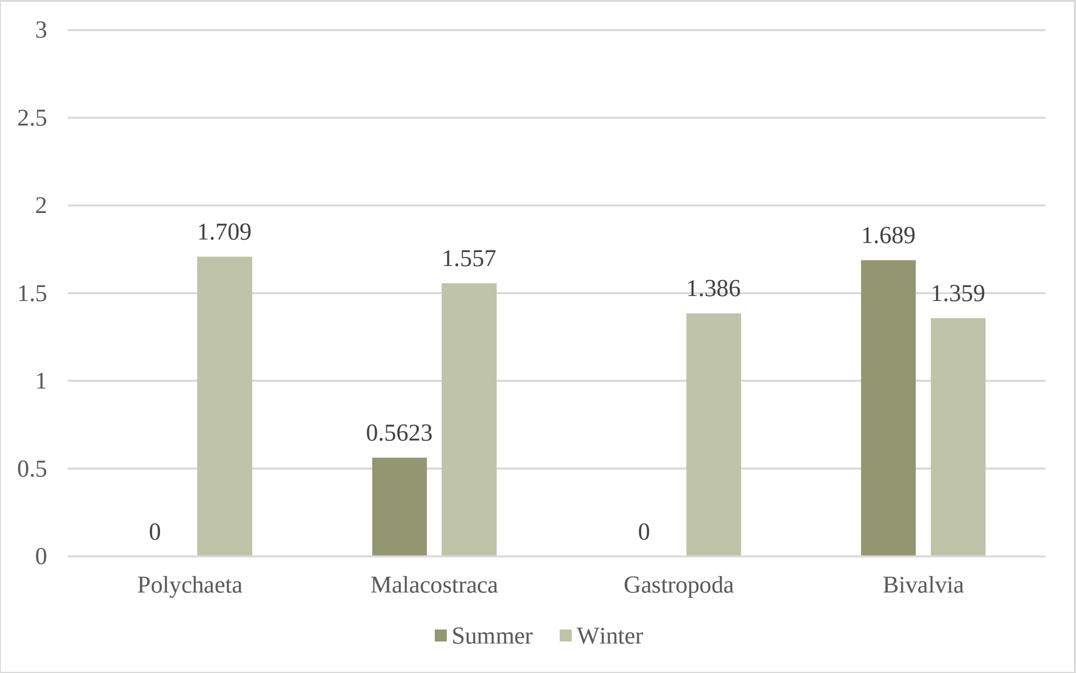

Figure 48: Macrofauna shannon index (H') at none protected area

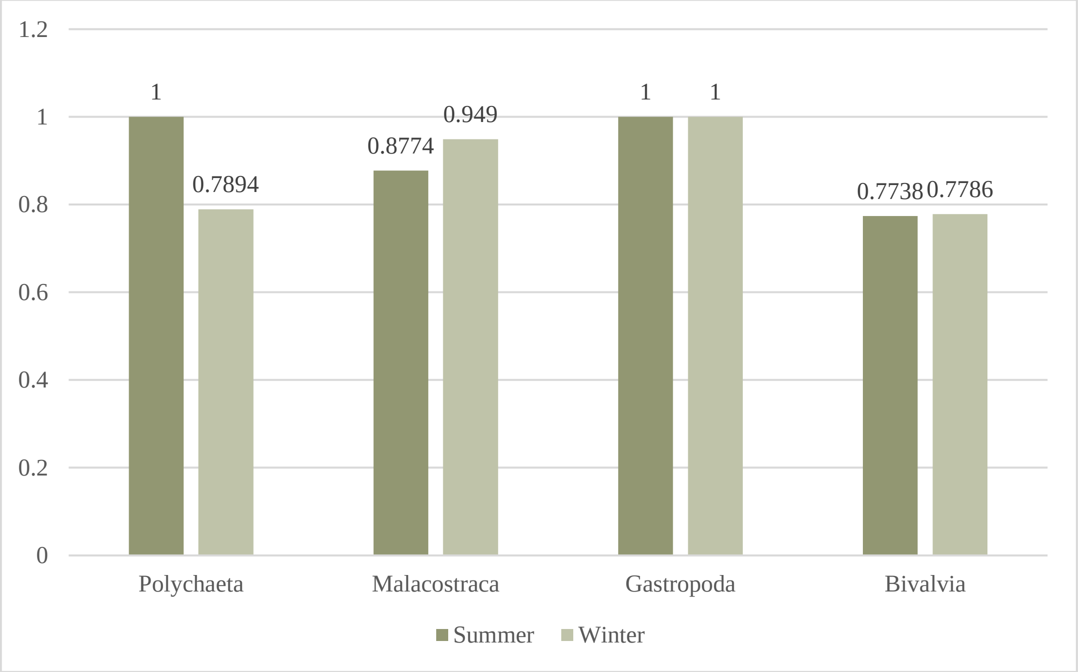

Figure 49: Macrofauna evennes_e^H/S at non protected area

Correlation analyses between the species diversity parameters and the other environmental parameters as well as the seagrass coverages are shown in Table 13. Where negative significant relations found between water temperature and species diversity as well as species evenness. The result show that diversity and evenness are strongly negatively correlated with temperature and with Seagrass coverage with correlation coefficients of -0.907 and -9.22 for temperature and diversity index (H), temperature and evenness (E), respectively and correlation coefficients of -0.9818 and -0.9495 for seagrass covarage and diversity index (H), seagrass covarage and evenness (E), respectively.

Table 13: Correlation analysis

	Shannon _H	**Evenness _e^H/S**	**Simpson _1-D**	**Temp**	**Salinity**	**pH**	**Dissolved Oxygen**	**Seagrass Coverage**
Shannon's H	1							
Evenness_e^H/S	0.9782	1						
Simpson_1-D	0.9997	0.9810	1					
Temp	-0.9071	-0.9215	-0.9016	1				
Salinity	-0.2170	-0.0197	-0.1967	0.1627	1			
pH	-0.1555	0.0420	-0.1347	0.1120	0.9980	1		
Dissolved Oxygen	0.6995	0.8069	0.7163	-0.5757	0.5186	0.5722	1	
Seagrass Coverage	-0.9818	-0.9495	-0.9770	0.9527	0.3175	0.2604	-0.5822	1

Table 14: Paired sample t-test for diversity of the different sample spaces

Shannon Index			
Summer PA		**Winter PA**	
H:	2.3328	**H:**	2.6398
Variance	0.013007	**Variance**	0.022309
t	-1.6336		
df:	98.05		
p(same)	0.10555		
Summer NPA		**Winter NPA**	
H:	2.4205	**H:**	3.061
Variance	0.01896	**Variance**	0.010954
t	-3.7028		
df:	105.42.5		
p(same)	0.00034128		
Summer PA		**Summer NPA**	
H:	2. 3328	**H:**	2.4205
Variance	0.013007	**Variance**	0.01896
t	-0.49042		
df:	124.5		
p(same)	0.6247		
Winter PA		**Winter NPA**	
H:	2. 2.6398	**H:**	3.061
Variance	0. 022309	**Variance**	0.010954
t	-2.309		
df:	85.103		
p(same)	0.023368		

In Table 14, using a 95% confidence interval, the results show that the following diversity indices are statistically significant: Winter PA vs Winter NPA (p-value = 0.023368) and Summer NPA vs Winter NPA (p-value = 0.00034128). Therefore, we conclude that Winter NPA is the only sample space that has statistically significant diversity index compared to any other sample space.

Chapter 4: Discussion

The present study revealed some variabilities in environmental parameters between the protected and the non- protected areas during different seasons, which have resulted in differences of grass cover as well as Macrofauna communities.

The results obtained from field measurements indicated lower temperatures at the NPA compared with the PA; this could be attributed heavy boat traffic and other human activities, which pose an impact on the climate, which may, in turn change the temperature of a place. Similar findings have also reported by Robert and Heninz (1998) and by Brodie and N'Yeurt (2018), where they showed that in protected areas with low human stress water temperatures would be higher than surrounding areas due to intensive photosynthesis activities of seagrass beds during daytime and intensive respiration during night times. Consequently, water salinities in protected areas would be higher than at the non-protected areas. In fact, in the studied areas, the intensive navigation traffics and the water column mixing by boats propellers could create homogeneous water layer with lower salinities at the non-protected area compared with the more stratified protected area (Dinnex, 1973).

On the other hand, the slight differences in water pH noticed within the present study, with higher values within the protected area compared with the NPA is a result of the higher seagrass cover in the PA compared with the NPA. This can result in higher photosynthesis and consequently increase in the water alkalinity due to Oxygen release (Chislock et al., 2013).

The present study findings established that coarse sand was the most dominant sediment that was obtained, while mud was the least obtained sediment obtained in summer from the protected area. This can suggest that the heavy size of coarse sand particles with their absolute current velocity of less than 0.02 mm/second, which accelerates their deposition compared to other sediments. These findings were in line with the findings of another study by Fonseca and Friedman (1986). In contrast, within the non-protected areas, both fine and coarse sand sediments were uniformly distributed and accounted for the most dominant sediments, while the mud was the least collected sediment in the NPA. This, can be attributed to human activities in the non-protected areas, where dredging, industry, and other coastal development which is common around the area. That in turn increases the supply of sediments, nutrients and other solid pollutants in marine sediments, which interferes with the velocity of sediments and the force exerted by the pollutants breakdown the sediments making them finer and light in size as illuminated in these findings (Al Ghadban et al., 1998; Fraser, 2012).

In general, the composition of sand in both seasons and in the study area, the seagrass grown and survived well in fine, medium and coarse sand. This was similar to findings of a study in South Florida (Wright, 1993), and in other studies in the Bahamas (Scottish, 1988), where most seagrasses were found to survive well within a range of fine to medium to coarse sand sediments unlike in mud and clay sediments.

However, during winter, large disturbing events such as winter storms can result to erosion and subsequent disturbances, that may result in the small disparity in sediments grain sizes that was experienced when comparing the findings of summer with those of winter on sediment composition.

Although, the trace metal concentrations in the present study has analyzed, the obtained results did not show significant differences in the trace metals concentrations between the protected and the non-protected areas during the different seasons. Sulphur high concentrations in the water column remains the destiny of this aquatic environment where oil industries emit high quantities in the atmosphere that eventually get deposited in the surrounding terrestrial and aquatic areas. The similarity in other metals concentrations within PA and NPA could be due to the diffusion of its ions within the water layers. However, its concentration impacts may result in the difference of the seagrass species dominance due to its tolerance capabilities, which can also reflect in its cover of the studied areas.

In the present study, the calculated average seagrass cover during summer was 80%. This was lower than demonstrated theoretical maximum limit seagrass meadow density of 98% by Horrigan et al. (2017), This can be a result of unbalance and may be the increase of certain trace elements concentration, not only in the water column but also in sediments. It may also be due to the increase of feeding pressure on the seagrass beds by herbivores organisms. However, the findings of this study were slightly lower to the 87% reported by Horrigan et al. (2017), in Florida probably due to geographical variations and perhaps reflecting the harsh environmental conditions of temperatures and salinity in the Arabian gulf (Hamza & Munawar, 2009). Further, this finding could be attributed to variations emerging from innate differences among species in which this study focused on species found in the locale to include; *Halodule uninervis, Halophila stipulucea and Halophila ovali* whereas Horrigan et al. (2017) focused on *Thalassia testudinum* native in the Florida marine park.

The present study has also showed variation in the density of seagrass meadows in winter and summer. Where, in both protected areas and the non-protected areas, the density of the seagrasses was higher in summer than winter. This finding is consistent with that of Alcoverro et al. (1998), who reported that seagrass growth exhibited seasonal variations, in which they were relatively abundant in summer than in winter. This shown to depend on the availability and quality of light and temperatures in the photic zones. During winter, light and temperature known to reduce in the benthic zone. Al Ghadban et al. (1998) noted that in the Arabian Gulf temperatures in winter could reach an average of 17^{o}C in winter opposed to 31^{o}C during summer. This decrease greatly reduces enzyme kinetics and decline in metabolic process that sustains in life in the benthic zone. Seagrass also known to occupy an ecosystem in the photic zone, which receives up to 11% of solar radiation that strikes the water surface. During winter, not only irradiance reduced to less than 1% but also the number of daylight hours reduced drastically decelerating rates of photosynthesis and metabolic process. These dynamics known to cause a reduction in the density of the seagrass beds like the one observed in the findings of this study. Kelly et al. (2017) also noted a 20% reduction in seagrass meadows density during winter. Further, it was noted that in winter, rhizoid elongation was reduced and germination rates were lower few leaves and of smaller sizes and seeds took longer to germinate than during summer accounting for decreased seagrass meadows density during winter.

Notwithstanding the decrease of seagrass meadow coverage, there is an equivocal decrease in wet weight and dry weight of seagrasses during winter. This finding is consistent with the findings of Kelly et al. (2017). Horrigan et al. (2017) observed reductions in the average length of shoots, decrease in leaf size in winter in the sea and aquatic plants in Florida during winter relative to summer pointing to reduced metabolism and photosynthesis that resulted in decrease in Seagrass meadow biomass in winter.

Seagrass meadow variables in the present study, included density, moisture content dry weight, and wet weight. There was a spatial variation in the protected areas compared to samples from the non-protected areas with the latter having lower variables. Protected areas are less exposed to pollution resulting from anthropogenic activities. In the past few decades, human activities in the Arabian Gulf to set up ports massive land reclamation exercises, rapid industrial advancements have had a negative impact on the proliferation of seagrass. This resonates with the finding by Lotze (2006), who has stated that having over 1 Billion of human beings living in a 50km coastal strip worldwide places an immense strain to this fragile ecological niche.

The present study finding, a spatial variation in seagrass mass density between the protected and non-protected areas in Abu Dhabi, with the density being significantly lower in the non-protected areas. Biomass is a more valid and reliable indicator of metabolism activity and cellular processes that facilitate growth. In view of this, lower biomass in non-protected areas is an indication of diminished metabolic activities. Kelly et al. (2017) noted that water degradation by anthropogenic activities can greatly disrupt sea meadows growth. Silted water stuffed with sediments is highly turbid and reduces permeation of water to 0.4% of that striking the surface 20 meters down the photic zone. This has the effect of slowing down rates of photosynthesis. Lotez (2006) noted that by affecting negatively on the rates of photosynthesis, there is reduced plant proliferation with weakened shoots, small leaves, and few rhizomes. This can underpin the relative decrease in biomass among seagrass meadows in the non-protected zones. On the other hand, Hall et al. (2009) have pointed out that seagrass biomass in Florida Bay is decreasing due to building up sulfide levels. Moreover, Harun et al. (2008) pointed out that sulfide is a metabolic poison that inhibits biological processes such as photosynthesis. Furthermore, Borum et al. (2013) supported this point that increase in levels of sulfide correlates with small size shoots, decreased rhizome regeneration and root formation could lead in the reduction of biomass observed in the non-protected areas. These reports complimenting the findings of high Sulphur concentrations in the water samples analyses at both PA and

NPA. It is known that Sulphur concentration in the Arabian Gulf is high due to oil industries byproduct. These high concentrations may be the reason of lower seagrass covers compared to other parts of the world with similar latitude.

In this study, both the protected and non-protected area *Halodule uninervi*s was the most dominant species. The study findings shed light further that during winter there were no samples containing the *Halophila stipulacea* species. The findings are consistent with the findings of a study conducted in the Arabian Gulf by Al-Ghadban et al. (1998), who stated that *Halodule uninervis* was the most dominant species in the Arabian Gulf and had demonstrated further that the highest density situated at the North of Abu Dhabi highland around the Al Sammaliah Island. Fraser (2012) noted that the species is highly adaptable and capable of tolerating hostile conditions such as those of Arabian Gulf. Zimmerman et al. (2014) concluded that *Halophila* species is one of the most Eurihaline species and grows over a range of saline conditions such as variations observed in Dubai. This could underline the relatively high density of the species in the protected and non-protected areas in Abu Dhabi since it is able to outcompete rival species in an ecosystem.

In that concern and in parallel with the high seagrasses cover of the protected area the present study have identified nine (9) different classes of macrofauna to include; Sipunculidea, Polychaeta, Isopoda, Malacostraca, Gastropoda, Bivalvia, Asteroidea, Ophiuroidea, and Osteichthyes. Further, these were classified to yield 19 different species denoting an extensive ecosystem built around the seagrasses. The findings are in agreement with Smale et al. (2019), who point out that not only is seagrass a primary producer but also a foundation species which critically and exhaustively influences ecosystem structure and function by creating locally stable conditions and habitat for other species. In addition, it is observed that the seagrasses are the only species of plants that are able to tolerate marine environment, therefore, support other species in the aquatic ecosystem. Qiu et al. (2014) have observed that seagrass meadows are characterized by high primary productivity thus are able to support a larger ecosystem. This could explain the finding that shows extensive ecological diversity. Species in the seagrass ecosystem derived benefits that include habitat, oxygen, and nutrients directly and indirectly.

Various spatial variations detected when the protected area compared with the non-protected area. In fact, species composition during winter is more diverse at the non-protected area, but unlike the protected area, the species density was higher. The probable reason for diversity in winter was an increase in the polychaeta species where these species were seen to have contributed to the biodiversity adding in 15 species. Since the seagrass forms the foundation species in the ecosystem it occupies (Qiu et al., 2014), dead and rotting that occurs in winter attracted the polychaeta species who primary feed on detritus. On the flipside, it has been noted that there was a relatively low abundance of organism in the non-protected areas when compared to the protected areas. This points to a lower carrying capacity of ecosystem in the non-protected area. The non-protected area had sparse seagrass and lower biomass compared to the protected area. This brings into the highlight the fact that the non-protected areas have a lower carrying capacity. These finding further points to the benefits that can be derivable from legislation and policies aimed at conserving aquatic life and ecosystems.

The greater biodiversity in winter for the non-protected areas mainly due to the influx of members of the Polychaeta. In summer protected areas had higher biodiversity compared to the non-protected areas. Kelly et al. (2017) pointed out that biodiversity of an ecosystem is an indication of stability and tolerability of an ecosystem and that intolerable ecosystems have few organisms inhabiting them. This could provide insight into the impacts of anthropogenic activities on the biodiversity of the non-protected areas. As the non-protected area experience more pressure and strain, they become intolerable to other species who migrate of the ecosystem decreasing biodiversity (Qiu et al., 2014).

Various temporal variations in organisms count and biodiversity were noted in winter when compared to summer. A general decrease in the number of organisms in winter when compared to summer would suggest a decline in the carrying capacity of the ecosystem underpinned by a decrease in primary producers. Seagrass is the primary producer and in winter there is a decline in photosynthesis and metabolism reflected in decrease of biomass per unit area (Borum et al., 2013), hence reduced carrying capacity. The variations that follow to include bio numbers and biodiversity underpinned by complex ecosystem variables. Osteichthyes, Isopoda and Asteroidea were not enumerated in the protected area during winter. During winter there was noted increase in the members of the Sipunculidea. This observation could be explained by the fact that members of this class are detritus that feed on dead decomposing matter. It is noted that due to limited photosynthesis and metabolism during winter, seagrasses died off. Rotting seagrasses provide many detritus materials accounting for increase in numbers of the Sipunculidea class.

Another temporal variation established was a significant increase in the number of Polychaeta species in winter. Grasby et al. (2008) noted that members of this family are pelagic thriving in numbers in the environment containing rotten materials. Therefore, it is not a coincidence that they were on the rise in winter, as Kelly et al. (2017) also note that in winter masses of seagrass are lost and are decomposed by bacterial activity. These events provide food for worms such as bristle worm in the polycheate species. It was also established that Isopoda and Asteroidea are absent in the winter samples. Organisms of the Astroidea have diverse feeding patterns, not only do they feed on detritus, but also feed on sponges, bivalves, snails and small animals (Chislock et al., 2013). In addition to this, they are highly mobile and can occupy diverse niches (Hall et al., 2009). This might have explained their decline in winter as they sought other stable niches. Further, they are known to predate on small animals commonly found in the Isopoda suggesting a probable reason for the absence of both groups. An appearance of Scaphopoda in winter was also noted. Members of the class Scaphopoda are composed of exclusive marine infauna that resides in the floor sediment in the intertidal zone; their primary diet constitutes of foraminifera's, vegetative matter, and detritus. Their appearance in winter could be also linked to abundance of detritus that results from decaying seagrass.

The Quantification of the ecosystems' variability and biodiversity of the present study, revealed both spatial and temporal variations. Calculation of the Shannon's H revealed that the value was highest for the winter in the Non-protected area. Since Shannon's H depends on the variety of species and the proportion. An influx of Polychaeta class into the ecosystem with a relatively higher abundance could be attributed to the higher Shannon's H. Therefore, this did not indicate a harmonious diverse ecosystem rather increased diversity and richness due to influx of detritus feeders. A dominant temporal variation was also noted in summer at the protected areas where the Shannon's H was lower in comparison to summer in the non-protected area despite the distribution of seagrass being sparse and having lower biomass in this area. This finding does not imply more stability and biodiversity in non-protected areas, rather would be pointing to higher number and variety of organisms feeding on decaying matter and detritus that result from the death of seagrass due to anthropogenic factors.

The Richness indicator, which is the measure that quantifies the number of different classes and species of interest in the study ecosystem, was found to be higher in both the protected and the non-protected areas. Despite the observed decrease in species such as those of class Asteroidies and newer species to include Scaphopoda and Ascidiacea were only recorded in winter in addition to the observed newer species of the polychaeta resulting in the observed richness in winter. In summer only *Oenidae sp* were observed; however, in winter newer species observed included *Nerieidae sp, Glycera sp, Orbiniidae,* and *Oedenia fusiformis* adding to the richness of the ecosystem in winter. This also supported by the findings that showed Shannon index was higher for the members of the polychaeta class in winter when compared to summer.

The resulted non–significant relationship of sediments grain sizes with the macrofauna community structure in general does not mean that grain sizes does not affect the community structure of living macrofauna in both areas. When such analyses done on the whole community many other factors are interfering. However, when classes such as Gastropoda and/or Bivalivia as well as Polychaeta analyzed individually in relation to grain sizes significant values may result. In fact, the appearance of high densities of gastropods in the protected area in summer compared to the non-protected area could be the result of its grain sizes differences. Moreover, the appearance of polychaeta in high densities and diversity at the non-protected area during winter season could be due to its high percentage of mud and fine grain components where organic matter and detritus can easily blend with.

Chapter 5: Conclusion

The present study has succeeded in showing that there is indeed a spatial and temporal variation in macrobenthic fauna communities, seagrass density and seagrass biomass. The results highlighted the importance and the advantages of establishing marine protected areas; not only for the ultimate goals which is to protect marine threatened species and critical habitats, but also to build up healthy and robust ecosystem capable to sustain higher densities and diversified food web to satisfy the living biota. The present study showed that the relatively higher seagrass meadows density in the protected areas could lead to possible positive benefits by establishing protected areas across Abu Dhabi.

This study also, showed the importance of seagrass biomass as an indicator of seagrass health and should be incorporated in Seagrass monitoring programs in the region. As well as recommending the importance of establishing a continuous monitoring program based on scientific knowledge and on benthic macrofaunal community structure in evaluating the health of the seagrass beds in Abu Dhabi.

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