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DISTRIBUTION OF MACROALGAE IN THE INTERTIDAL ZONE OF GHANA

BY

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DECLARATION

This dissertation is the result of research work undertaken by Phyllis Akua Amamoo in the Department of Marine and Fisheries Sciences, University of Ghana under the supervision of Professor George Wiafe and Professor Gabriel Komla Ameka. I do hereby declare that the dissertation consists entirely of my own work and that no part of it has been previously published or submitted for a degree or diploma elsewhere.

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ABSTRACT

Marine macroalgae or seaweeds, as they are generally referred to, are primary producers which play a central role in the productivity of coastal habitats and also serve as a source of ecosystem goods and services. They are used directly or indirectly in the production of food products, fertilizer, animal feed additives, bioenergy, nutraceutical, confectionary, textiles, paper, paint, and varnish among others. How far this can be exploited depends on the knowledge of available species. In Ghana, there have been sporadic studies of seaweeds or macroalgae since the 1950s, when inventory of the species began, until recent investigation which considered community structure analysis. Following from what is known about this biological community, this study was designed to comprehensively evaluate macroalgal distribution across the coast of Ghana. The key objectives of the research were to: (1) assess of species diversity within the intertidal zone of Ghana; (2) characterize the distribution and community structure of the macroalgae in the intertidal zone of Ghana; and (3) determine the effect of nutrients on observed distributional patterns. Ten sampling locations were selected in a manner that allowed the entire Ghana coast to be covered – i.e. Dixcove, Takoradi, Aminano, Mumford, Kokrobite, Christianborg Castle, Teshie (Next Door), Tema, Prampram and Old Ningo. The macroalgae were purposively sampled using a 1m x 1m quadrat constructed from polyvinyl chloride pipes. Species abundance were estimated as percentage cover within each quadrat, from the high to the low water mark on selected days where the tidal height was lowest. Water quality at each location was analysed for five nutrients (i.e. phosphate, nitrate, ammonia, silicate and sulphate). The sampling period was from 11th October, 2018 to 5th January, 2019. The data was subjected to various statistical analyses using Plymouth Routines in Multivariate Ecological Research (PRIMER version 6). Altogether, forty-one species belonging to 25 families were identified. Of these, ten species played an important role in influencing the spatial community structure, i.e. *Ulva fasciata, Ulva flexuosa, Ulva lactuca, Hydropuntia dentata, Hypnea musciformis,*

Ralfsia expansa, Lithothamnion bisporum, Centroceras clavulatum, Chaetomorpha linum and *Caulerpa taxifolia*. This study identified these species as keystone species in terms of their dominance and contribution to observed spatio-temporal patterns in community structure, and zonation within the intertidal region; from the supra-littoral across the mid-littoral to sub-littoral zones. This study did not find any evidence of the role of nutrients on the observed macroalgal distributional pattern, and attributed it possibly to the short-term temporal nature of the study. Therefore, it is recommended that long-term investigation, in relation to the effect of nutrients on macroalgae community characterization, be undertaken in future studies. Furthermore, adoption of molecular techniques to assist taxonomic characterization of macroalgae and use of unmanned aerial vehicle in field assessment should be explored towards a more comprehensive assessment.

DEDICATION

This work is dedicated to the Almighty God and family, most especially my parents, Mr and Mrs Amamoo for their financial support and also to Abena Serwaa Sebe for her encouragement throughout my research.

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For the favour, health and fortitude during this project, I am most grateful to God.

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LIST OF ABBREVIATIONS

AMI	Aminano
CAS	Christianborg Castle
DEC	December
DIX	Dixcove
JAN	January
KOK	Kokrobite
MID	Mid-Littoral
MOD	Moderately
MUM	Mumford
N-Door	Next-Door
NOV	November
NXT/N-Door	Next
OCT	October
ONG/O-Ningo	Old-Ningo
PRA	Prampram
SUB	Sub-Littoral
SUP	Supra-Littoral
TDI	Takoradi
TEM	Tema

CHAPTER 1

INTRODUCTION

1.1 Background

Algae are simple plants that are mainly aquatic and comprise of two types - macroalgae and microalgae (Murphy et al., 2013). Microalgae are microscopic and usually range from uni-cells to colonies, with almost up to a few hundred cells of filaments. They comprise prokaryotes, cyanobacteria or blue-green algae (including eukaryotes) green algae, diatoms, red algae, and dinoflagellates (Benemann and Oswald, 1996). Macroalgae occur in both freshwater and marine environments. The marine types are also referred to as seaweed, and comprise the majority of larger and usually attached, multicellular green, brown, and red algae inhabiting the intertidal zone of rocky shores and extending downward into the shallow subtidal.

Marine macroalgae differ from land plants in that the former have fronds, stalks, and holdfasts whereas the latter have leaves, stems and roots. They, however, have some similarities to land plants in relation to chlorophyll type and biochemical structures (Quigg et al., 2003). According to McHugh (2003), the red pigmentation in red marine macroalgae, for example, is as a result of the dominance of the accessory photosynthetic pigment phycoerythrin. Generally, the type of pigment and chemical composition of marine macroalgal as well as their specific location in the intertidal determine the specific light absorbed (Falkowski, 1981). For example, the brown and green algae are found in intertidal regions whereas most red algae inhabit relatively deeper areas of the sea up to 25 m below the surface (Santelices et al., 1991). It has been found out that pigments in red marine macroalgae, such as phycoerythrin and phycocyanin, have the capability of absorbing light in these deeper areas (Yu *et al*., 2002).

Marine macroalgae are most commonly found growing in the wild, in warm and cold climates, epilithic on pebbles or rocky substrata, and other hard substrates in intertidal and subtidal zones around the world (John *et al*., 2003; McHugh, 2003). They can also act as a substrate for communities such as epiphytic diatoms (Al-Handal et al., 2016; Majewska et al., 2016). Studies conducted by Fredericq *et al*., (2009) indicates that, there are about 10,000 – 20,000 recorded species of marine macroalgae worldwide with about 1,800 validly accepted species of green algae, 2,400 species of brown algae, and 6,100 species of red algae (Guiry and Guiry, 2019).

Marine macroalgae are primary producers which play a central role in the productivity of coastal habitats (Harley et al., 2012). They support coastal and marine biodiversity (Christie et al., 2009) and are the base of the food chain in the oceans (Figueiredo and Creed, 2009). They are generally widespread in the world's ocean, and play significant roles in the economy of many countries, especially Asian countries such as China, Philippines, Japan, Korea and Indonesia where marine macroalgae are harvested in large quantities either from the wild or from cultivated fields. For centuries, macroalgae have been consumed as food in Asian countries (Ainis et al., 2014; Dillehay et al., 2008; Erlandson et al., 2015; Yang et al, 2017). In the Americas and Europe, about 54,000 tons of macroalgae are cultivated annually worth US $51 million (FAO, 2017). Marine macroalgae also serve as a source of ecosystem goods and services, providing nutrition, medicine and storm protection (Ronnback et al., 2007). The marine macroalgae industry relies on macroalgae for the production of fertilizers, animal feed, and bioenergy (McHugh, 2003; Sharif et al., 2008). Edible marine macroalgae are a rich source of essential vitamins and minerals.

Marine macroalgae also provide some therapeutic benefits and are used in traditional medicines to induce antiviral effects (herpes viruses), anticancer effects (breast cancer), immunity, and to reduce inflammation, plasma cholesterol and hypertension (Fitton, 2003). The algae produce

biogenic compounds (such as halogenated compounds, alcohols, aldehydes, terpenoids) of pharmacological importance. Marine macroalgae are the only source of biogenic compounds producing phytochemicals including agar (China grass), carrageenan and algin. The phytochemicals from seaweeds are used as gelling, stabilizing and thickening agents in the food, pharmaceutical, confectionary, dairy, textiles, paper, paint, and varnish industries (Kolanjinathan et al., 2014).

In the marine environment, seaweed distribution is known to be influenced by physical factors of the ocean, especially the tidal regime, exposure to sunlight and type of substrate appear (Martínez, 2012). In many parts of the world, temperature, salinity, photosynthetic active radiation, tides, ocean currents and the type of substrate, in diverse combination determines the spatial and temporal distribution of seaweeds (Keith, 2014). As the tides recede, organisms found in the intertidal region are exposed to desiccation, salinity fluctuations, high temperatures and light intensities, which affect species composition and abundance of macroalgae within the intertidal zone.

1.2 Justification for the study

There is a global concern on the impact of climate change on marine macroalgae distribution and abundance (Straub et al., 2016). Maturing subtidal marine macroalgae is most likely to increase as a function of carbon dioxide availability (Kübler et al., 1999; Diaz-Pulido et al., 2007; Hall-Spencer et al., 2008), which will enhance the seaweed's potential to overgrow and thereby kill neighbouring organisms (Jompa and McCook, 2002). In light of this, seaweed biomass can vary greatly in time and space (Bell et al., 2015), necessitating research in this field.

As indicated earlier, seaweeds are an important resource in the marine environment. How far this can be exploited depends on the knowledge of the algal species present. In countries where seaweeds are exploited for food or their extracts for industrial usage, such as in many Asian countries, there is sustained interest in its research (Xie et al., 2013). In Ghana, there have been sporadic studies of marine macroalgae since the 1950s (Lawson and Price, 1969; Price et al., 1978, 1986, 1992). Inasmuch as these studies presented the species occurrence and abundance of macroalgae at specific locations, there was no attempt to characterize the community structure from an ecological perspective. Although a recent study by Gbedemah (2014) included community structure characterization the extent was limited to only two sites along the Ghana coast. The current study was, therefore, designed to provide a broader perspective of macroalgal distribution along an extensive stretch of Ghana's coast. It is expected that findings from this study will contribute immensely to understanding the diversity and distribution of macroalgae along the Ghana coast and lead to exploitation of same for economic gains. This study also sought to provide a comprehensive update on the knowledge of macroalgae species occurrence along the coast of Ghana.

1.3 Objectives of the study

The main objective of this study was to investigate the diversity and distribution of marine macroalgae species occurring in the intertidal zone of the coast of Ghana.

The specific objectives were to:

a) Assess species diversity within the intertidal intertidal zone of Ghana.
b) Characterize the distribution and community structure of the macroalgae in the intertidal zone of Ghana.
c) Determine the effect of nutrients on observed distribution patterns.

CHAPTER 2

LITERATURE REVIEW

Marine macroalgae are generally referred to as seaweeds and they inhabit rocky intertidal shores. The group can be divided into three broad categories based on taxonomic classification – i.e. Chlorophyta (green algae), Rhodophyta (red algae) and Ochrophyta (brown algae). The rhodophytes are mainly marine with some species occurring in fresh water habitats; the ochrophytes are rarely found in freshwater since they are predominantly marine; and the chlorophytes occur as benthic and planktonic marine species (Barsanti, 2014).

In describing their habitat and ecology, the universally accepted scheme is that developed by Lewis (1964), which characterizes benthic plants and animals on rocky shores throughout the world according to the littoral zones. These are the upper littoral fringe or supra-littoral, the eulittoral zone or mid-littoral, and the lower littoral or sub-littoral fringe. The littoral fringe is the area of the shore influenced by wave splash or spray whereas the part of the shore influenced by tides is the eulittoral zone. The sub-littoral fringe is the area of shore only exposed by exceptionally low tides. Algal zonation is due to the differences in tolerance of species to environmental factors and the pattern varies with changes in the prevailing factors (Harley et al., 2006). Zonation is therefore a dynamic process in which the actual level a particular organism occupies may be influenced by seasonal changes in climate, tides and oceanographic conditions.

When different species of seaweeds are exposed to air, they lose water at different rates. For example, *Sargassum vulgare* loses water more rapidly than *Bryocladia thyrsigera* which in turn loses water faster than *Ulva fasciata* (Serfor-Armah, 2018). Therefore, these species occur at different zonation within the intertidal zone. This simple relationship between resistance to desiccation and height on the shore may not always hold since other factors such as sea level

rise and global warming may also influence the distribution of macroalgae. Studies of macroalgae have gained worldwide importance due to their role in the pharmaceutical, food, agricultural and bioenergy industries, among others (Chacon-Lee and Gonzalez-Marino, 2010).

2.1 Biology of macroalgae

Biological communities are living systems of interacting species that exhibit particular structure based on prevailing conditions (Krebs, 1999; Starr and Taggart, 2006). Early proponents of community structure viewed the organization of species at the individual level, where the behaviour and population dynamics of individuals were examined (e.g. May, 1981). This ideology was enhanced later by Simberloff and Dayan (1991), who introduced the concept of guild — an assemblage of species utilising particular resource or group of resources in a functionally similar manner. In view of the fact that ecological communities embody all the various ways individual members of the community interact with one another through patterns of resource allocation, some ecologists proposed the term functional groups to define community structure (e.g. Steneck and Dethier, 1994).

Both the guild and functional group concepts differ in that competitive relationships within groups of species but do not serve as the focus of the functional group concept, in the same way as processes or functions are not the focus of the guild concept (Blondel, 2003). However, as noted by Steneck and Dethier (1994), benthic macroalgae may share certain attributes polyphyletically, and thus the functional group approach aids in understanding such communities. These authors examined patterns of algal functional group abundance, diversity and dominance relative to extrinsic characteristics of three biogeographically distinct regions to support their assertion.

Macroalgae have a photosynthetic system based on chlorophyll a, b and c, carotenoids and phycobiliproteins. Their reproductive structures are made up of cells which are all potentially fertile and devoid of embryos. Macroalgae include both the prokaryotic and eukaryotic types, and among the latter, differences appear in chloroplast structure (groups of thylakoids, endoplasmic reticulum and layer of the chloroplast envelope), flagella and their associated structures (Lee, 2018).

Generally, algal body structure varies in form and shows a wide range of growth forms from a relatively simple single cell to the complexity exhibited by giant kelps. Seaweeds lack true roots, stems and leaves as seen in higher plants. The body is known as thallus, whether filamentous, leafy sheet or giant kelp. The leaf-like portion of the thallus is known as blade because it has no veins and aids in photosynthesis. Gas filled bladders, known as pneumatocysts, are found on some species and help keep the algae on the sea surface thereby maximizing their exposure to sunlight. The stem-like structure, stipe, provides support from which the blades originate. It is long and tough in large giant kelps. A root-like structure, the holdfast, attaches the thallus to the substrate which is mostly hard rocky surfaces. This structure is not only involved in significant absorption of water, but also allows for nutrient uptake like true roots would. Water and nutrient which bathe the entire thallus are diffused directly on the surface of the thallus without specialized tissues for transport as in higher plants.

Macroalgae lack the waxy cuticle and multi-cellular sex organs typical of land plants, and also use compounds such as mannitol and floridean to store their energy instead of as starch (Iwamoto, 2003). Reproduction in seaweeds is either asexual (vegetative or by fragmentation) or sexual. Some species produce spores which are specialized for dispersing to new locations, or persist till favourable conditions are met. In sexual reproduction, gametes from two separate individuals are fused to form a new offspring containing the genetic information of the parent

cell ensuring genetic variation. It is also likely that, both male and female gametes may be formed from the same thallus. The existence of diploid and haploid cells is fundamental in understanding the life histories of seaweeds which can be grouped into four basic types; sporophyte, gametophyte, alternation of generation and carposporophyte (Lobban, 1994).

2.2 Importance of marine macroalgae

Seaweeds are distributed worldwide, however, their exploitation for industrial use predominates in Asian countries, mainly in China, Japan, Philippines, Korea and Indonesia (Roesijadi et al., 2010). China harvests 3.2 million tonnes by wet weight of sea weeds annually, whiles it cultivates about 11.2 million tonnes (wet weight) annually. Ireland is one of the major producers of seaweed in Europe, producing 29,500 tonnes per annum, which is equivalent to 13% of the total European production (Burton et. al., 2009).

The use of macroalgae in industry ranges from direct consumption by humans and animals, as extracts for pharmaceutical products, in agriculture as fertilizer, as culture base in microbiology laboratories and as biofuel for industrial machinery and automobiles. For example, the use of seaweeds as vegetables for direct human consumption has become much more significant in modern times (Bixler, 2011). The seaweed industry accounts for about US $5 billion per annum worldwide (Tabassum et al., 2017). The commercial value of seaweed keeps increasing due to its chemical constituents such as alginate, carrageenan and agar, which are useful food components. The seaweed polysaccharides industry is estimated to run into millions of dollars. The market drive focuses on cultivation, processing, harvesting, isolation/extraction of polysaccharides with its related applications. The commercial value of seaweed polysaccharide

is based on, for example, the utilization of alginate and carrageenan in tissue engineering and drug-delivery products (McHugh, 1987; Renn, 1997; BeMiller and Whistler, 2012).

Seaweeds, as food, are consumed by many Asians and people in the Pacific region, compared to other parts of the world. The main seaweeds used as food are the brown seaweeds (e.g. *Laminaria japonica* and *Undaria pinnatifida*) and red seaweeds (e.g. *Porphyra* sp.) Apart from these species, *Sargassum* is ubiquitous in the worlds' oceans but traditionally utilized as food and medicine in Japan, China, and Korea (Xie et al. 2013). *Sargassum* (i.e. *S. muticum S. thunbergii*, *S. fulvellum*, *S. horneri, S. fusiforme* and *S. fulvellum* is a major species cultured in Asia (Hwang et al., 2006; Xie et al., 2013). The nutritional value and health benefits of seaweeds are already well known (Balina et al., 2017). Seaweeds can provide humans with necessary vitamins, minerals and antioxidants and also a valuable calorie source (Kumar et al., 2015). It has been predicted that by 2050, global population will reach 9 billion, and with current trend in food production it is impossible to feed the world population (FAO, 2017). Hence, new sources of food, such as seaweeds are required to sustain life on earth. Seaweeds do not compete with plants for land space and are advantageous as nutritional supplement. Several researchers anticipate a future where seaweeds will be grown for more valued purposes than as product of food and feeds (Neori, 2016).

According to Sharif *et al*. (2008), both macro- and micro-algae can provide different types of renewable bioenergy. Renewable biofuels from algae include methane produced by anaerobic digestion of algal biomass, biodiesel, and biologically produced hydrogen (Laurens et al., 2017). Pilot programmes to grow large masses of seaweed in the ocean and then ferment this biomass to produce methane gas for use as fuel have been attempted in the Americas, Europe and Asia (McHugh, 2003).

As an ingredient in fertilizer, the usage of seaweeds dates back at least to the nineteenth century. Coastal inhabitants collected storm-cast seaweed, commonly large brown seaweeds, and dug them into the soil. The high fibre content of the seaweeds acted as soil conditioner and assisted moisture retention; while the mineral content served as a source of trace elements (McHugh, 2003). Currently, the industrial usage of seaweed biomass has shifted from its use in fertilizers and a source of potash, to extraction of phycocolloids (Synytsya et al., 2015). In many cases, the 'potential' of the industry has been viewed as having high prospects than its original scale and this is very significant today as it appeared over 100 years ago, when the industry was viewed from a different perspective (Hafting et al., 2015). These include their use as raw materials for polysaccharides e.g. agar, carrageenan and alginates (Bixler and Porse, 2011), or transformation of the biomass into products for agronomic applications (Buschmann et al., 2008; Craigie, 2011). Among the valuable products one can find are ingredients for food and feed (Fleurence, 2016), cosmeceuticals (Balboa et al., 2015), nutraceuticals and pharmaceuticals (Thanh-Sang Vo et al., 2012; Cao et al., 2016; Anis et al., 2014), and for bioenergy (Korzen et al., 2015). Seaweeds also yield bioactive compounds, antiviral agents, pharmaceuticals, nutraceuticals and antioxidants. They can also be used as energy-carrying molecules in biofuels, bio-alcohols and heat/power generation (Sudha, 2014).

The red algae *Gracilaria sp.* has a global cultivation value of over 3.8 million tons annually, and worth about US $1 billion (FAO, 2017). *Gracilaria sp.* has been widely cultivated in China (70%) and Indonesia (28%) in relation to global production. Countries like Chile have been estimated to produce about 13 tons of the red algae annually with a yearly value of US $29 million (FAO, 2017). Most of the biomass used in the phycocolloid industry serve as the principal source of food grade agar and as an animal feed (Qi et al., 2010). *Gracilaria sp.* contributes nearly 66% of the total agar production worldwide (Guiry and Guiry, 2016).

Propagation (asexually and sexually) is easy among these species as they grow rapidly (Abreu et al., 2011; Kim et al., 2016; Gorman et al., 2017).

The cell walls of red algae consist of cellulosic fibre embedded in a matrix of non-fibrillar materials referred to as phycocolloids, the most abundant of these polysaccharides are known either as agars or carrageenans (Fredericq *et al*., 2009). Polysaccharides such as alginate (El Atouani et al., 2016; Sellimi et al., 2015), carrageenan (Aliste et al., 2000; van de Velde et al., 2002) and agar (Hii et al., 2016; Rhein-Knudsen et al., 2015) are commonly used in food preparation. Oil and glycerol are also extracted from seaweeds for biodiesel production. High quality agars are produced from agarophytes in the Gelidiaceae and Gracilariaceae families (Marinho-Soriano and Bourret, 2005). For agar, the usual production process may include extraction, filtration, concentration and dehydration. According to Fredericq *et al*., (2009) and Li *et al*., (2008), agar finds its widest use as a solid microbiological cultural substrate in several laboratory applications.

Majority of carrageenans are extracted from two carrageenophytes, i.e. *Kappaphycus alvarezii* and *Eucheuma denticulatum* (McHugh, 2003). Due to its high viscosity, carrageenans are widely used as thickening or gelling agents in the food industry (Saha and Bhattacharya, 2010; Prajapati et al., 2014), and as a stabilizing agent, air freshener gel, and toothpaste binder (Rahardjo et al., 2013). The use of carrageenan is becoming a common ingredient in drug delivery (Li et al., 2014), tissue engineering (Popa et al., 2015), or bio-sensor applications (Esmaeili et al., 2017; Ooi et al., 2015).

Alginates, unlike the carrageenans, are extracted from the cell walls of brown algae. They are obtained by acid pre-treatment of alginophytes followed by an alkaline extraction, and widely used in industries to give consistency (viscosity) or to form gels. For example, it is used in baked foods, textile prints, beer foam stabilizers, welding rod bandages and dental impression

material (McHugh, 2003). Brown seaweed produces alginate, an anionic polymer used in maintaining the structure in frozen foods (Hu et al., 2014) and salad dressing (Silva et al., 2013). The alginate also plays an important role in the biomedical field as tableting agent (Rahim et al., 2015), as an ingredient for immobilized systems (Jain and Bar-Shalom, 2014; Kim et al., 2017) and as a material for dental fixtures (Al-Enazi and Naik, 2016; Demajo et al., 2016), tissue engineering and medication (Agarwal et al., 2015; Boekhoven et al., 2015).

2.3 Distribution of marine macroalgae

The distribution of macroalgae in terms of their regional assemblages have mostly been linked to historical processes. Studies of algal biogeography is influenced by tectonic changes over geological time and changes in species diversity with changing sea levels and temperature regimes (Kerswell, 2006). Thus, considering all macroalgal genera, tropical regions tend to have less diversity than temperate regions. Situations where diversity peaked at low latitudes was when a more reef-associated order such as the Bryopsidales was examined (Kerswell, 2006). In addition, Konar et al., (2010) confirmed the common trend of higher diversity of taxa at mid-latitudes compared to low latitudes in the northern hemisphere, especially in the intertidal region. Maps depicting species distribution and diversity on a global scale reports of distinct gradients in species diversity. There is a likely shift in algal species richness from temperate regions towards the tropics and poles with regards to the Indo-Pacific and Atlantic oceans (Kerswell, 2006).

In the tropics, algal richness is not highest because of low metabolic processes which is assumed to improve speciation (Kaspari et al., 2004). Competition with corals is usually mentioned to explain the lower algal richness in the tropics compared to temperate zones (e.g.,

Fraser and Currie, 1996; Miller and Hay, 1996). Within temperate areas, sections of highest algal richness also match up with large areas of conducive habitat (Silva, 1992).

In the mid-latitudes, between 108°N and 108°S, low diversity floras are present on both the east and west shores of South America and Africa. The greater part of global landmass (and coastlines) is in the northern hemisphere and thus provide more habitat for colonization of marine macroalgae. However, the tropical marine environments harbour numerous benthic fauna which graze on the macroalgae, thereby reducing their species richness. Another factor contributing to reduction in species richness is presence of large bodies of freshwater entering into the ocean, such as the Amazon (Garbary, 2001). The bulk influx of freshwater limits seaweed diversity as an outcome of both declined salinity and unfavourable substrate as a result of siltation.

Ocean fluxes play an important role in defining the location of hotspots for macroalgal species richness as a result of propagule dispersal and alteration of oceanic circulations. These currents leave the tropics, travelling poleward along western ocean boundaries and back towards the tropics along the eastern edges. It is possible to link species richness through dispersal, to current systems and conclude that tropical algae would occur in western ocean regions along with low diverse tropical floras in the east. Furthermore, equatorial currents increase the extent of the distribution of tropical algae into temperate regions, and thus contribute to overall algal richness where tropical and temperate floras overlap (Kerswell, 2006) .

2.5 Distribution of macroalgae in Western Africa

The diversity of flora in Western Africa is significantly lower southward, remaining low throughout the Angolan coast (Lawson and John, 1987). In northern Namibia, where many cooler marine algae are at the northernmost limit of their range, there is an abrupt change to a temperate flora. West African marine flora has little to do with mere latitude, but governed by

the movement of cooler water along the coast (Bolton et al., 2003). The cooler Canary and Benguela currents run from the north and south along the western coast of Africa, thus limiting the occurrence of warm water algae to a relatively narrow band. Even in this narrow tropical band there is a local upwelling of cooler and nutrient-rich sub-surface water, which between July and September causes the surface water temperature to fall to as low as 19°C (Bakun, 1990). Seasonal upwelling, inflow of turbid, silt-laden water, reduction in inshore salinity, lack of adequate substrates in intertidal areas are all factors contributing to the low species diversity of marine algae in Western Africa (Figure 1).

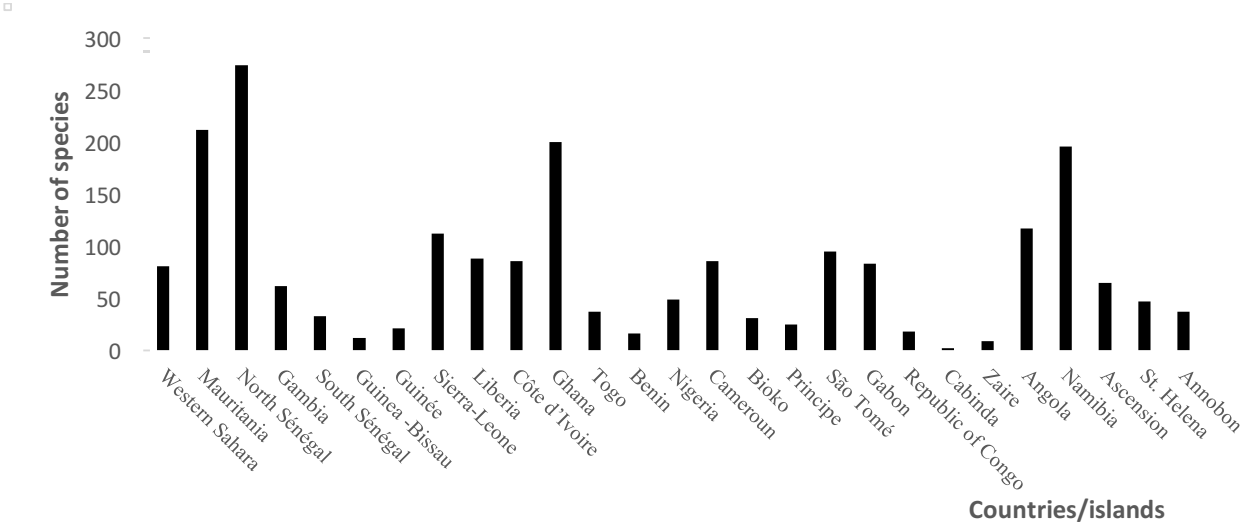


Figure 1 Number of marine macroalgae species in Western Africa (David et al., 1994)

2.5 Distribution of macroalgae in Ghana

The first record of investigation into the macroalgae distribution along the coast of Ghana was by Dickinson and Foote (1950) where they described for the first time the species assemblage. Since then authors like Lawson, (1957); Lawson and Price (1969); Lawson and John (1982, 1987); Lawson et al., (1995) and Gbedemah (2017). The earlier studies were focused on exploring species diversity followed by their quantification. Gbedemah (2017) was the first to

attempt assessment of community structure of the macroalgae in Ghana. However, his work was based on only two locations at the East and West of the country's coast.

2.6 Factors affecting marine macroalgae distribution

The intertidal zone is an area of open beach regularly exposed to tidal wave action and serves as the main habitat of macroalgae. Various abiotic factors affect the benthic fauna and algal species in the intertidal areas. Significant among these are type of substrate, wave action, nutrient, exposure and sedimentation (Dawes, 1998). During low tide, for example, intertidal organisms are exposed to the atmosphere with associated stresses such as desiccation, salinity fluctuations, high temperatures and light intensities (Raffaelli, 2012).

It has been observed that increasing temperatures influence the spatial distribution of some species of algae with low resistance to desiccation to the point of extinction. Biological processes of growth, reproduction, and mortality are affected by temperature and help define species' biogeographical boundaries (Breeman, 1988). It has been proposed that tropical marine macroalgae are the most stenothermal macroalgae of any biogeographical region (Pakker et al., 1995). However, those endemic to tropical western Atlantic could only survive temperature variation of 10-13°C.

Studies indicate that macroalgae are grazed upon extensively within the intertidal region, and it is considered one major biological factor that affects their distribution and abundance (Carpenter, 1986; Hay, 1997; Hughes et al., 2007). Fish and sea urchins are the principal grazers of macroalgae in tropical habitats (Williams et al., 2001). Some experiments have shown that herbivory has the potential of removing entire algal turfs of coral reef habitats within a day (Duffy and Hay 1990; Hughes et al. 2007; Mumby, 2009). Many fishes prefer

macroalgae because of their high protein content (Paul et al., 1990; Bruggemann et al., 1994; Cvitanovic and Bellwood, 2009).

Nutrients are very important for macroalgal production, and especially tropical waters that receive effluents from land are rich in nutrients and potentially enhance algal production (Teichberg et al., 2008). The increased supply of nutrients is mainly due to human practices such as farming and sewage discharges. The concentration of nutrients in the marine environment require other factors such as photosynthetic active radiation, temperature for increased growth rate of macroalgae. It is possible for macroalgae to have high growth rate when other factors are optimal and nutrient is low (McCook, 1999).

Tropical macroalgae are very efficient nutrient users and capable of making use of nutrient pulses through uptake mechanisms. Furthermore, they can store and recycle nutrients in their tissues for extended periods of time (Fong et al., 2003). Small increment in nutrient concentration in the tropics is able to cause an absorption of nutrient towards a bloom (Kennison, 2008; Fong et al., 2001, 2003). In some cases, readily available phosphorus reduces the production of fleshy macroalgae in nutrient deprived environments (Lapointe et al., 1987, 1992; Littler et al., 1991). Conversely, alkaline phosphatase activity (APA) enables some macroalgae to fulfil their phosphorus requirements by facilitating the utilization of organic phosphorus (Schaffelke, 2001).

CHAPTER 3

METHODOLOGY

3.1 Study sites

The coast of Ghana lies along the Gulf of Guinea in West Africa with its southernmost point at about 04º.44 north of the equator. The coastline is about 550km long and extends from 06º.06; 01º.12 E, where it is bordered by the Republic of Togo, to 05 º.05; 03º.06W, where it is bordered by Cote d'Ivoire. The coastal zone of Ghana may be defined as the area below the 30m contour representing about 7% of the land area. This portion of the land, though small, supports about 25% of the nation's total population (Armah and Amlalo, 1998).

Based on geomorphologic characteristics, Ghana's coast has been sub-divided into three major zones; Eastern, Central and Western coasts (Boateng, 2009). The Eastern coast has a major river, the Volta River that tends to influence the geomorphology of the zone (Wellens-Mensah, 2002). The Central coast is characterized by of rocky headlands, and sand bars with spits enclosing coastal lagoons, whiles the Western coast consists of flat and wide beach backed by coastal lagoons (Boateng, 2006).

Anthropogenic activities in the coastal zone have several impacts on the environment. Such activities have led to pollution of the water bodies along the coast leading to changes in the marine environment (Craig-Smith et al., 2006) with effects on ocean circulation and the carbon cycle (Huber and Nof, 2006). The coastal area of Ghana experiences tropical climatic conditions, which is hot and humid (EPA, 2004). Rainfall distribution is bimodal with one peak in May/ June and a second peak in September/ October. Mean annual rainfall ranges from 625mm to 1500mm (EPA, 2004). However, there are occasional rainfall in January, although it is recorded as lowest in the year (Hall and Swaine, 2013).

Coastal upwelling in the Gulf of Guinea is located off the coasts of Cote d'Ivoire and Ghana where two seasonal upwelling occur each year; a major (July to September) and a minor (December to January) upwelling. Between the upwelling periods are a long warm season from February to June and a short warm season from October to November. During the two warm seasons, the warming of the ocean and coastal rains produce a very stable stratification with a well- mixed surface layer, 30m to 40m deep, over a very sharp pycnocline (Koranteng and McGlade, 2001).

The hydrography of the coast is influenced by the oceanic gyral currents of the North and South Atlantic Oceans, which forms the Equatorial Counter Current that flows eastward. The ECC joins as the Guinea Current and runs from Senegal to Nigeria. A westward-flowing counter-current lies beneath the Guinea Current at about 40m depth, and this appears to turn to the southwest near the sea bottom (Longhurst, 1962).

The tidal regime of Ghana is semi-diurnal, but the average varies along the coast from 0.58 m at neap tide (Takoradi) to 1.32 m at Spring tide (Aflao). The tidal wave across the entire coast has the same phase (Wiafe et al., 2013). The waves are not local, consisting of a swell which originates from the oceanic area around Antarctica and the Southern seas. The significant height of the waves range between 0.9 m and 1.4 m and rarely reach 2.5 m. The most common amplitude of waves in the region is about 1.0 m but annual significant swells could reach 3.3 m in some instances. Swells attaining heights of 4.8-6 m, however, occur with a 10 to 20-year periodicity (Wiafe et al., 2013).

The coastline of Ghana is characterized by sandy shores (70%) and rocky beaches (30%) along the entire stretch (Armah and Amlalo, 1998) (see Figure 2). Rocky shores are found largely between Axim and Prampram observed as rocky out-crops alternating with sandy bays (Boateng, 2009). The rocky out-crops provide substrate for a wide variety of macroalgae and other living organisms.

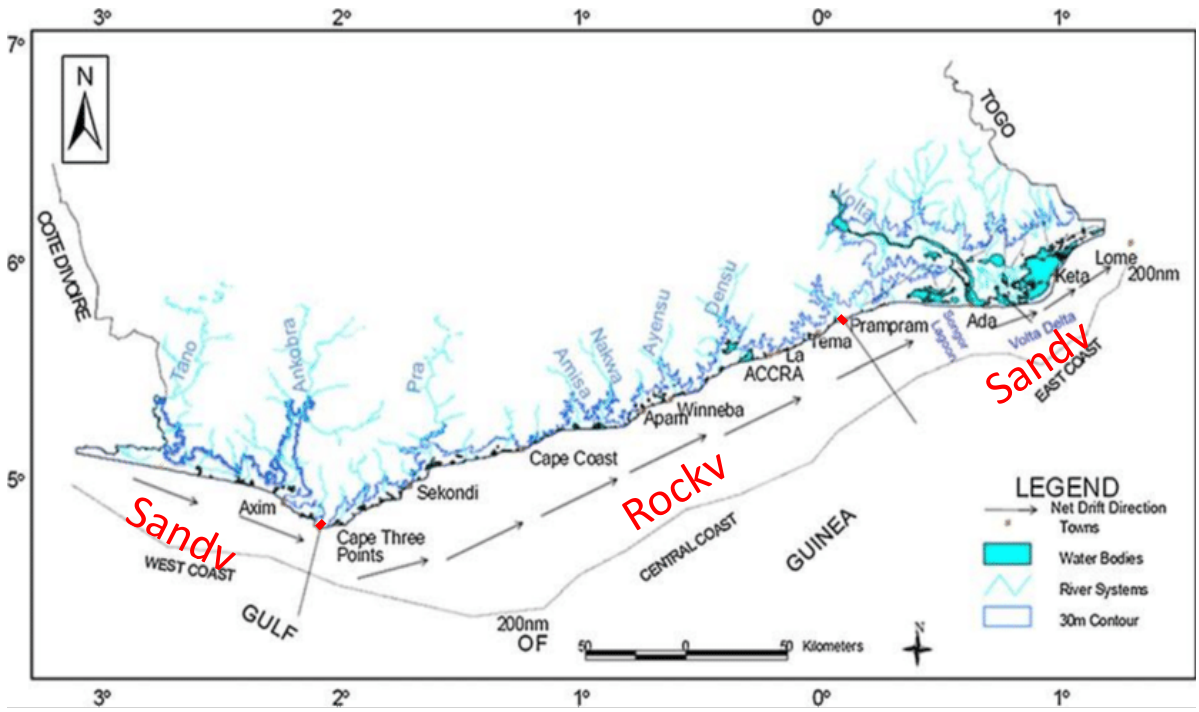


Figure 2 The shoreline of Ghana showing the sandy and rocky areas (Source: Boateng 2012).

3.2 Field Sampling

Macroalgae were sampled from ten (10) selected sites along the entire coast of Ghana. A reconnaissance survey of 29 sites was carried out from which the 10 sampling stations were chosen (Figure 3). The sampling stations were located mainly at rocky beaches within the Eastern, Central and Western coast of Ghana.

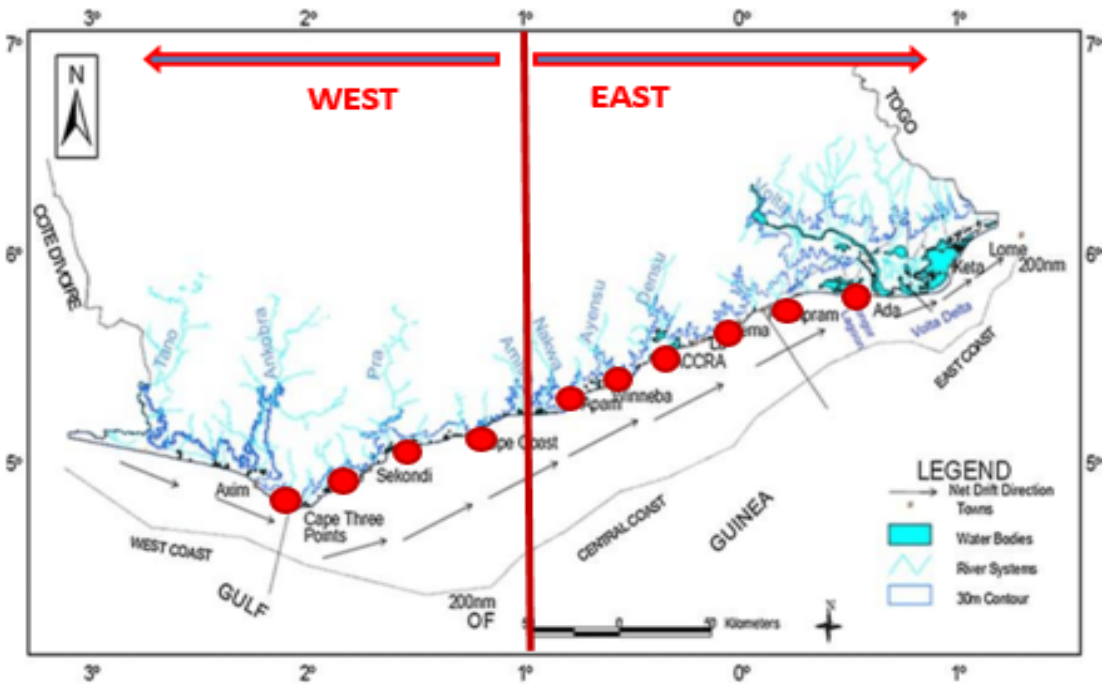


Figure 3 The coast of Ghana showing the sampling locations.

3.3 Assessment of species diversity and Community structure

Field sampling took place from 11th October, 2018 to 5th January, 2019. Visits to the sampling sites were determined on the basis of the tidal chart; the lowest tide was selected to enable extensive coverage to the sub-littoral zone. Table 1 shows the selected low tides at the various locations during which sampling was conducted.

Table 1 Sampling locations and predicted times of selected low tides

Sampling date	Location	Time of preferred low tide	Tidal height (m)
11-Oct-18	Teshie (Next Door)	1102	0.2
23-Nov-18	Old Ningo	1106	0.1
25-Nov-18	Prampram	1227	0.1
26-Nov-18	Tema New Town	1146	0.2
27-Nov-18	Christianborg Castle	1234	0.2
10-Dec-18	Kokrobite	1139	0.2
11-Dec-18	Mumford	1214	0.2
3-Jan-19	Takoradi	0832	0.3
4-Jan-19	Dixcove	0908	0.2
5-Jan-19	Aminano	0942	0.2

Macroalgae found at different sampling stations were randomly sampled using purposive sampling technique. A 1m x 1m quadrat constructed from polyvinyl chloride (PVC) pipes was used for the estimation of percentage cover of macroalgae species. At each location, three transects (A, B and C) were defined, from the high water mark to the low water mark (Figure 4). The distance between the transects was 100m, (see fig 4). The macroalgae were identified to species level and their percentage cover determined for each quadrat (Plate 1). A Garmin etrex Global Positioning System (GPS) was used for taking the coordinates of the transect positions.

For each transect, species were identified were categorized into three lateral zones seaward, namely, supra-littoral (0 – 30m), mid-littoral (31m – 60m) and sub-littoral (61m – lower water line).

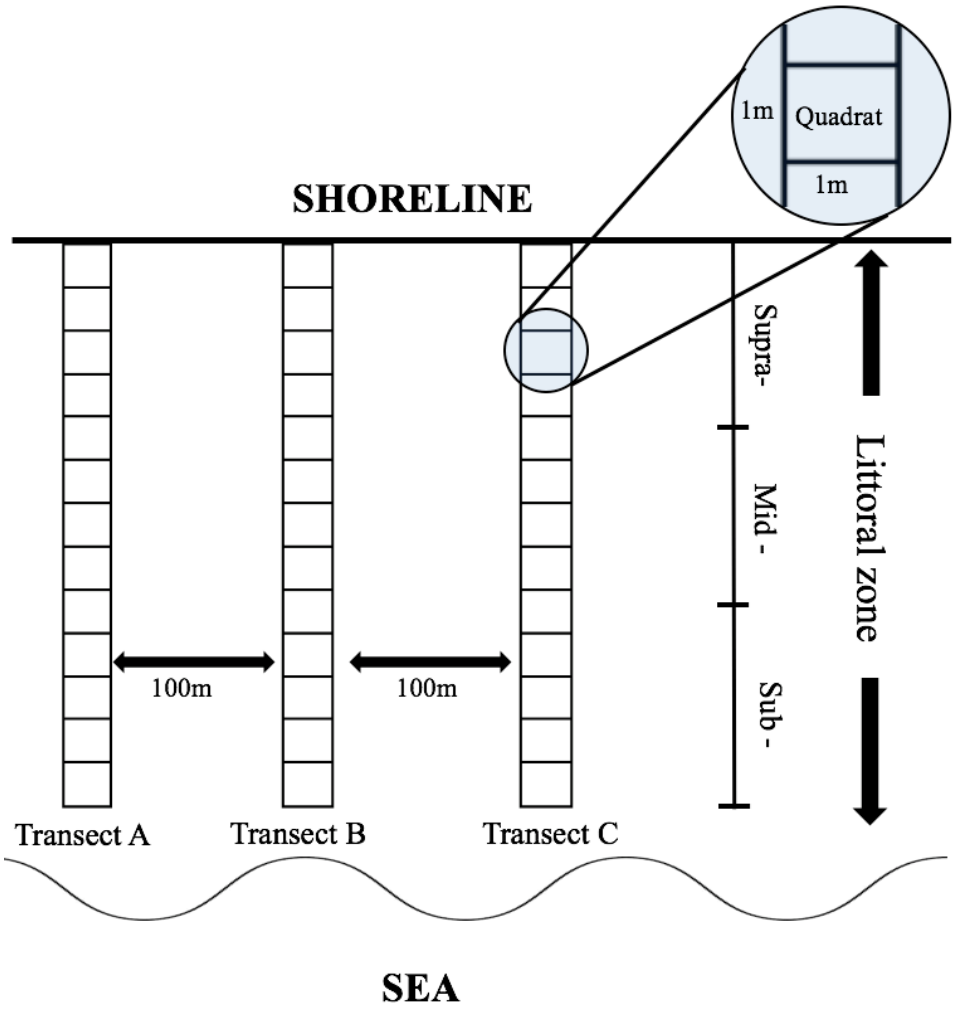


Figure 4 Demarcation of transect at sampling location showing quadrat (inset)

(a) Collection and preservation of species

Standard protocols were followed in the collection and preservation of samples for laboratory analyses (Charrier, 2018). Fragments and attached materials such as shells, sand and rock particles were detached from samples before preservation. To avoid samples from rotting, they were placed in airtight bags or plastic containers in fixatives. The pigmentation of most

specimens were best preserved by fixing the specimens in about 4% formalin-seawater. In addition, some of the samples were kept frozen to maintain their freshness for subsequent identification in the laboratory.

Plate 1 Sampling of macroalgal species and estimation of percentage cover within quadrat at Next Door.

In the laboratory the seaweeds were rinsed with clear tap water to remove any remaining salts. Any other remaining debris like shells, adhered materials were removed on the field before further rinsing in the laboratory to clear any other salts and mud at this stage providing clean seaweed samples. Voucher specimens were made following Bridson and Forman, (1998) and deposited at the Ghana Herbarium in the Department of Plant and Environmental Biology,

University of Ghana. Voucher specimens and sub-samples of the cleanly wiped seaweeds were used to examine the morphology and taxonomic composition of the species. Digital images of the morphology were collected using an Olympus digital camera SP-51OUZ, and measurements of the fronds were used to describe the species. The morphological and taxonomic description of the specimens were done using taxonomic keys and identification books (e.g. Manoylov, 2014). The species were identified with the aid of a Leica stereoscopic microscope having a magnification of X6.3 and X40, and Leica DMLM light microscope at X35 and X630.

3.4 Water quality analyses

Seawater samples were collected within the perimeter which was indicative of the station. Water samples were collected at low tide from a depth of about 2 centimeters below the water surface from each band transect. Measurement of physical parameters such as salinity were taken in situ with a handheld 0-28% ATC salinity refractometer. Three replicates of water samples were collected at each transect, using water sampling bottles. The water samples were preserved on ice in an ice box and transported for transportation to the laboratory where they were kept in a refrigerator at 4ºC and analysed within 48 hours of preservation.

The nutrients that were analysed were nitrates, phosphates, silicates, ammonia and sulphates using a Spectrophotometer DR2800. Analysis of samples were carried out according to APHA (1998).

Nitrate

According to APHA (1998), the cadmium reduction method was used in determining quantities of nitrates in samples of seawater. 10ml of the sample was measured into the reaction bottle and the reagent (Nitriver 5) added. The mixture was shaken vigorously for a minute and allowed to stand for about five minutes. It was then poured into a cuvette for reading in the spectrophotometer at wavelength of 500nm.

Phosphate

Phosphate was determined in the water samples using the ascorbic acid method. 10ml of the sample was measured into the reaction bottle. The phosphate reagent was then added to the sample and swirled to completely dissolve. After about 2 minutes of settling, it was poured into a cuvette, placed in the spectrophotometer and the reading recorded at a wavelength of 880nm.

Silicate

The silicomolybdate method according to APHA (1998) was used in determining silicate amounts in seawater samples. The first reagent, silicate molybdate, was added to 10ml of the samples in a reaction bottle. After swirling the second reagent, the acid reagent was added and the mixture allowed to stand for 10minutes. The solution was then transferred to the cuvette for reading in the spectrophotometer in mg/L SiO_2 at a wavelength of 452 nm.

Ammonia

At a wavelength of 655nm, ammonia analysis was conducted by the Ammonia Salic Test using the HACH 385. A 10ml aliquot was measured into a reaction tube and was diluted with distilled water. Ammonia Salicylate Powder Pillow was added to the samples and the blank. The reaction tubes were shaken vigorously after their stoppers had been inserted until completely dissolved. A three-minute reaction was allowed to occur in the reagent tubes. When the time had elapsed, Ammonia cyanurate Reagent Powder Pillow was added to the samples and allowed to dissolve completely. A green colouration was then observed after five minutes. The spectrophotometer was zeroed using the blank sample after which the actual samples were transferred into a cuvette and its volume measured. Appropriate dilution factors were incorporated into the programme of the spectrophotometer to obtain final readings for the concentrations of ammonia.

Sulphate

According to APHA (1998), the Sulfa Ver 4 method was used in determining sulphate in the water samples. 0.1ml of the samples was measured into the reagent bottle using a pipette and deionised water added to reach the 10ml mark. After adding the reagent, the mixture was swirled and then allowed to stand for about five minutes. The solution was then transferred into a cuvette and reading taken in the spectrophotometer in mg/L SO_4^{2-} at wavelength of 450nm. Readings were multiplied by a dilution factor of 100.

3.5 Data Analyses

(a) Enumeration of percentage cover of macroalgal species

Percentage cover of macroalgae species was calculated using the following formula (Putri, 2017):

$$Pi = \frac{ai}{A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where, **Pi**= covered species i (%); **ai**= total cover species i (%); and **A**= total area covered by macroalgae (%)

Species diversity analysis

Species diversity indices were computed for the pooled data for all sampling stations to provide indication of species richness and evenness for the whole period as well as for each sampling locations on the basis of their geomorphic characteristics. Indices of Shannon-Wiener and Pielou were computed (Smith, 1996).

Shannon-Wiener diversity index (H)

Computation of this index assumes that individuals were randomly sampled from an independently large population, and that all the species were represented in the sample. Calculating this diversity index normally requires transformation using Log_2, and it is important to maintain such consistency for comparison with other published works.

Shannon – Wiener diversity index (H):

$$H = -\sum Pi \ In \ Pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

where Pi = S / N; S = number of individuals of a species; N = total number of all individuals in the sample; In = logarithm to base e

Shannon diversity index is useful for comparing diversity between different habitats (Clarke and Warwick, 2001).

Pielou's evenness (J)

Evenness index is also an important measure of species diversity. It expresses how evenly the individuals are distributed among the different species.

$$J = H / \ln S \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3)$$

Where H = Shannon – Wiener diversity index; S = the total number of species in the sample

(b) Characterization of community structure

All multivariate analysis and calculation of biodiversity indices were done using statistical routines in Plymouth Routine in Multivariate Ecological Research, PRIMER v6.0 (Clarke and Gorley, 2005). Biological data was fourth-root transformed to preserve information concerning relative abundance and minimize differences in scale among variables (Clarke, 1993). Samples were standardized by dividing each transect by the number of quadrat forming it.

The multivariate analyses explored similarities in macrophyte assemblages among locations based on abundances. The biological data was initially 4th-root transformed (to minimise weighting of numerically dominant taxa), standardised (zero mean, unit standard deviation), and Bray-Curtis similarity matrix computed as:

$$BC_{ij} = \sum \frac{|n_{ik} - n_{jk}|}{(n_{ik} + n_{jk})} \quad \text{..... (4)}$$

where BC = Bray-Curtis, i and j = different species, n = abundance, k = sample.

Spatial (sampling locations) and temporal variations of macroalgal community structure were investigated using cluster analysis technique (Clarke and Warwick, 2001). Group average agglomerative hierarchical clustering was performed with the production of a dendrogram to visually depict relationships between and within sampling locations. The criteria for selecting samples with similar community structure was set at Bray-Curtis similarity of >60% (Clarke and Warwick, 2001).

Further analysis was carried out on the Similarity Percentages (SIMPER) test using transformed and standardised data, which helped to examine the contribution of individual species to the average Bray-Curtis dissimilarity between groups of samples. It also determined the contribution to similarity within a group. The analyses were carried out with Plymouth Routines in Multivariate Ecological Research (PRIMER) statistical software version 6 (Clarke and Gorley, 2005).

A 2D non-metric Multi-dimensional scaling (MDS) of biological data overlaid with related parameters such as location, nutrients, and zonation enable investigation of the influence of the latter on the former. The contribution of nutrients to observed biotic distribution was assessed from BIOENV analysis in PRIMER, similar to a multiple regression analysis. Non-parametric one-way ANOVA with post-hoc tests of comparison in nutrient concentration was performed.

CHAPTER 4

RESULTS

4.1 Species diversity and abundance

A total of forty-one species of macroalgae belonging to 25 families and three phyla were identified from the samples from October, 2018 to January, 2019 (Table 2).

Table 2 List of macroalgae species, and their taxonomic classification, identified in the intertidal zone of Ghana (October, 2018 – January, 2019)

Phyla	Class	Order	Family	Species
Chlorophyta	Ulvophyceae	Bryopsidales	Bryopsidaceae	*Bryopsis pennata*
			Caulerpaceae	*Caulerpa sertularioides*
				Caulerpa taxifolia
		Cladophoraceae	Codiaceae	*Codium guineense*
				Cladophora prolifera
				Chaetomorpha antennina
				Chaetomorpha linum
			Cladophoraceae	*Cladophora ruchingera*
			Siphonocladaceae	*Ernodesmis verticillata*
		Ulvales	Ulvaceae	*Ulva fasciata*
				Ulva flexuosa
				Ulva lactuca
Ochrophyta	Phaeophyceae	Ectocarpales	Scytosiphonaceae	*Choospora minima*
		Dictyotales	Dictyotaceae	*Dictyota ciliolata*
				Padina antillarum
				Padina durvillaei
				Spatoglossum schroederi
		Fucales	Sargassaceae	*Sargassum vulgare*
		Ralfsiales	Ralfsiaceae	*Ralfsia expansa*
		Scytothamnales	Asteronemataceae	*Asteronema breviarticulatus*
		Scytothamnales	Bachelotiaceae	*Bachelotia antillarum*
Rhodophyta	Florideophyceae	Ceramiales	Ceramiaceae	*Centroceras clavulatum*
			Rhodomeniaceae	*Bostrychia radicans*
				Bryocladia thyrsigera
				Laurencia majuscula
				Polysiphonia ferulacea
		Corallinales	Corallinaceae	*Corallina pilulifera*
				Jania rubens
			Lithothamniaceae	*Lithothamnion bisporum*
		Gelidiales	Gelidiaceae	*Gelidium corneum*
		Gigartinales	Cystocloniaceae	*Hypnea musciformis*
			Gigartinaceae	*Chondracanthus acicularis*
				Gigartina acicularis
			Phyllophoraceae	*Gymnogongrus tenuis*
		Gracilariales	Gracilariaceae	*Gracilaria verrucosa*
				Hydropuntia dentata
		Halymeniales	Halymeniaceae	*Cryptonemia crenulata*
				Cryptonemia luxurians
				Grateloupia doryphora
				Grateloupia filicina
		Rhodymeniales	Lomentariaceae	*Gelidiopsis variabilis*

The major species identified in this study have been shown pictorially in Appendix A. Of the three phyla, Chlorophyta or green algae dominated in total abundance (i.e. percentage cover of 58%) followed by Rhodophyta (i.e. red algae with percentage cover of 29%) and Ochrophyta (i.e. brown algae with percentage cover of 13 %) (Figure 5).

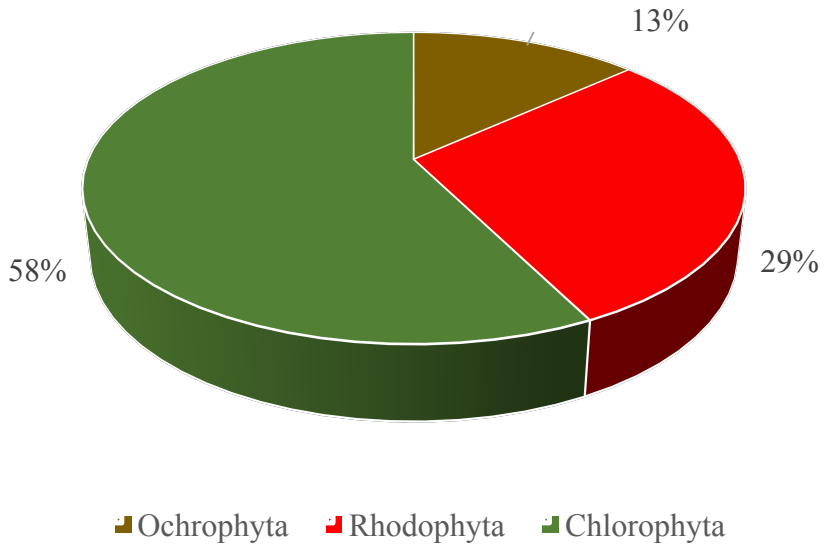
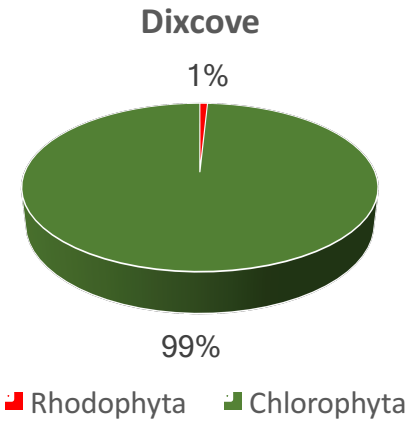
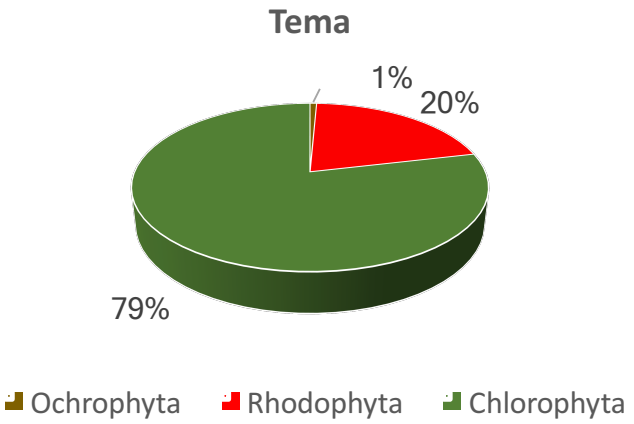
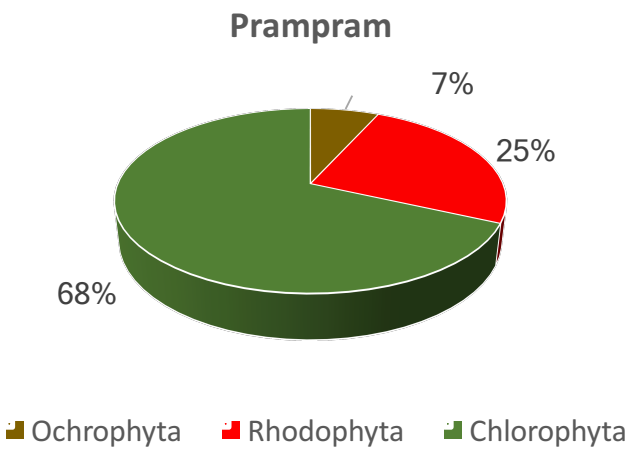


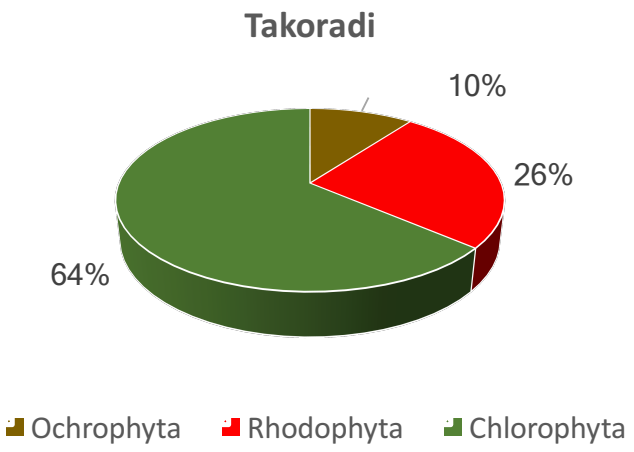
Figure 5 Distribution of macroalgae by phyla (based on pooled data for all samples)

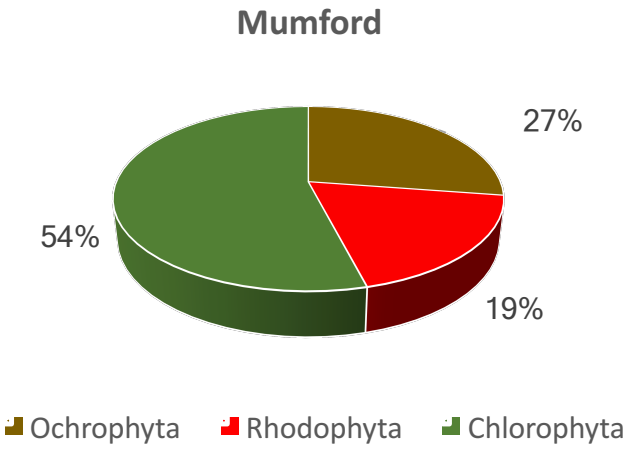
Pie chart distribution with respect to the taxonomic groups showed Chlorophyta dominance in terms of total percentage cover Chlorophyta at all the sampling stations with the exception of Aminano and Kokrobite (Figure 6). The latter site recorded the highest abundance of Ochrophytes compared to all the sites. At Dixcove and Tema, the percentage cover of Ochrophytes were less than 1% or about 1%, respectively. However, Chlorophytes were highest at 99% and 79%, respectively.

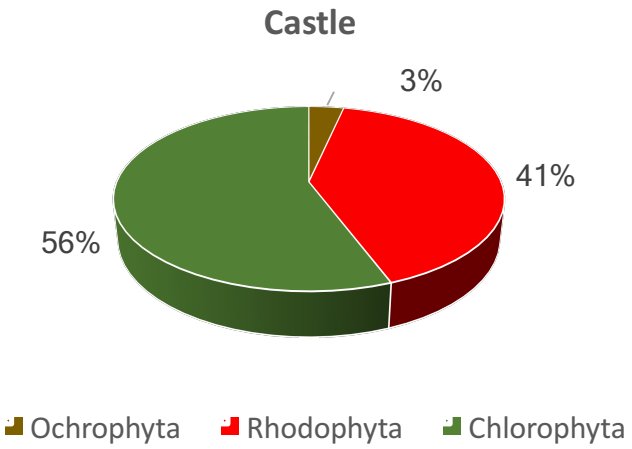


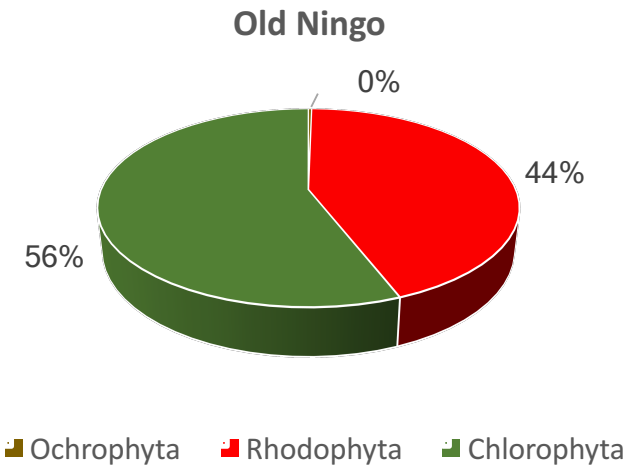


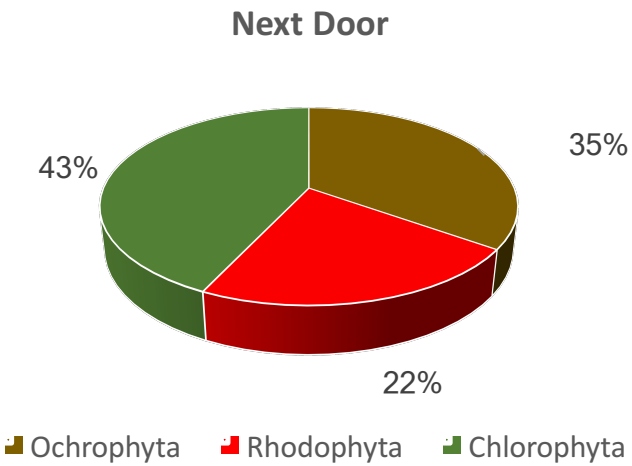












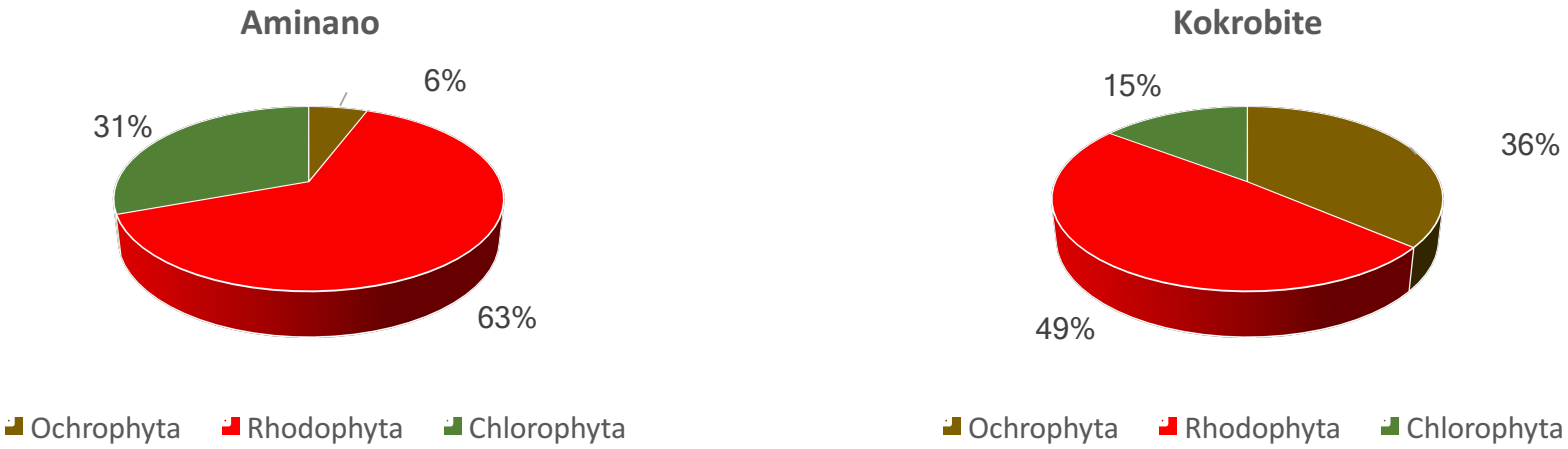


Figure 6 Plot of taxonomic groups showing percentage distribution of algal taxonomic groups across the 10 locations during the entire sampling period.

Analysis of spatial distribution of macroalgae with respect to beach morphology from multidimensional scaling revealed a weak association of taxonomic groups with particular beach morphology. Chlorophytes were observed to be distributed along sheltered areas where there was less wave action. Ochrophyta were generally found at exposed beaches, since they were tolerant to wave action, and rhodophytes were observed at moderately sheltered areas (Figure 7).

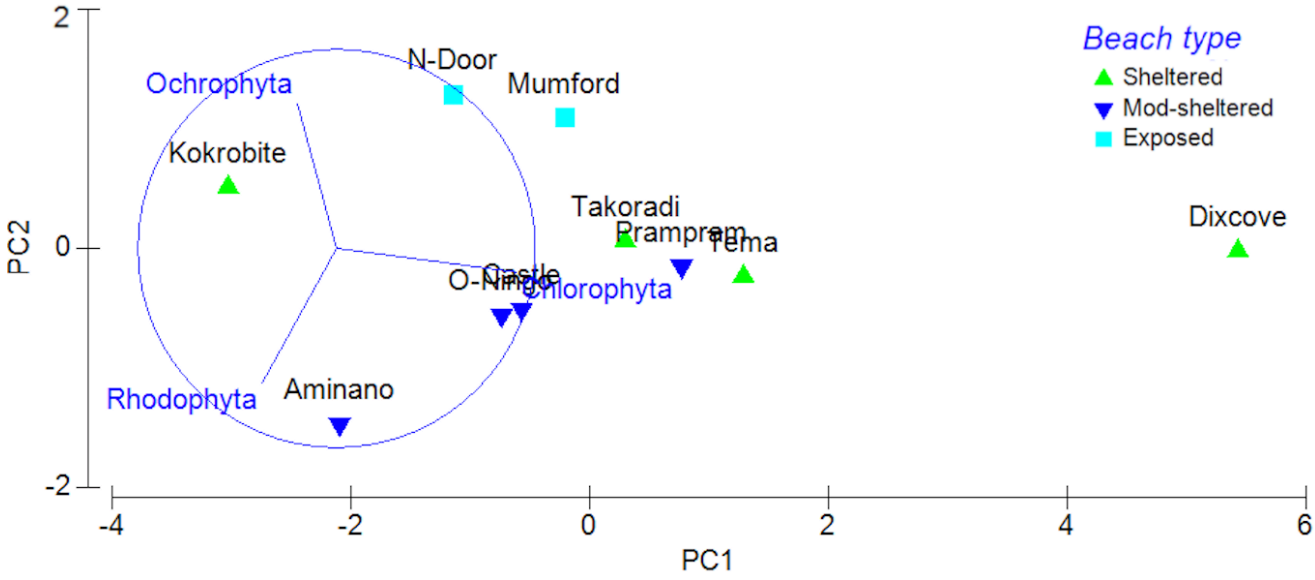


Figure 7 Multidimensional scaling for the 10 sampling locations based on beach type mapped from Bray-Curtis similarities on 4th root transformed abundances and superimposed with taxonomic groups

At the species level, *Ulva fasciata* and *Hydropuntia dentata* representing the green and red algae, respectively, were the two species which had the highest average percentage cover in terms of pooled data (Figure 8). Each of these two species had above 20% relative percentage cover. In comparison with the brown algae, the species which recorded the highest average percentage cover, *Ralfsia expansa*, was as low as 5% (see Figure 8).

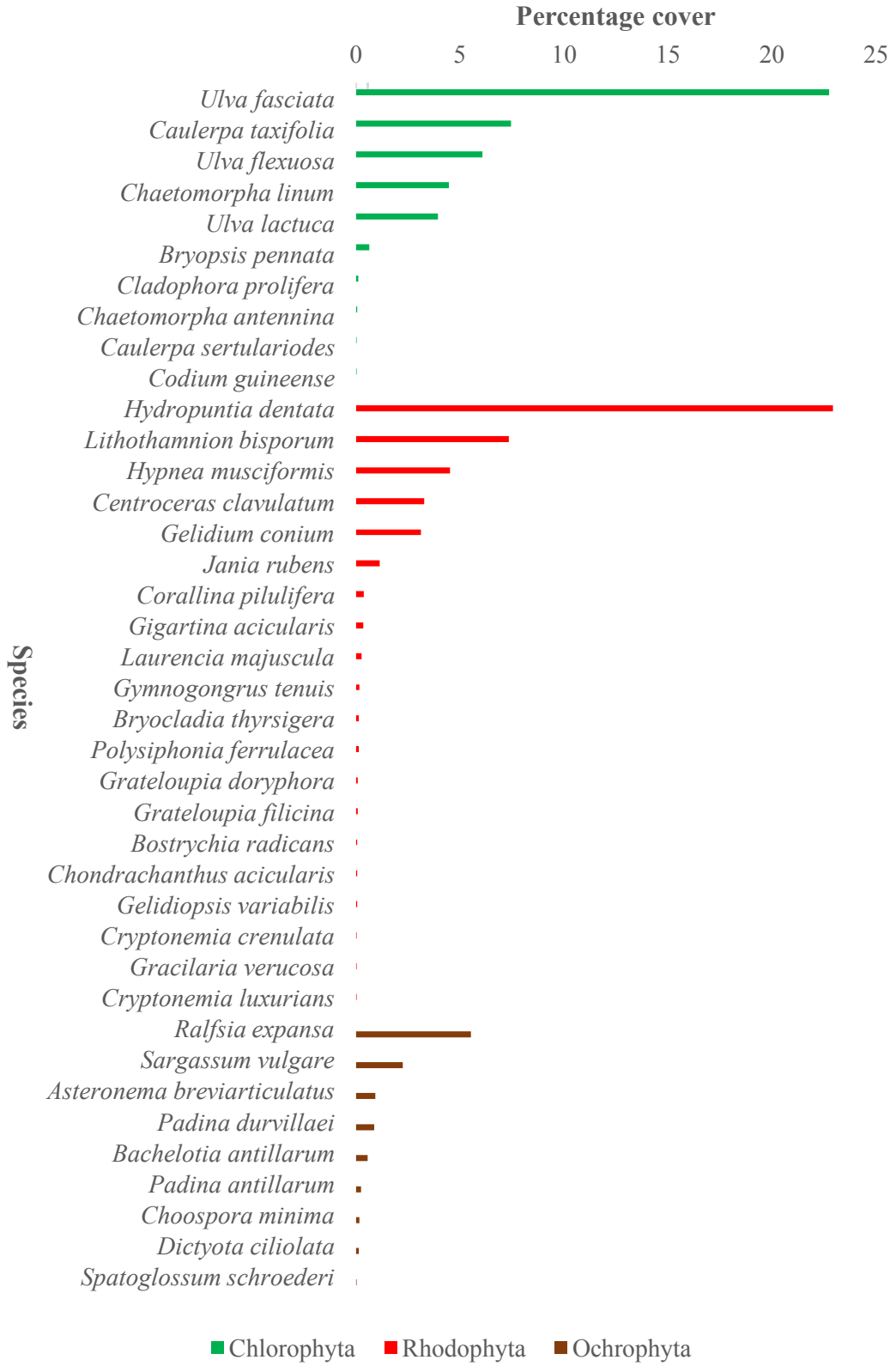


Figure 8 Relative abundance (% cover) of macroalgae species along the coast of Ghana, categorised into Chlorophyta, Ochrophyta and Rhodophyta for pooled data from October, 2018 to January, 2019 pick from file plot average location species3.xlsx

4.2 Species diversity indices

In terms of species richness from this research, Aminano recorded the highest number of species followed by Kokrobite and Dixcove, with Next Door recording the lowest number of species (Figure 9).

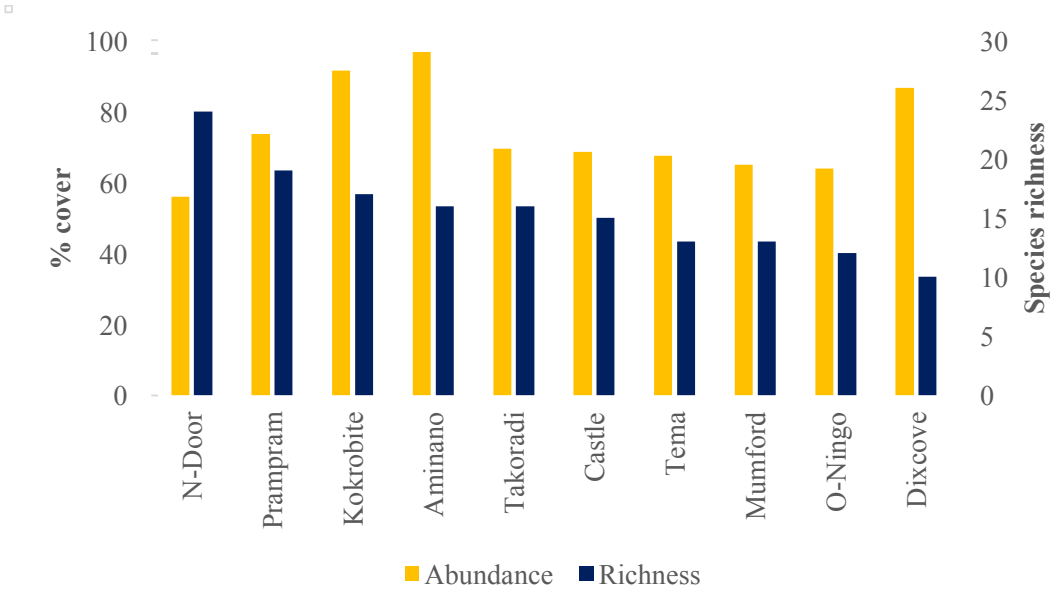


Figure 9 Plot of macroalgal species abundance measured as percentage cover and species richness at the various sampling locations

The location with highest species diversity was Next Door because the level of dominance was very low (i.e. relatively high eveness) (Figure 10). A trendline on Shannon-Wiener diversity showed a decline in species diversity from the eastern coast to the west of Ghana, with an R^2 value of 0.69.

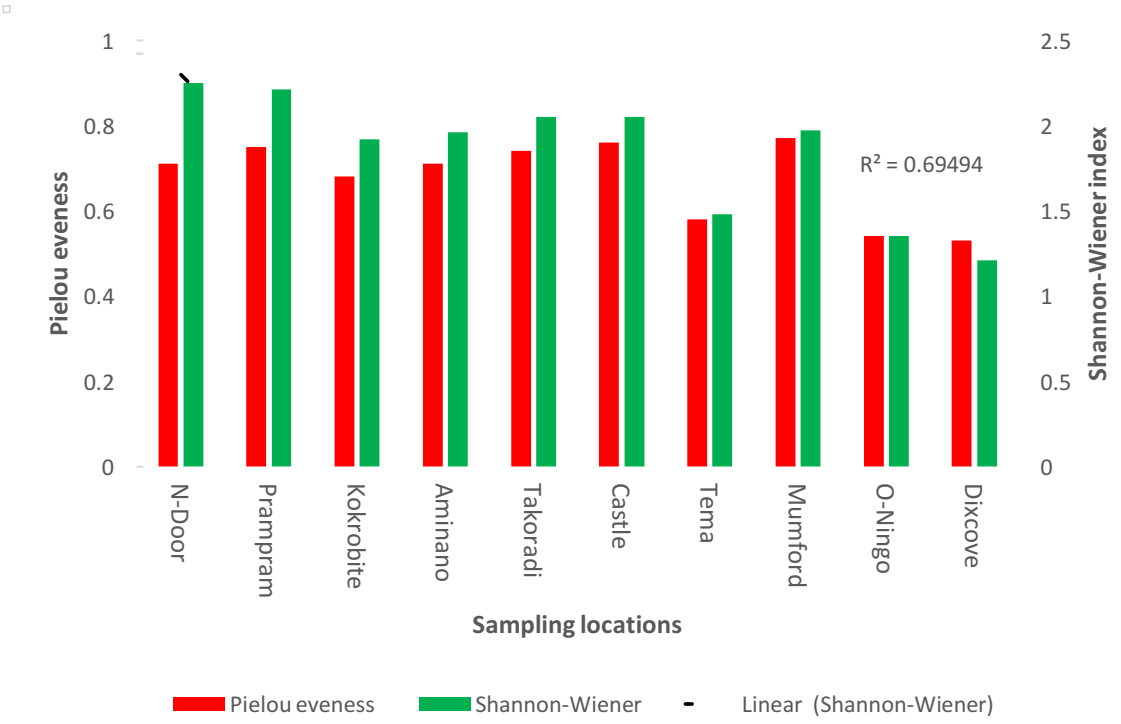


Figure 10 Comparison of diversity (i.e. Shannon-Wiener) and eveness (i.e. Pielou's) between the sampling locations.

4.3 Temporal distribution

Short-term temporal distribution was investigated by pooling the data and producing an error plot of mean percentage cover for the four months of sampling (October, 2018 – January, 2019), for all the ten sampling locations. Four species dominated above 5% average abundance at least in a particular month. These were *Ulva fasciata, Lithothamnion bisporum, Ralfsia expansa, and Caulerpa taxifolia* (Figure 11). Of the most common species, *U. fasciata* was the only species that occurred above 10% percentage cover during the entire sampling period.

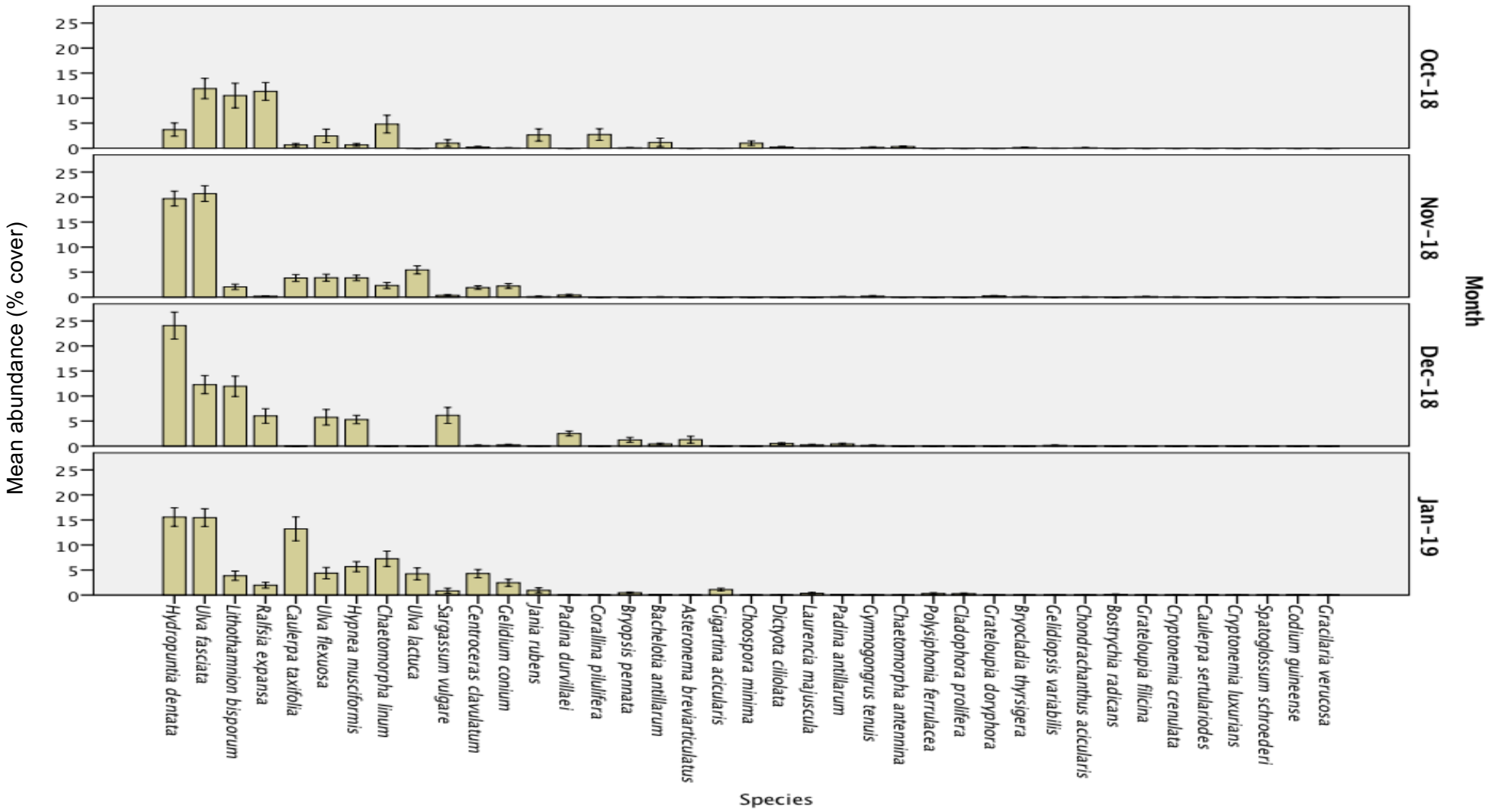


Figure 11 Monthly mean abundance (% cover) of macroalgal species for sampling periods (Oct, 2018 – Jan, 2019)

4.4 Spatial distribution of algal species.

The percentage cover of macroalgal species within each transect at each sampling location was plotted along its horizontal gradient – i.e. supra-littoral, mid-littoral and sub-littoral. The details of the plot have been provided in Appendix B. Thereafter, the transects for each location were pooled together to determine the overall zonation within the algal community at each of the sampling stations.

Dixcove

This site recorded three dominant Chlorophyte species namely *Caulerpa taxifolia, Ulva fasciata* and *Ulva lactuca*. The two Ulva species were only recorded in the supra-littoral zone whiles the former dominated in both the supra-littoral and mid-littoral zones (Figure 12). The rest of the species were recorded in low abundance.

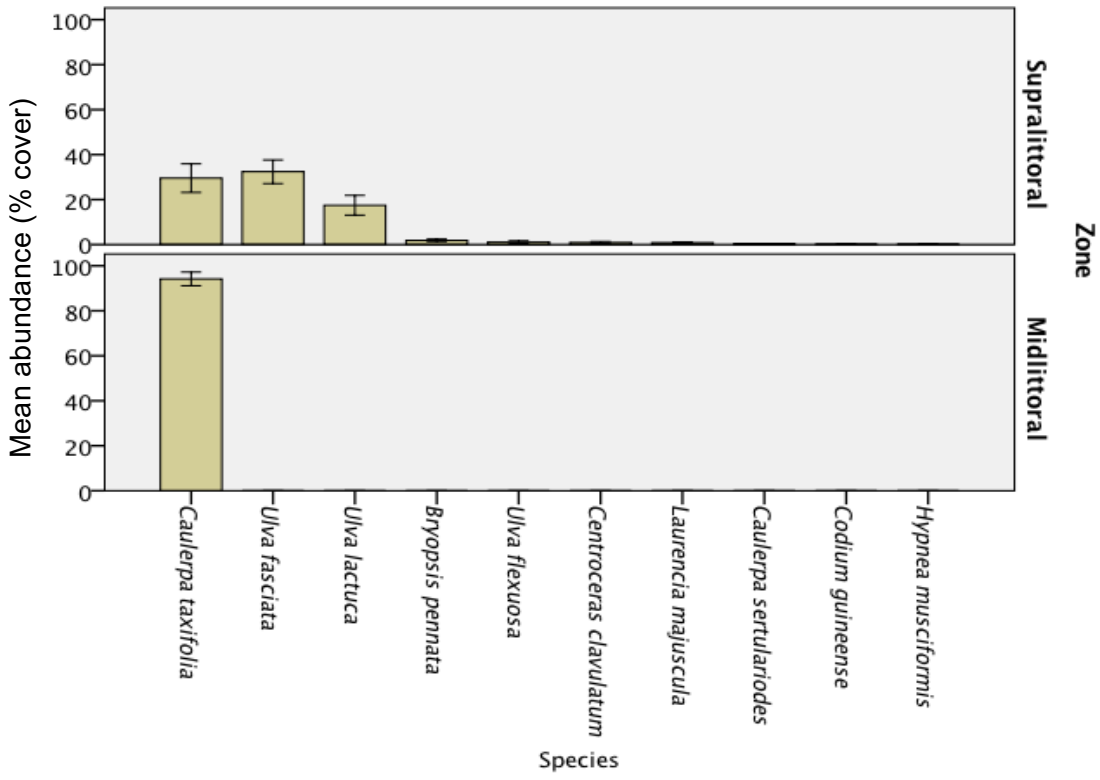


Figure 12 Zonation of macroalgal species at Dixcove along the coast of Ghana.

Takoradi

Most of the species present were distributed in the mid-littoral zone with only two species recording just above 20 percentage cover (i.e. *Ulva flexuosa* and *Chaetomorpha linum*) (Figure 13).

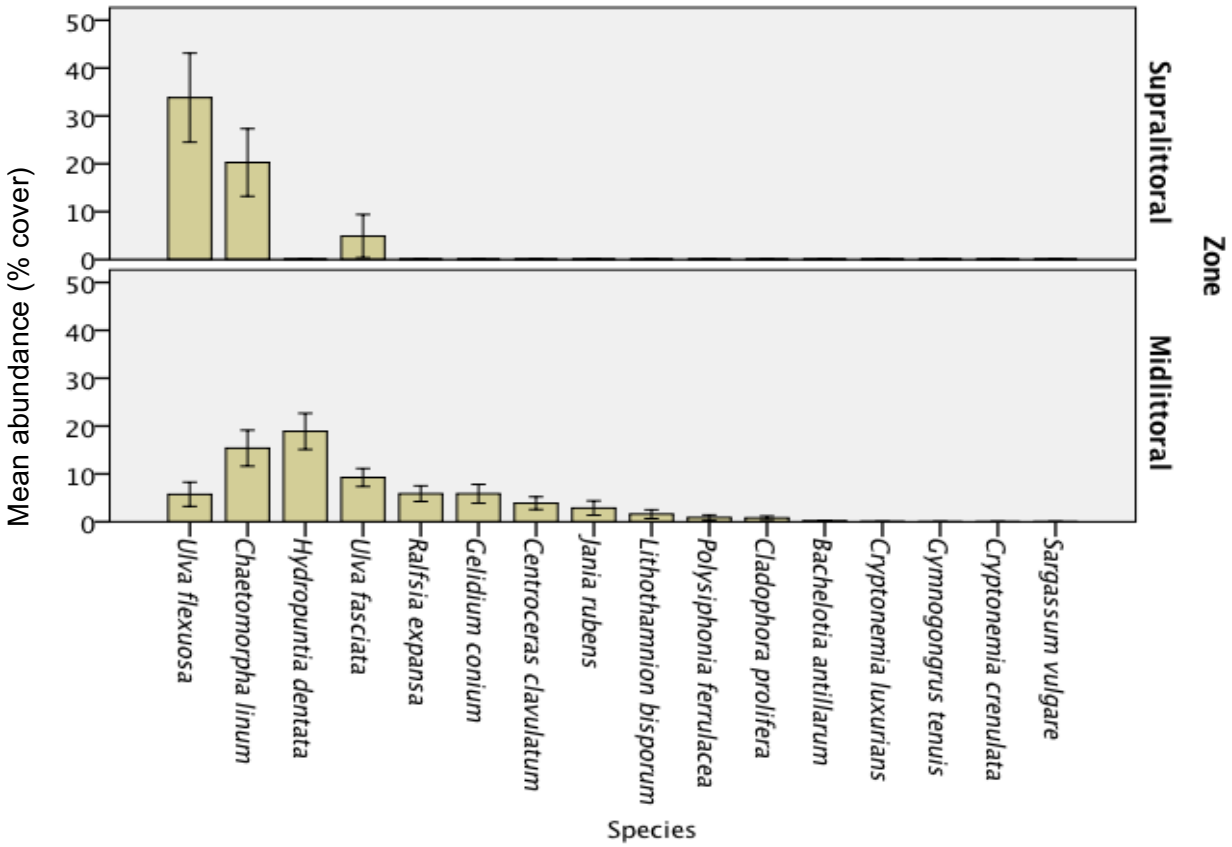


Figure 13 Zonation of macroalgal species at Takoradi along the Ghana coast.

Aminano

The distribution at both supra-littoral and mid-littoral were to some extent similar in the type of species which dominated. The algal species that dominated at this site belonged to the Rhodophytes (i.e. *Centroceras clavulatum, Hypnea musciformis, Lithothamnion bisporum* and

Hydropuntia dentata) followed by a couple of Chlorophytes (*Ulva fasciata* and *Chaetomorpha linum)* (Figure 14). It must be noted that no species were recorded in the supra-littoral zone, and at this location, the distribution was extended into the sub-littoral zone.

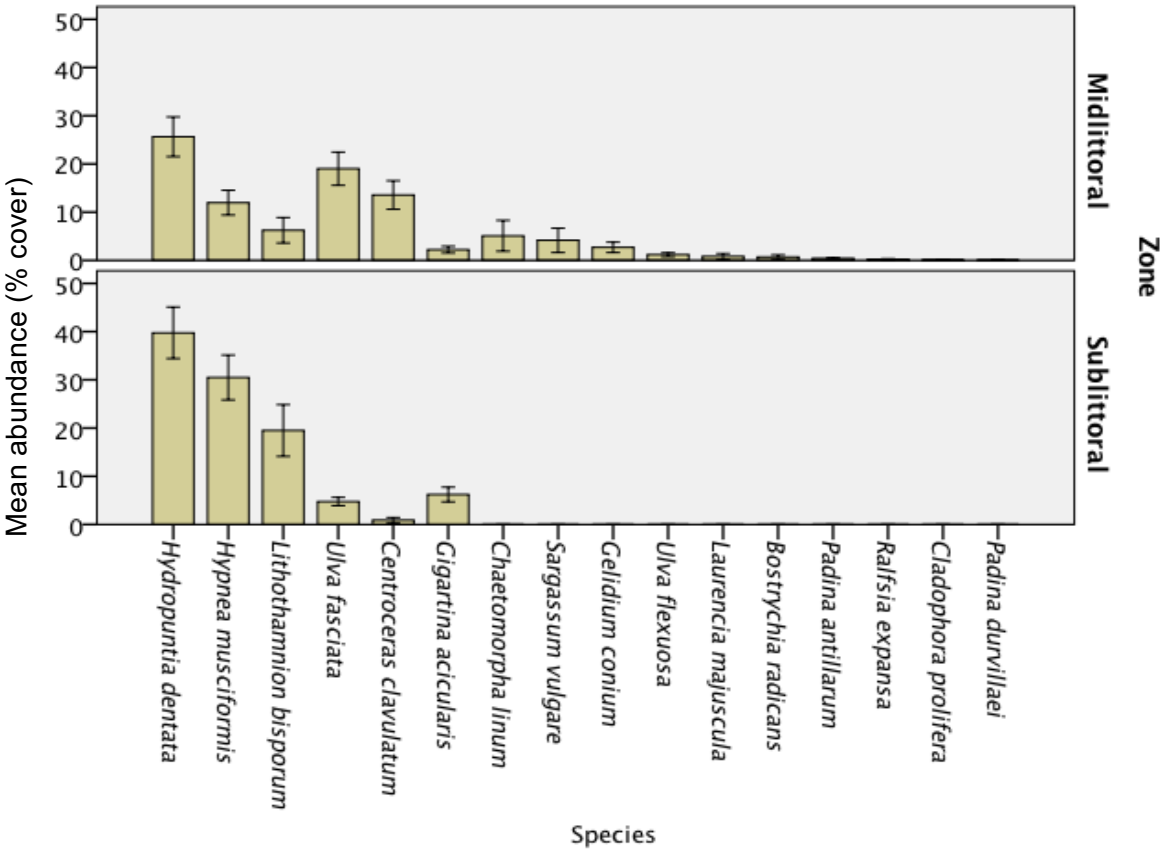


Figure 14 Zonation of macroalgal species at Aminano along the Ghana coast.

Mumford

Species dominance was recorded relatively higher at the supra-littoral zone than the mid-littoral. It is only at this location that *Sargassum vulgare* was recorded in appreciable quantity, the distribution of which was more within the mid-littoral zone (Figure 15).

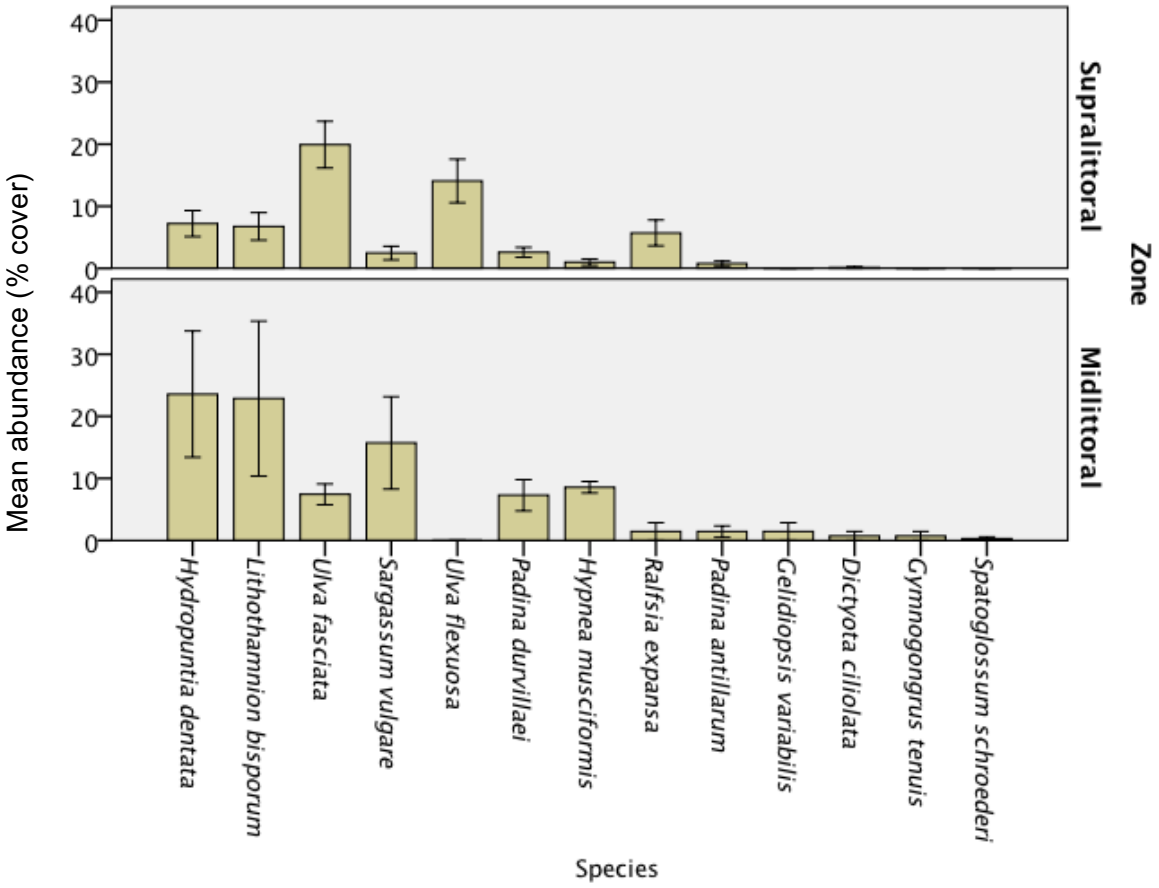


Figure 15 Zonation of macroalgal species at Mumford along the Ghana coast.

Kokrobite

At this location, just like Aminano, three species of Rhodophytes dominated the algal community, i.e. *Hypnea musciformis, Lithothamnion bisporum* and *Hydropuntia dentata* (Figure 16). This location also recorded appreciable percentage of *S. vulgare*

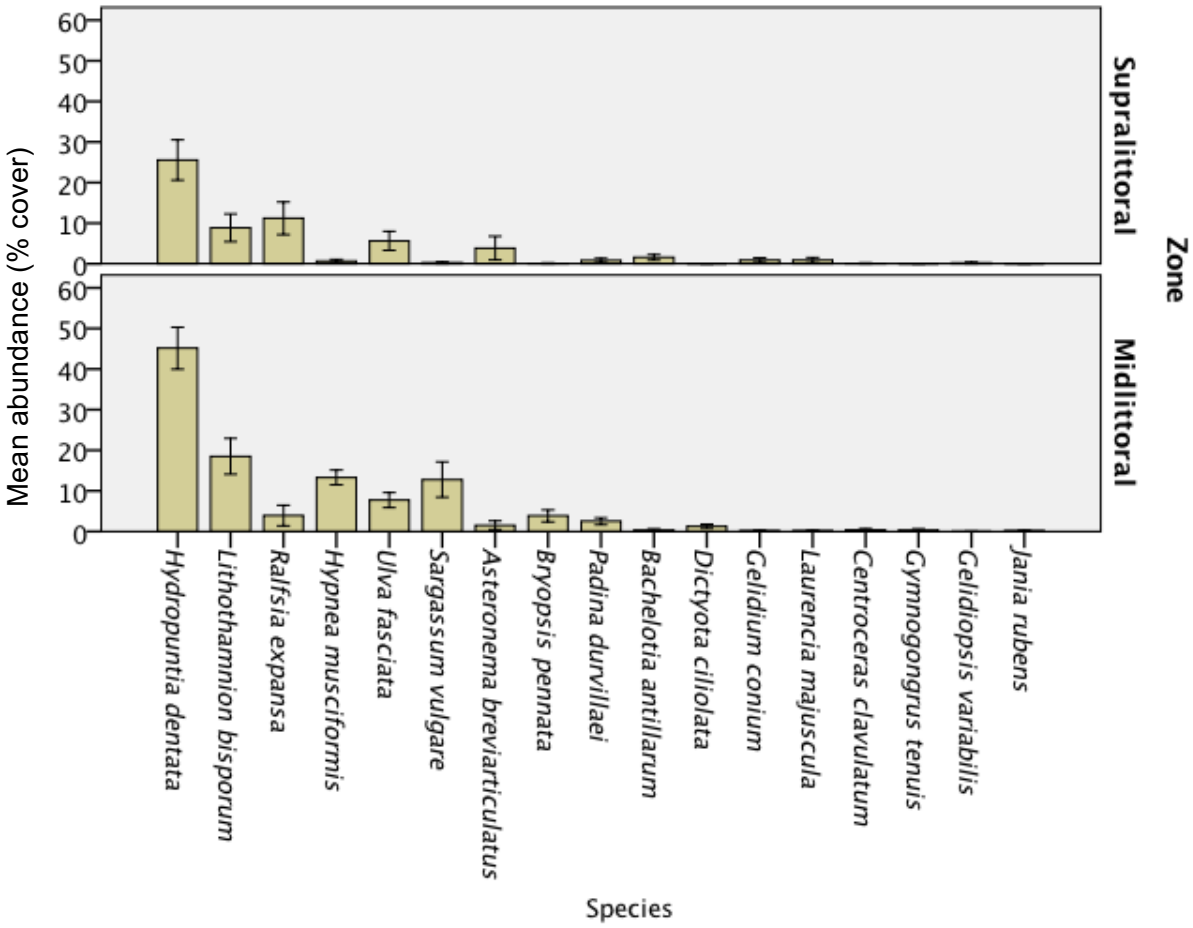


Figure 16 Zonation of macroalgal species at Kokrobite along the Ghana coast.

Christianborg Castle

This is one location where species dominance was relatively lower than all other places. This was applicable to both supra- and mid-littoral zones (Figure 17).

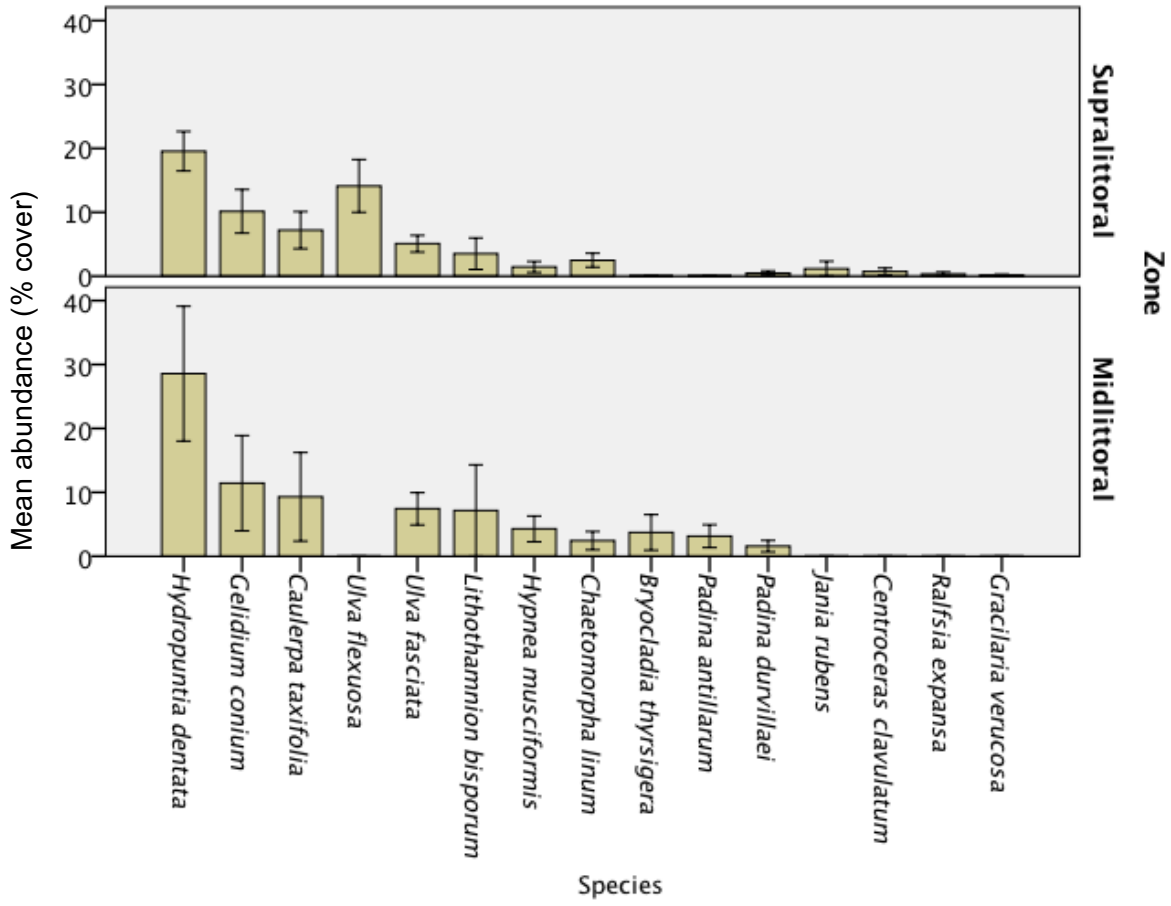


Figure 17 Zonation of macroalgal species at Christianborg Castle along the Ghana coast.

Next Door

Species dominance was relatively higher at the supra-littoral than the mid-littoral zone. *Ralfsia expansa* dominated at the supra-littoral zone (Figure 18). *L. bisporum* and *U. fasciata* dominated at the mid-littoral zone. Species richness at this location was relatively higher than all the other locations (see Figure 10).

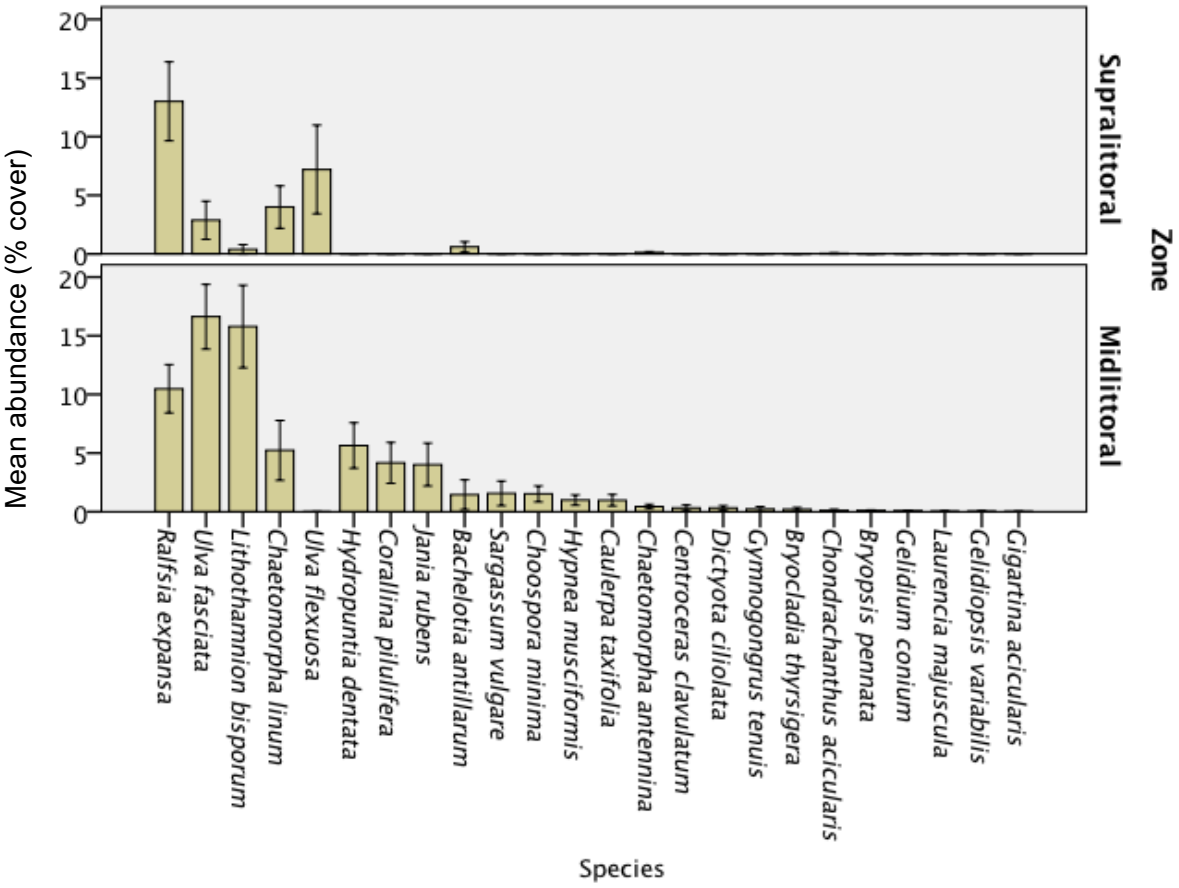


Figure 18 Zonation of macroalgal species at Next Door along the Ghana coast.

Tema

At both the supra-littoral and mid-littoral zones, all three species of *Ulva* were recorded in appreciable levels, in addition to *H. dentata* and *H. musciformis* (Figure 19).

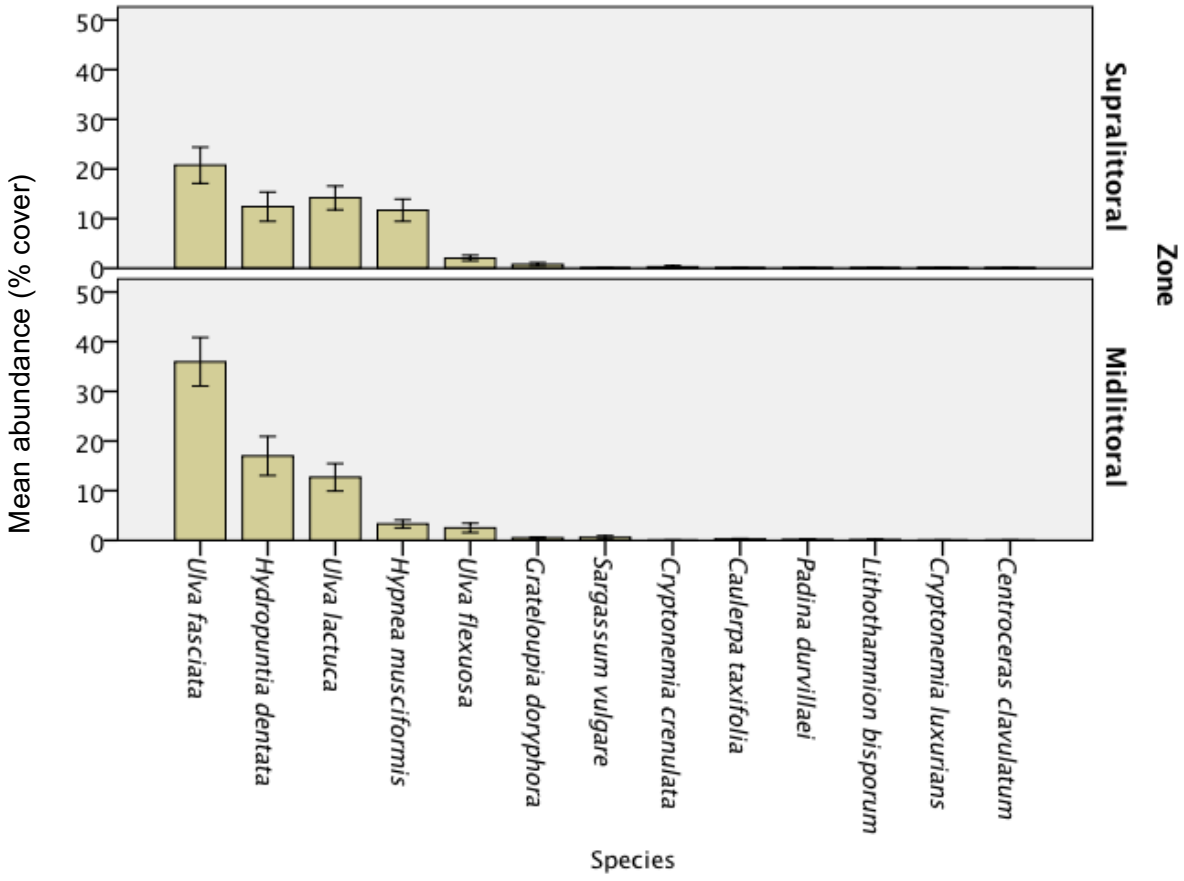


Figure 19 Zonation of macroalgal species at Tema along the coast.

Prampram

Chlorophytes such as *Chaetomorpha linum*, *Ulva fasciata* and *U. flexuosa* had high algal percentage cover in the supra-littoral zone whereas Rhodophytes like *Hydropuntia dentata* followed in the mid-littoral zone (Figure 20). Only *Hydropuntia dentata* and *Ulva fasciata* showed relatively high percentage cover in both supra- and mid-littoral zones. The other dominant ones showed an alternation in abundance between the two zones.

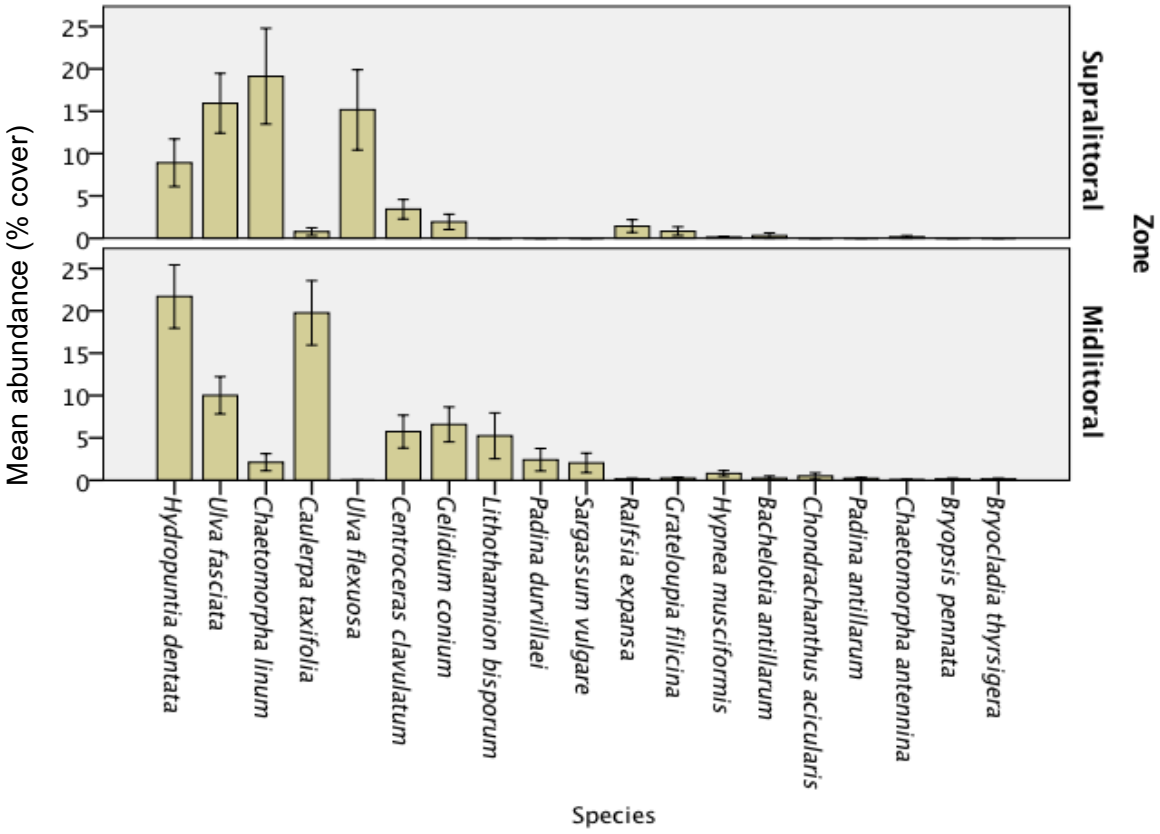


Figure 20 Zonation of macroalgal species at Prampram along the Ghana coast.

Old Ningo

Zonal distribution of macroalgae at Old Ningo was similar to that of Aminano, where no species were recorded at the supra-littoral zone but the algae extended into the sub-littoral zone. It must also be noted that the red algae, *Hydropuntia dentata* recorded the highest percentage cover at this location, similar to Aminano (Figure 21).

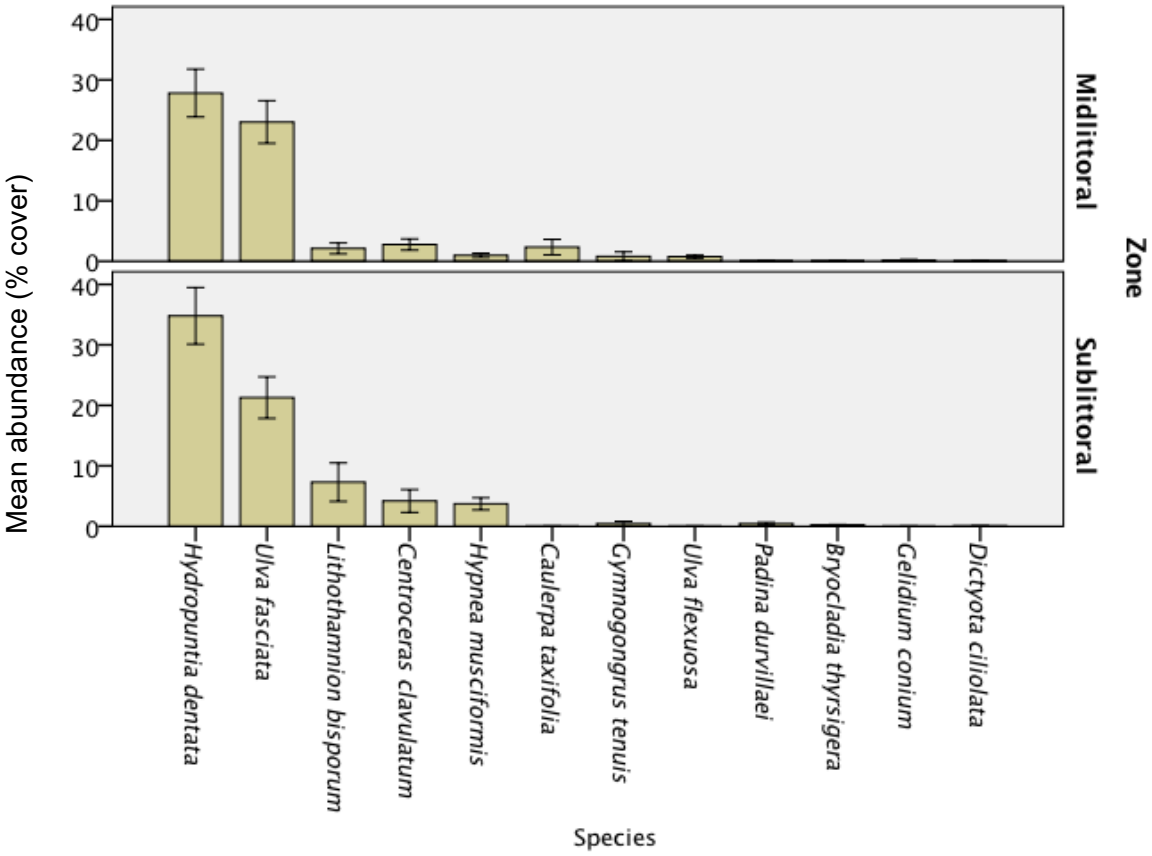


Figure 21 Zonation of macroalgal species at Old Ningo along the Ghana coast.

In summary, ten species were observed to have dominated in total abundance at specific locations – i.e. *Ulva fasciata, Ulva flexuosa, Ulva lactuca, Ralfsia expansa, Lithothamnion bisporum, Hydropuntia dentata, Hypnea musciformis, Centroceras clavulatum, Chaetomorpha linum* and *Caulerpa taxifolia* (Figure 22).

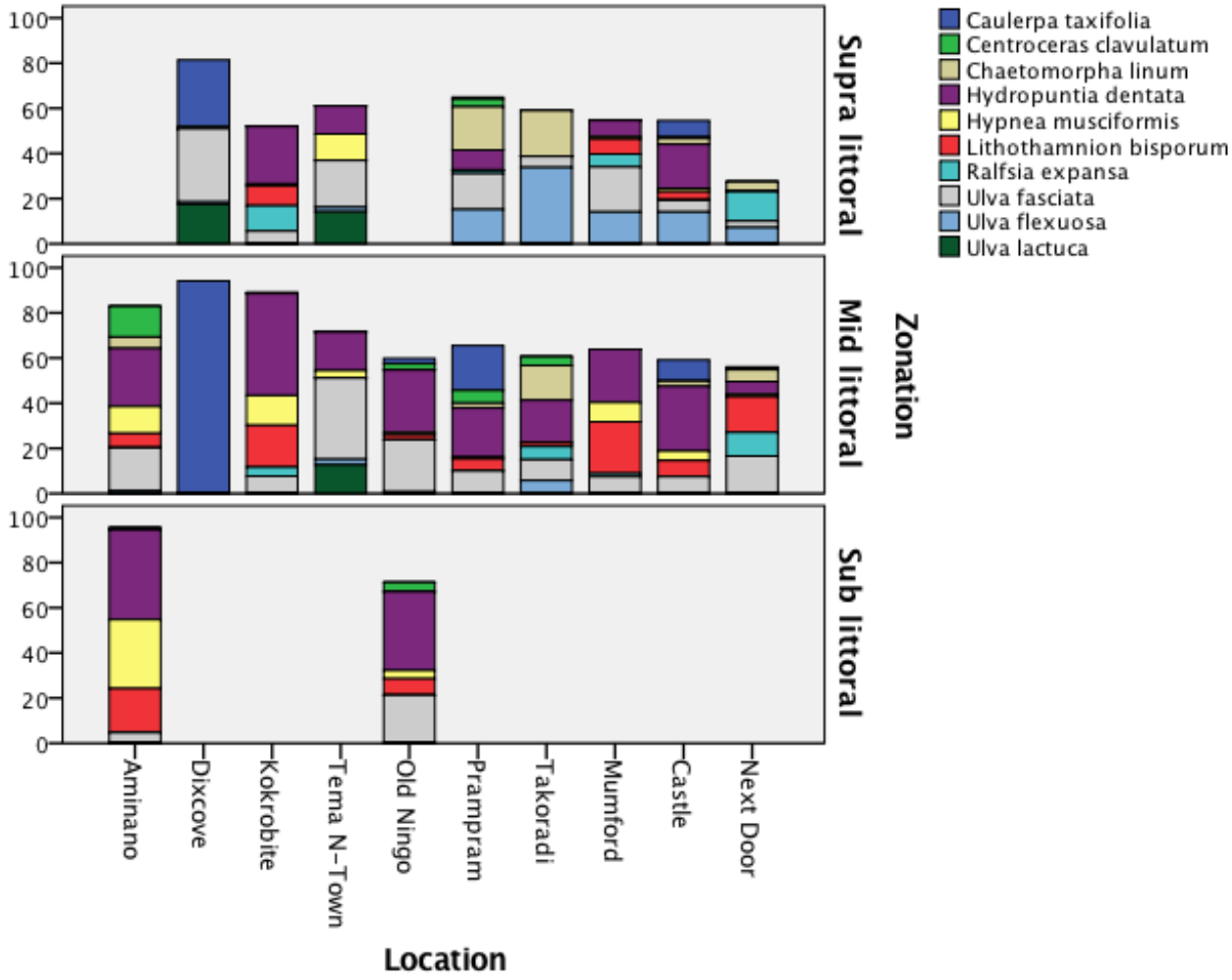


Figure 22 Zonation of dominant species recorded at the ten sampling locations along the Ghana coast.

4.5 Community structure analyses

It was observed that Rhodophytes and Chlorophytes shared similar affinity in distribution at Bray-Curtis similarity of 65% (Figure 23). The overall assessment of species distribution at all the ten locations revealed that these two taxonomic groups dominated in abundance.

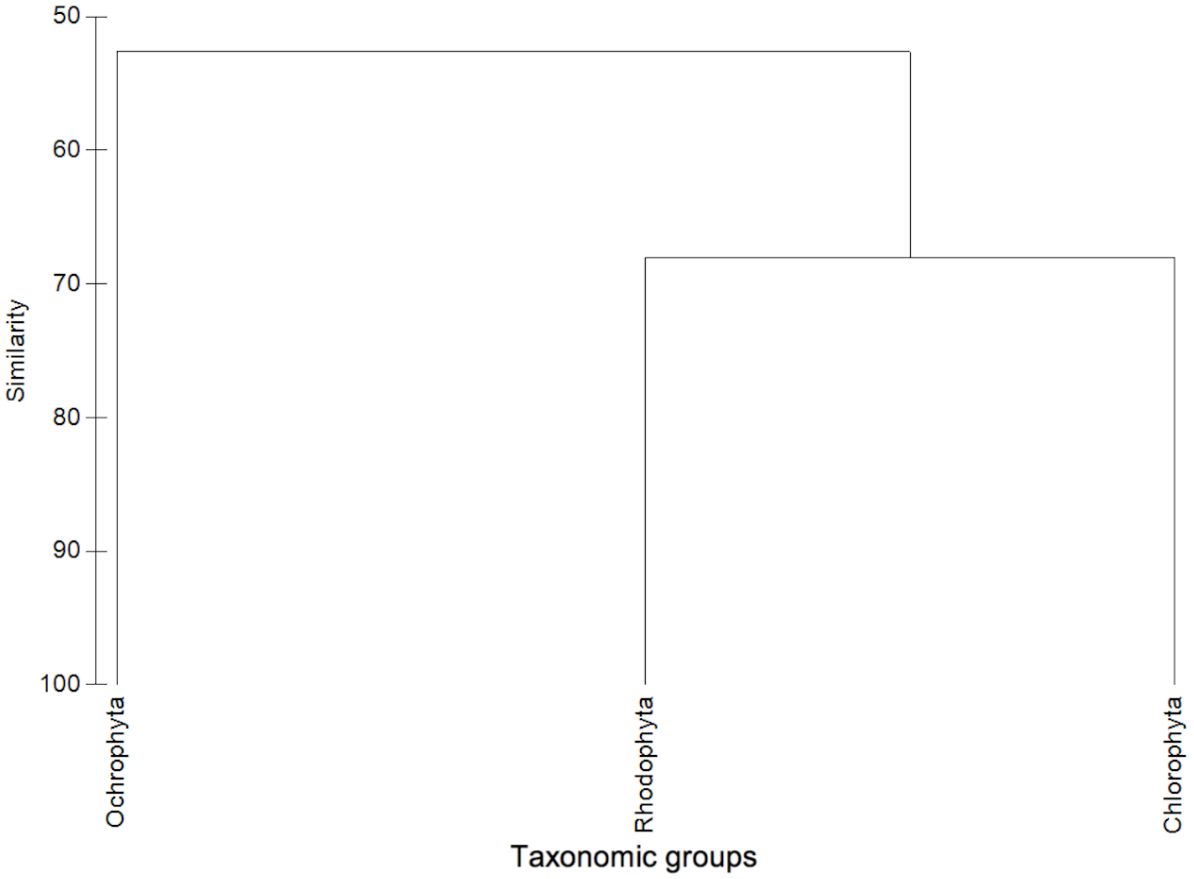


Figure 23 Hierarchical dendrogram using Bray-Curtis (B-C) similarity measure in cluster analysis. Phyla clustering at B-C >60% were considered to have species exhibiting similarity in distribution.

In terms of characterization of temporal community structure, the distribution in terms of species composition and abundance during October, 2018 was distinct from that of the following three months at a Bray-Curtis similarity of 60% (Figure 24). From the species density plot, it was observed that *Hydropuntia dentata* was in high abundance in November and December, 2018 and January, 2019 compared to October, 2018 (see Figure 11)

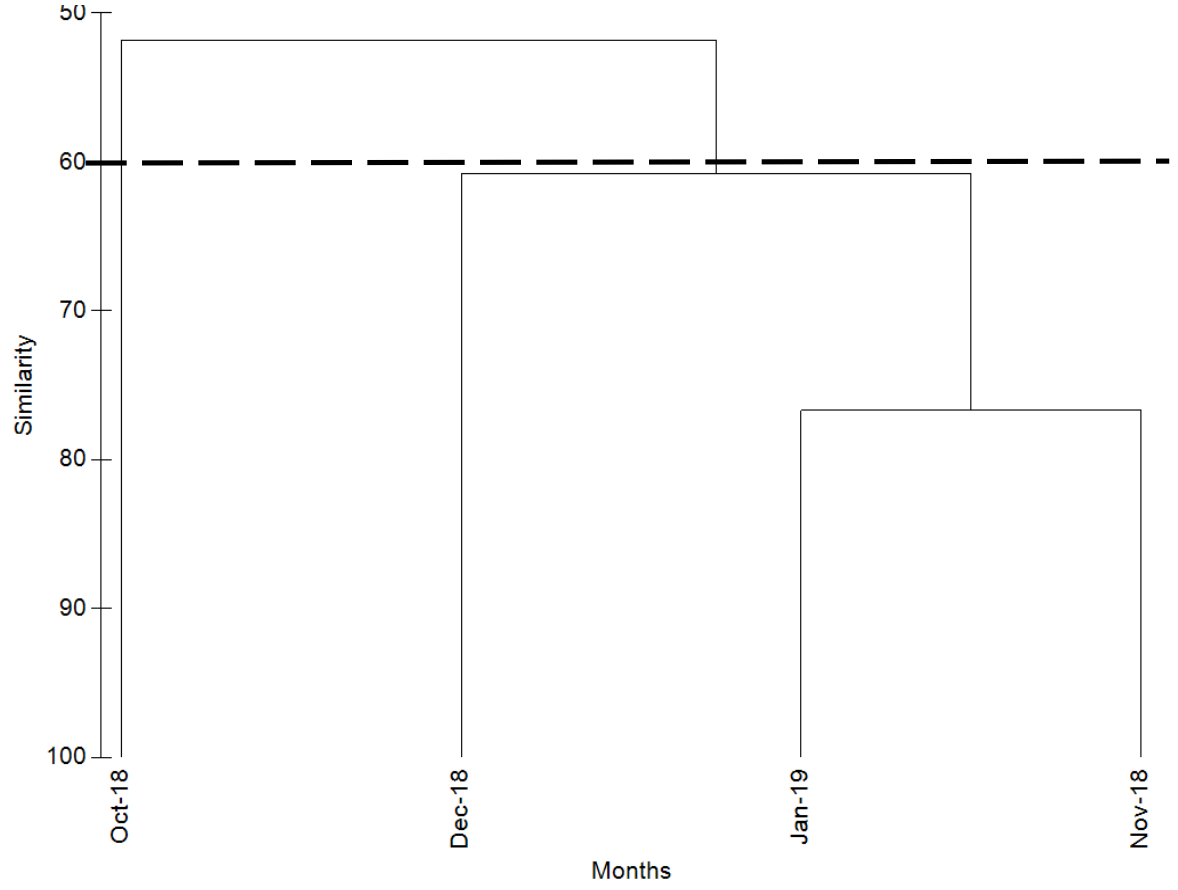


Figure 24 Short-term temporal distribution pattern of marine macro algae in Ghana. Communities clustering at Bray-Curtis (B-C) similarity measure >60% were considered to exhibit similarity in community structure.

Investigation of spatial pattern in the distribution of macroalgae between the sampling locations, based on cluster analysis, showed six distinct communities at Bray-Curtis similarity of 60% - i.e. Group 1 (Dixcove); Group 2 (Next Door); Group 3 (Takoradi, Christianborg Castle, Prampram); Group 4 (Kokrobite, Aminano, Old Ningo); Group 5 (Mumford); and Group 6 (Tema) (Figure 25).

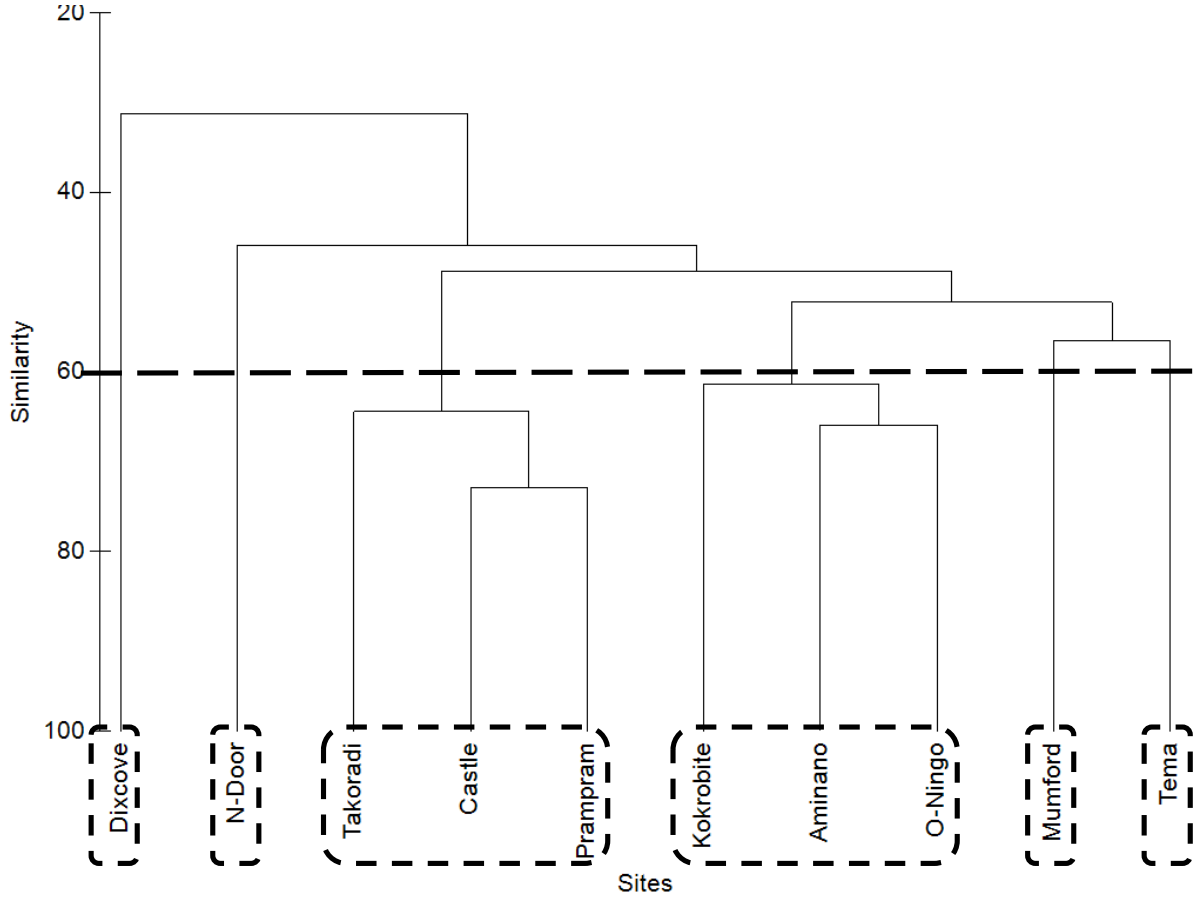


Figure 25 Hierarchical dendrogram using Bray-Curtis (B-C) similarity measure in cluster analysis between sampling locations. Six clusters (i.e. locations with similar community structures) were identified at B-C >60%.

The Similarity Percentages (SIMPER) test carried out on the transformed and standardised data, extracted species that contributed significantly to the threshold Bray-Curtis similarity at each sampling location. It was noted that *U. fasciata* was the only species that was represented among the key species contributing to the observed pattern in all the six community structures identified in Figure 25, and especially contributed the highest similarity at Old Ningo (Table 3). The next species of importance was *H. dentata* which was a key species at all the locations with the exception of Group 1 (Dixcove) and Group 2 (Next Door).

Table 3 Results of Similarity Percentages (SIMPER) analysis showing contribution of key macroalgal species to Bray-Curtis similarity at each sampling location.

Species	Group 1	Group 2	Group 3			Group 4			Group 5	Group 6
	Dixcove	Next Door	Takoradi	Castle	Prampram	Aminano	Kokrobite	Old Ningo	Mumford	Tema
Caulerpa taxifolia	19.6			1.8	3.9					
Centroceras clavulatum						3.3				
Chaetomorpha linum		1.4	6.3		2.2					
Gelidium conium			1.0	2.4	1.2					
Gigartina acicularis						2.1				
Hydropuntia dentata			4.1	16.0	7.9	17.1	22.5	19.8	2.0	2.4
Hypnea musciformis						10.4	4.3			2.4
Lithothamnion bisporum		2.2					3.5		1.1	
Padina durvillaei									2.8	
Ralfsia expansa		9.4	1.6							
Ulva fasciata	12.0	9.9	4.5	4.7	7.3	9.3	5.5	20.5	15.3	15.2
Ulva flexuosa			1.5	3.3	1.1				6.2	
Ulva lactuca	2.7									7.5

Analysis of Similarity (ANOSIM) routine was performed in PRIMER software using square root transformed data to ascertain the level of significance in the macroalgal community structure between the 10 sampling locations. The global similarity index (R) was significant at 28% (a = 0.002) for 999 permutations. Although this level of similarity is not so strong, it provides some evidence to support the similarity in community structure between locations based on beach morphology.

In order to determine whether there was any zonation in the distribution of macroalgae within the intertidal zone, three horizontal zones were demarcated at each sampling location as supra-littoral, mid-littoral and sub-littoral. Analysis using multidimensional scaling with extraction of principal components was used in determining if there was any relationship between percentage cover of the taxonomic groups and respective zonation. The results showed that chlorophytes and ochrophytes were predominant at the supra- to mid-littoral zones, whiles the rhodophytes occurred at the mid- to sub-littoral zones (Figure 26). The global similarity index (R) from ANOSIM was significant at 22.6% (a = 0.00) for 999 permutations.

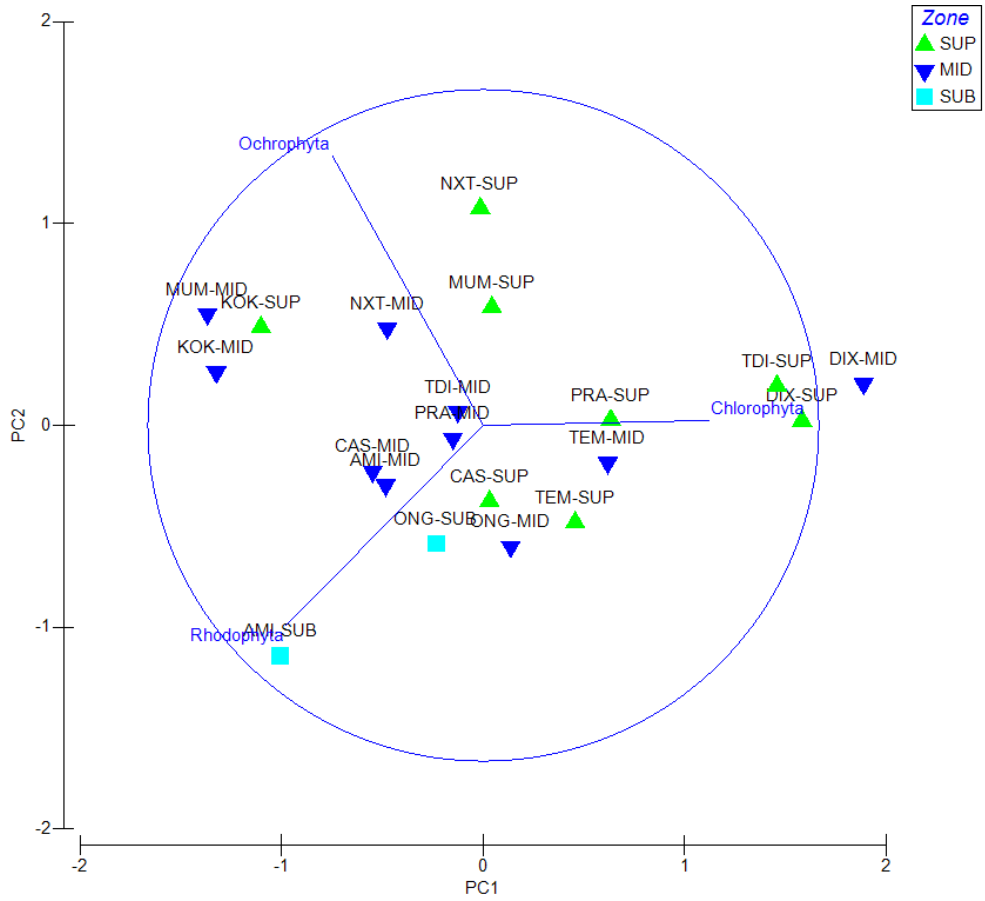


Figure 26 Multidimensional scaling for the 10 sampling locations based on horizontal zonation mapped from Bray-Curtis similarities on 4th root transformed abundances and superimposed with taxonomic groups (see list of acronyms)

From the SIMPER analysis to determine the species contributing to the observed zonation pattern, *Ulva fasciata and Hydropuntia dentata* were identified as key species at supra-, mid- and sub-littoral zones (Figure 27).

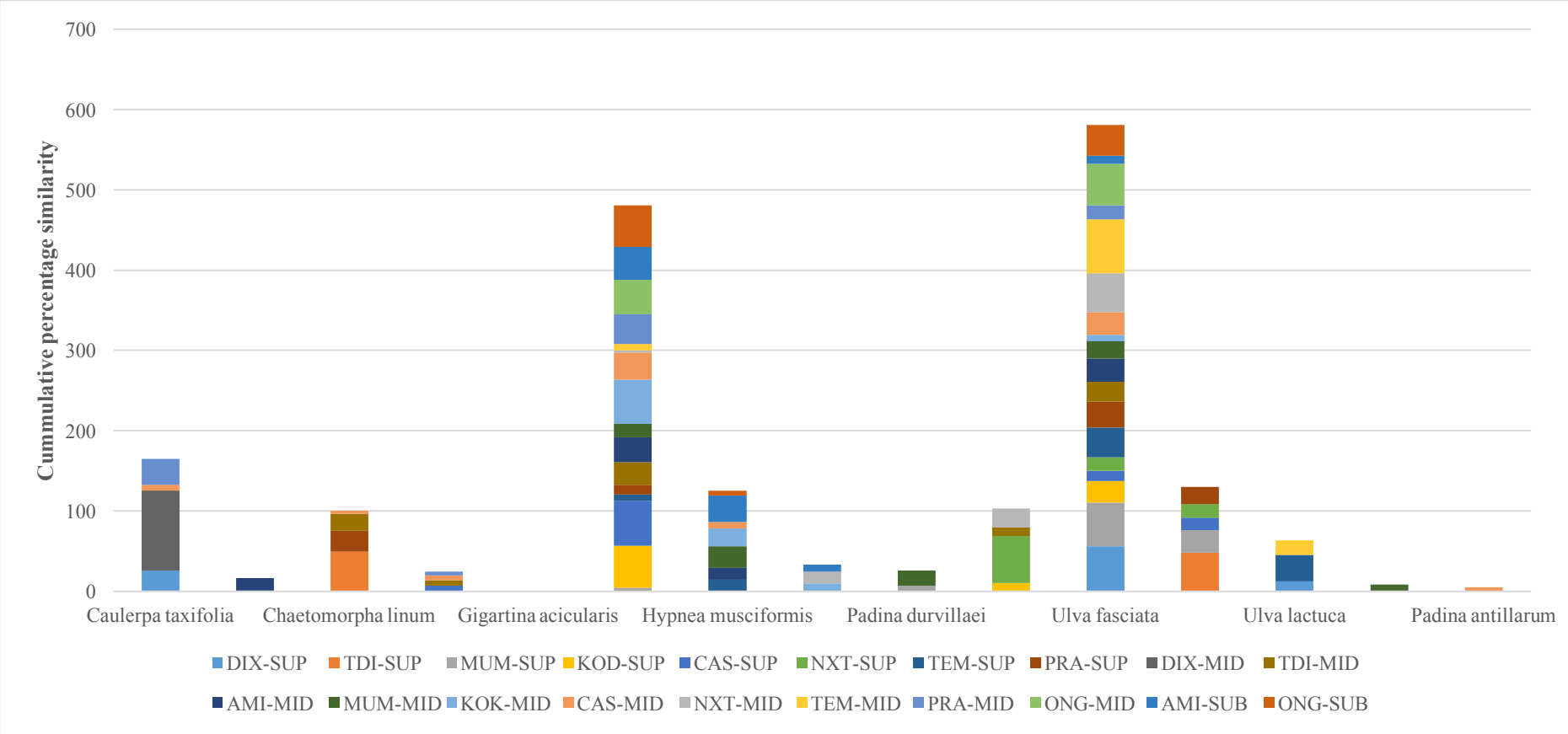
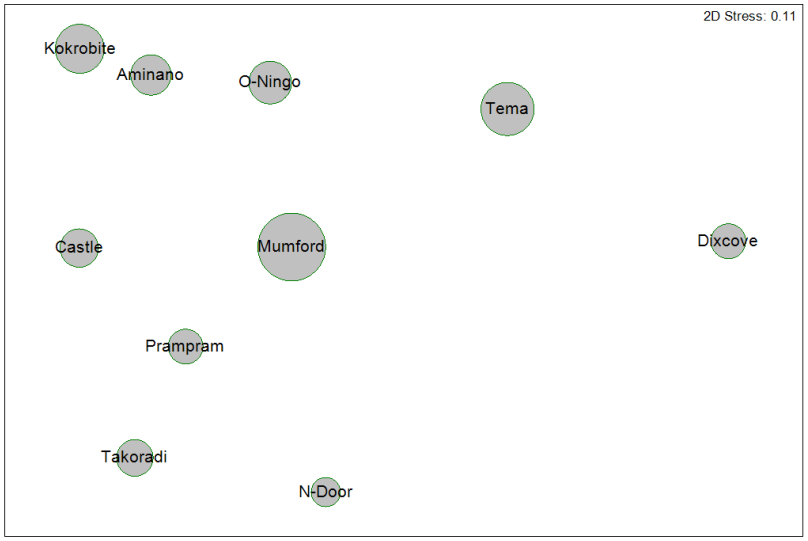


Figure 27 Figure 27 Plot of Similarity Percentages (SIMPER) of each species contribution to zonational pattern at the intertidal zone (supra-,mid-, and sub-littoral zones). (see list of acronyms)

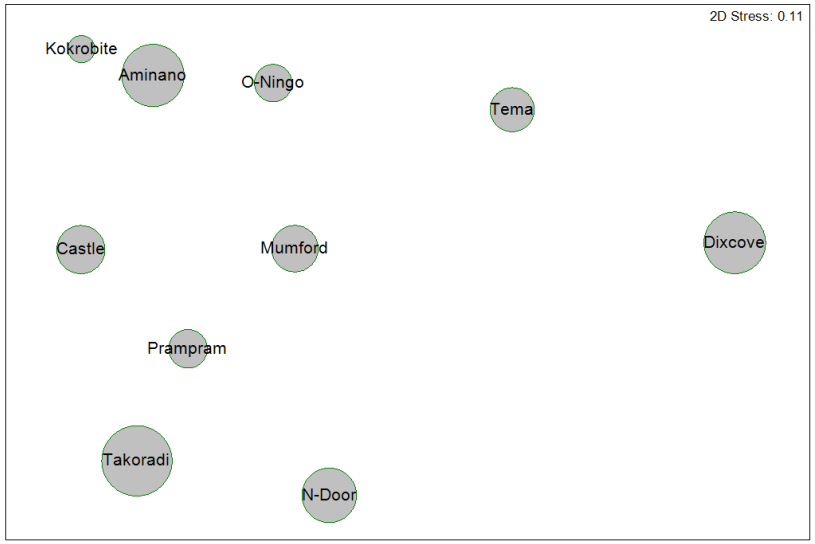
4.6 Effect of nutrients on species distribution

Water quality analysis with respect to 5 nutrients (phosphate, nitrate, ammonia, silicate, and sulphate), was carried out to determine the effect of these nutrients on the spatial distribution of the macroalgae. These nutrients generally showed variable concentrations at all the sampling locations, as shown from a non-metric multidimensional scaling (MDS) superimposed with bubble plot of the nutrient concentration (Figure 28). The stress values of all the MDS plots were below the acceptable 0.2 threshold (Clarke and Warwick, 2001).

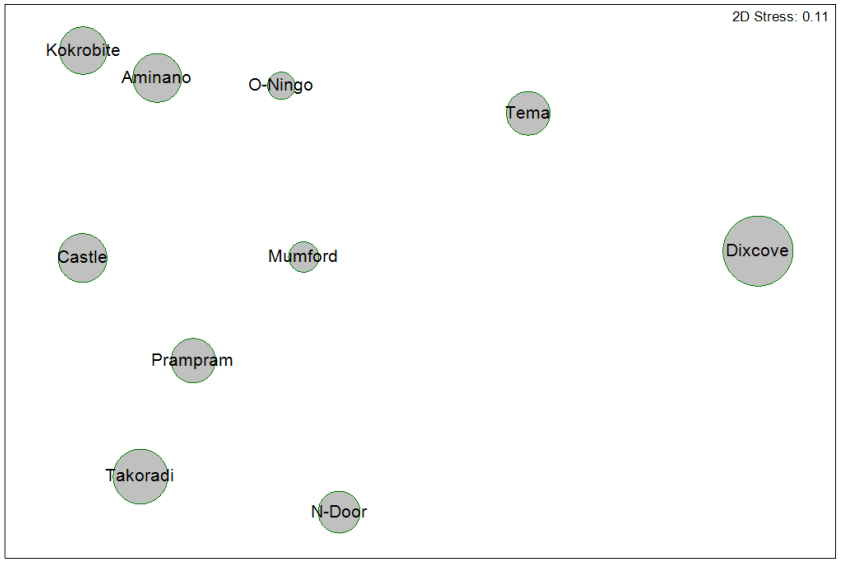
Silicate



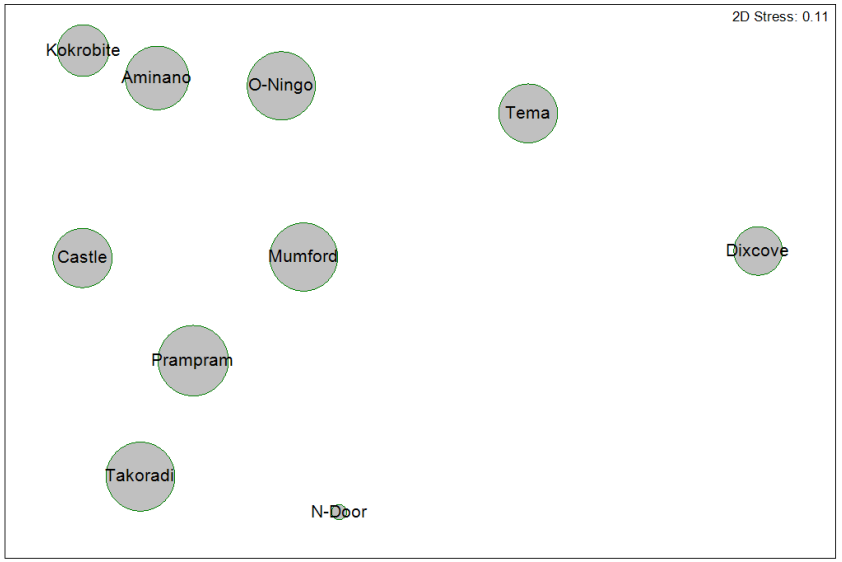
Ammonia



Phosphate



Sulphate



Nitrate

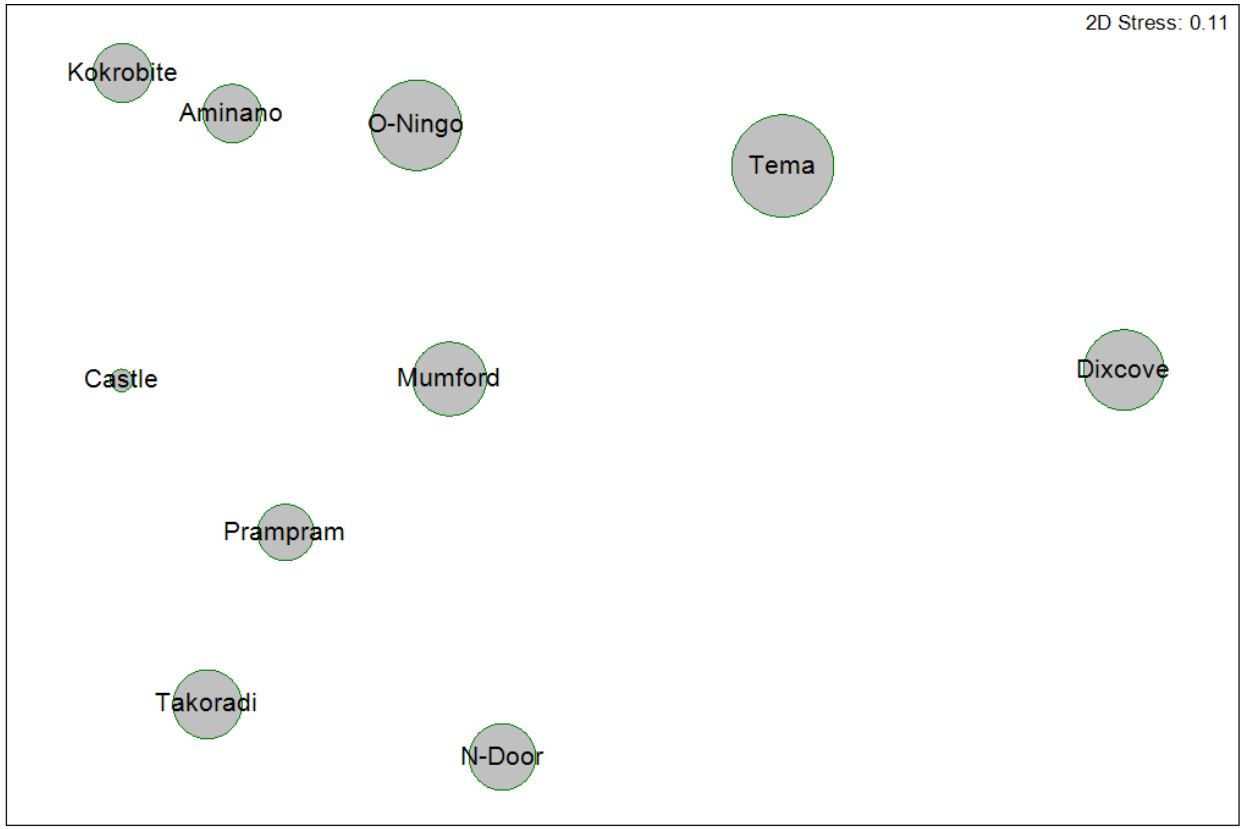


Figure 28 non-metric multidimensional scaling (MDS) of species abundances at the 10 sampling locations with superimposed circles of increasing size, which represent increasing concentrations of phosphate, nitrate, ammonia, silicate, and sulphate. (x-axis and y-axis are Principal Component 1 and 2, respectively)

From a one-way analysis of variance (ANOVA), with a post hoc Tukey HSD multiple comparison analysis between the sampling locations, it was found out that nutrient concentrations were significantly different between some locations (Table 4). At Kokrobite, Next Door and Old Ningo, the nutrient levels were significantly different compared to all the other locations (Table 4).

Using the water quality parameters to define ecological zones, it is possible to characterize a West and East zonation with respect to the sampling locations (Figure 29). The West ecozone comprise of Discove, Takoradi, Aminano, Mumford and Kokrobite, whiles the East ecozone comprise of Christianborg Castle, Next Door, Tema, Prampram and Old Ningo. The concentration of phosphate and ammonia showed an increasing trend westward. However, the concentration of sulphate decreased westward (see Figures 28 and 29).

Table 4 Comparison of nutrient concentrations (ammonia, phosphate, nitrate, silicate and sulphate) between the 10 sampling locations using one-way ANOVA at $a < 0.05$), with a post hoc Tukey HSD multiple comparison analysis between the sampling locations (see Figure 28 for concentration levels per sampling location)

No significance at a<0.05	Dixcove	Takoradi	Aminano	Mumford	Kokrobite	C. Castle	Next Door	Tema	Prampram
Takoradi									
Aminano	Ammonia								
Mumford		Sulphate	Sulphate						
Kokrobite	Sulphate		Nitrate						
C. Castle			Phosphate Sulphate	Nitrate					
Next Door									
Tema						Sulphate			
Prampram	Silicate	Sulphate		Sulphate				Phosphate	
Old Ningo		Sulphate		Sulphate					Nitrate Sulphate

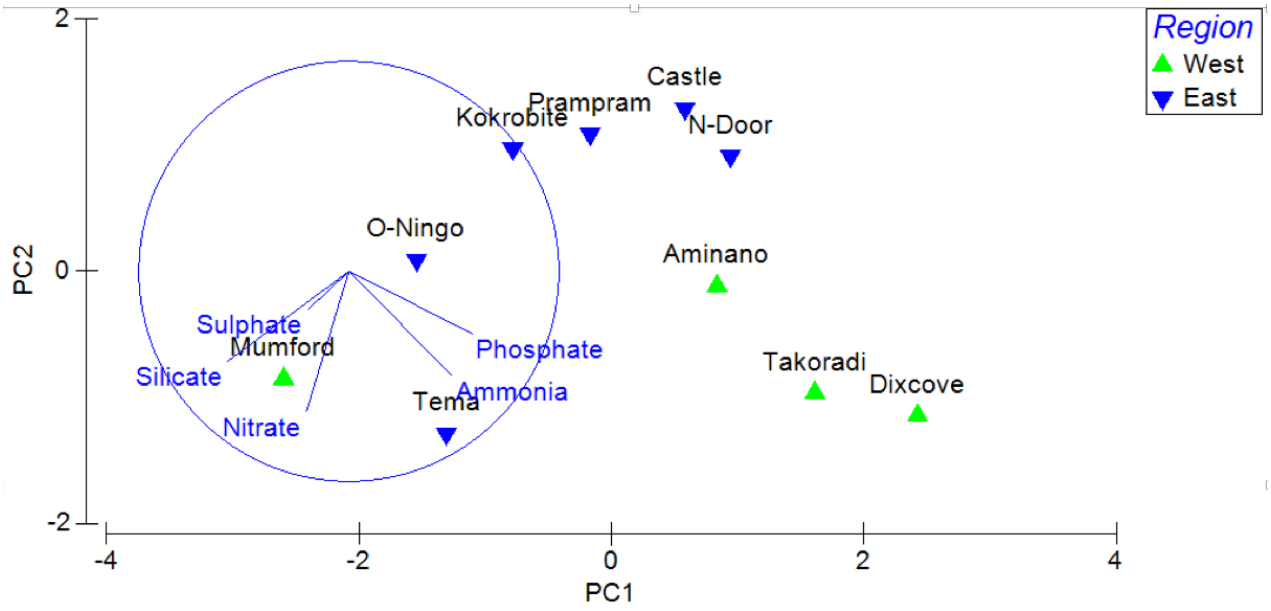


Figure 29 Multidimensional scaling for the 10 sampling locations based on nutrient concentrations

The effect of nutrients on macroalgal spatial distribution was determined from a BIOENV analysis in PRIMER. The results did show any significant effect of the water quality parameters measured on the biota (Rho = 0.315; $\alpha = 0.73$). Thus, this study could not provide any evidence of influence of any of the nutrients (i.e. phosphate, nitrate, ammonia, silicate and sulphate) on macroalgal spatial distribution during the sampling period, indicating that there were other factors other the nutrients in structuring the communities.

CHAPTER 5

DISCUSSION

5.1. Species diversity.

Characterization of biological communities is an important process in understanding the drivers governing species distributions (Parmesan, 2006; Peterson, 2003). This could go as far as helping to predict the nature of disturbance of an environment (Montesinos-Navarro et al., 2018; Littler and Littler, 1984). In this study, a total of forty-one (41) macroalgal species assemblages, identified within the intertidal region of the coast of Ghana, revealed ten (10) species which could be considered as keystone species (Miller and Spoolman, 2009), which influenced the community structure based on their abundances and distribution pattern. These keystone species were *Ulva fasciata, Ulva flexuosa, Ulva lactuca, Ralfsia expansa, Lithothamnion bisporum, Hydropuntia dentata, Hypnea musciformis, Centroceras clavulatum, Chaetomorpha linum* and *Caulerpa taxifolia*. Of these ten species, *U. fasciata* and *H. musciformis* were considered the most dominant in terms of their abundances on spatial and temporal scales, and thus could be considered as keystone species.

5.2. Species distribution pattern and community structure

The results obtained basically suggests a strong mixed pattern of distribution of the macroalgae species from the west to east coasts of Ghana. Both vertical and horizontal zonation confer strong changes on the macroalgal community structure, between the sampling locations, where some species thrive and others decline in cover or are absent. Fine-scale horizontal variation in species assemblages is a common feature of marine benthic habitats. Actually, from East to West of Ghana,

it has been found out that broad latitudinal gradient can be linked with the decreasing wave-exposure, as well as with changes in ocean climate (Lawson, 1957). Potential processes responsible for variability in benthic macroalgal assemblages include differences in the substrate, predation, competition, wave action, exposure, temperature or availability of nutrient (e.g. Benedetti-Cecchi, 2001; Coleman, 2003). However, broad-scale processes can further generate geographical patterns in the community structure.

Approaches at the species level to detect change are expensive because they are labour intensive and require high taxonomic expertise. According to Littler and Littler (1980) such changes may have prevailing effect on entire assemblages. In addition, taxonomic group assumption can provide wide insight into the structure of the community (Roberts and Connell, 2008), while these approaches may indicate a loss of sensitivity in detecting changes along environmental gradients compared to approaches at the species level (Phillips et al., 1997; Padilla and Allen, 2000). Nevertheless, as the findings show, both taxonomic groups and beach type were useful in extrapolating patterns in assemblies where some groups emerge at the detriment of others along latitude. That is, the species-level patterns recorded changed from site to site along the Ghanaian coast to represent the changing patterns of both taxonomic groups and beach types.

The observed trends could be especially useful as baseline data for future investigation where changes in such patterns could be useful as early warning proxy approaches to detect changes in environmental impact. Since each species can easily be designated to such reduced grouping categories, these proxies (taxonomic groups and/or beach type approaches) can significantly shorten the time and resources required for monitoring large geographic locations. As the global distribution of macroalgal species changes, such techniques may allow comparisons to be made

between regions elsewhere with different species sets, which could in effect enhance ecological synthesis.

The distinctive West African flora's diversity is significantly lower to the south of the Equator and remains low towards the south of Africa. Three West African countries, Senegal, Ghana and Sierra Leone, could be considered as 'hot spots' with respect to algal diversity because of their rocky shores suitable for attached algae (John and Lawson, 1991).

In general, the chlorophytes were observed to be distributed along sheltered areas where there was less wave action; whereas the Ochrophyta preferred exposed beaches, since they were tolerant to wave action, and rhodophytes were observed at moderately sheltered areas. In contrast, O'Connor et al., (2011) and Bustamante et al. (1997) found that shore exposure was not a reliable predictor for spatial and temporal distribution of sessile benthic species. With regards to horizontal zonation, it was observed in this study that chlorophytes and ochrophytes were predominant at the supra- to mid-littoral zones, whiles the rhodophytes occurred at the mid- to sub-littoral zones.

Irrespective of the nature of distributional pattern, i.e. temporal or spatial, *Ulva fasciata* and *Hydropuntia dentata* were identified as two most important keystone species during the study. The former was the dominant species among the chlorophyte which represented 58% in total abundance over the sampling period. Species of the Class Ulvophyceae which are green algae constitute the main primary producers of marine and brackish ecosystems. They are represented by the genus *Ulva* which are ubiquitous in coastal benthic communities around the world (Richard et al., 2015). By their nature, *Ulva* spp. are considered very suitable in modelling because of the following reasons: (i) their development patterns can drive ecologically important events, such as increase in green tides due to eutrophication, (ii) their symbiotic growth require close association

with bacterial epiphytes, (iii) their plastic development, can explain their transition from simple to complex multicellularity and (iv) provision of extra information with regards to development of their lineage and evolution.

5.3. Effects of nutrients on species distribution

Macroalgal growth could be limited by nitrogen and phosphate (Graham et al., 2009; Gordillo, 2012), and thus affect diversity (Steneck et al., 2002; Santelices et al., 2009). However, five nutrients considered in the current study (i.e. phosphate, nitrate, ammonia, silicate and sulphate), did not show any significant effect on the macroalgal distribution. The relative concentrations of essential nutrients required for growth and reproduction has been found to be different among algal species, and studies by Felisberto et al. (2011) indicate that changes in nutrient concentrations are more readily observed in microalgae than in macroalgae. Hence, macroalgal growth might respond to long-term changes in nutrient concentration than the short term period observed for this study. Nutrient levels on the local scale influence large scale processes in the ocean (Santelices et al., 2009). Notwithstanding, there is evidence to suggest that greater nutrient loads do not increase diversity (Bustamante et al., 1995) but rather contribute to the growth and reproduction of existing species. Additionally, strong permanent upwelling in the tropics can cause a decrease in species richness (Santelices et al., 2009) by inhibiting the establishment of subordinate species from increased growth of dominant species (Reed and Foster, 1984).

The role of biological factors, besides physico-chemical, have been shown to regulate macroalgal communities. For instance, in the tropics herbivorous species which have been found to dominate (Floeter et al., 2005) can significantly reduce the biomass of macroalgae (Mumby, 2009). A defensive mechanism of producing compounds in the tropics compared to temperate regions is an

advantage to macroalgal species survival amongst tropical Chlorophyta (Hay, 1998). This mechanism is similar amongst the ochrophytes in the Northern hemisphere compared to the Southern Hemisphere because some families of ochrophytes could be subjected to high predation pressures from sea urchins (Steneck et al., 2002). The weak relationship between diversity and physical factors, typically involve non-equilibrium mechanisms, such as insufficient time for individual taxa to occupy suitable habitat or for diversification to cause organisms to inhabit available niche in a region (Wiens and Donoghue, 2004).

Diversity indices are often used as representative measures of community richness, as they incorporate both species number and relative abundance. An index may indicate the degree of complexity of community structure, and the number of species and their relative abundances are described by terms such as 'simple', 'complex', or 'dominated by one or few species'.

Species richness is often given simply as the total number of different species. Alternatively, Shannon-Wiener's index is a commonly used diversity measure which also incorporates the total number of individuals.

Community structure in this study refers to the composition and relative abundances of interacting macroalgal species populations in a sample (Giller, 1984). Cluster analysis and plot of hierarchical dendrogram enables characterization of community structure based on measure of similarity, in this case the Bray-Curtis similarity.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This study is the first to characterize the macroalgal communities in an extensive manner, sampling ten locations spread across the intertidal region of Ghana's coast.

A total of forty-one species of macroalgae belonging to 25 families and three phyla were identified from October, 2018 to January, 2019. It was observed that Chlorophyta (green algae) was the dominant phyla in terms of total percentage cover (58%), followed by Rhodophyta (red algae) and Ochrophyta (brown algae) with total percentage cover of 29% and 13 %, respectively. There was evidence to suggest the preference of habitats for these groups since chlorophytes were observed to be distributed along sheltered areas where there was less wave action; ochrophytes at exposed beaches due to their tolerance to wave action, and rhodophytes at moderately sheltered areas.

At the species level, the green and red algae, *Ulva fasciata* and *Hydropuntia dentata*, respectively, were considered as the most important of the keystone species in terms of their dominance and contribution to observed spatial and temporal patterns in community structure. These two species also influenced the community zonation within the intertidal region, from the supra-littoral to the mid-littoral to sub-littoral zones. Among the brown algae, *Ralfsia expansa*, was the only species that was comparable to the other two, in terms of abundance. Altogether, the study identified ten species as important in defining the type of community structure occurring at the coast of Ghana – namely *Ulva fasciata, Ulva flexuosa, Ulva lactuca, Hydropuntia dentata, Hypnea musciformis,*

Ralfsia expansa, Lithothamnion bisporum, Centroceras clavulatum, Chaetomorpha linum and *Caulerpa taxifolia*.

One major finding of this research was evidence of a decrease in species diversity from the east to the west coast of Ghana, based on Shannon-Wiener diversity measure (H'). Unlike species richness which reports on number of species identified within a sample, H' incorporates the total number of individuals in computing species diversity, and thus, Teshie (Next Door) recorded the highest diversity.

The ten sampling locations of this study is spread across sandy/rocky region in the west to a central predominantly rocky beach and to sandy/rocky section at the east coast of Ghana (e.g. Boateng, 2009). These sections provide variable environmental conditions and habitats for the benthic macroflora. Thus, six communities were characterized as unique along the coast, and were related to the west-east demarcation. The remaining two communities were a combination of Eastern, Central and Western "habitats", i.e. Takoradi (Western), Christianborg Castle (Central), Prampram (Eastern) together with similar community structure; and Kokrobite (Central), Aminano (Central), Old Ningo Eastern) as another group with similarity in their community structure.

The role of nutrients in influencing species diversity and abundance was determined from assessment of five water quality parameters – namely, phosphate, nitrate, ammonia, silicate and sulphate. Studies have shown that these nutrients are essential for macroalgal growth (Juneja et al., 2013). From the short-term investigation in this study, the nutrients did not have any significant influence on the spatial nor temporal distribution of the macroalgae.

6.2 Recommendation

On the basis of assessment of the marine macroalgal distribution along the coast of Ghana and the findings thereof, this study recommends the following for future studies:

- assessment of temporal variation in macroalgae diversity to provide understanding of the type of succession in this community and their nature of distribution;
- analyses of environmental factors, including nutrients, collected over medium to long-term to help explain their effect on the distribution of marine macroalgae;
- exploration of molecular techniques in the identification of species since macroalgae species enumeration is prone to mis-identification using only morphological characteristics.
- inclusion of the farthest extent of the east coast of Ghana, close to the border with Republic of Togo

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APPENDIX

Appendix A

Keystone species identified in macroalgal samples – i.e. *Ulva fasciata, Ulva flexuosa, Ulva lactuca, Hydropuntia dentata, Hypnea musciformis, Ralfsia expansa, Lithothamnion bisporum, Centroceras clavulatum, Chaetomorpha linum* and *Caulerpa taxifolia*.

Plate 2 *Ulva fasciata*

Plate 3 *Ulva flexuosa*

Plate 4 *Ulva lactuca*

Plate 5 *Ralfsia expansa*

Plate 6 *Lithothamnion bisporum*

Plate 7 *Hydropuntia dentata*

Plate 8 *Hypnea musciformis*

Plate 9 *Centroceras clavulatum*

Plate 10 *Chaetomorpha linum*

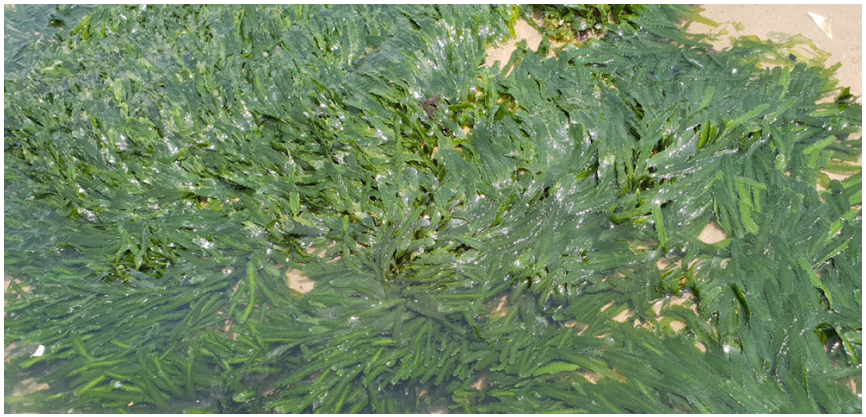
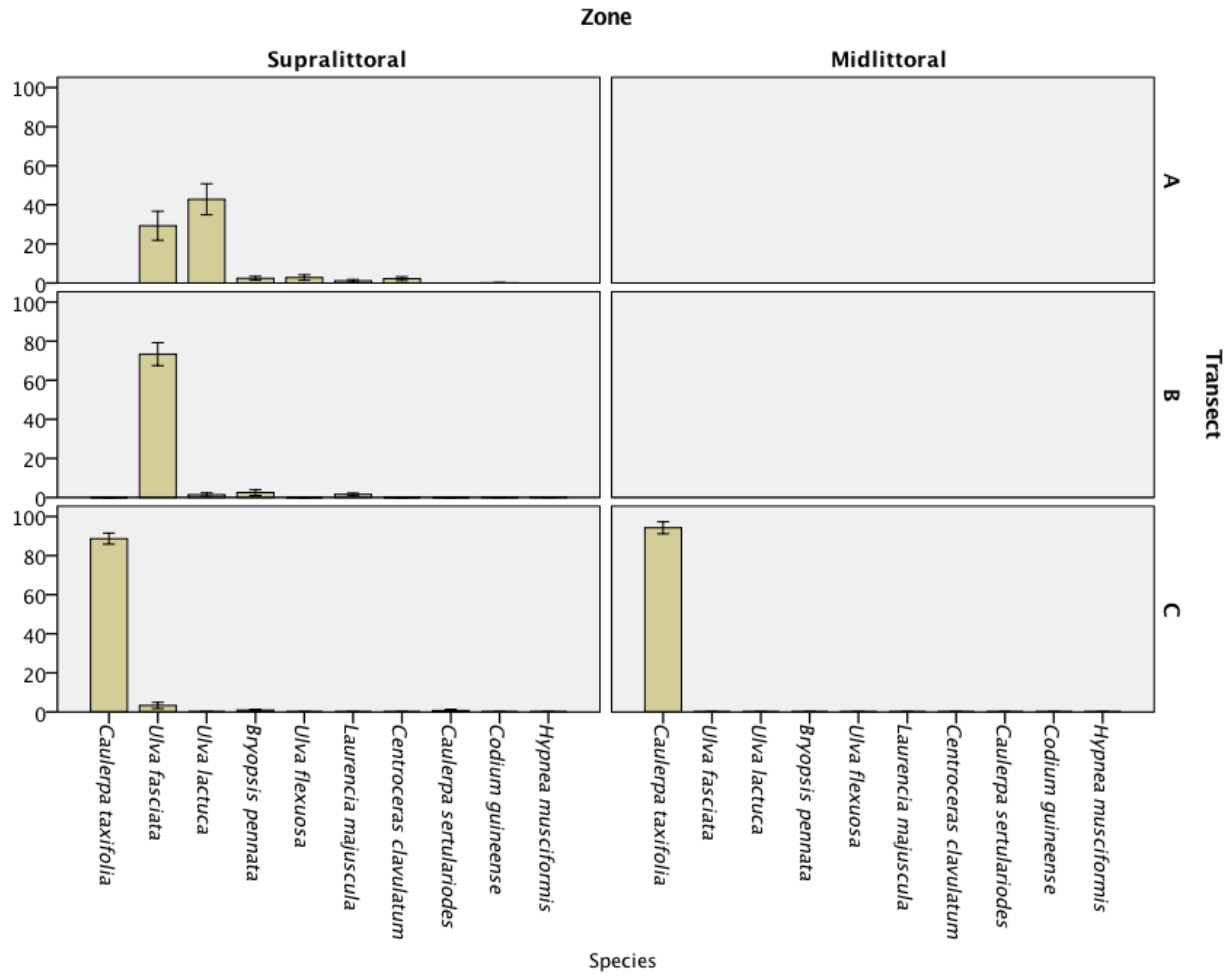


Plate 11 *Caulerpa taxifolia*

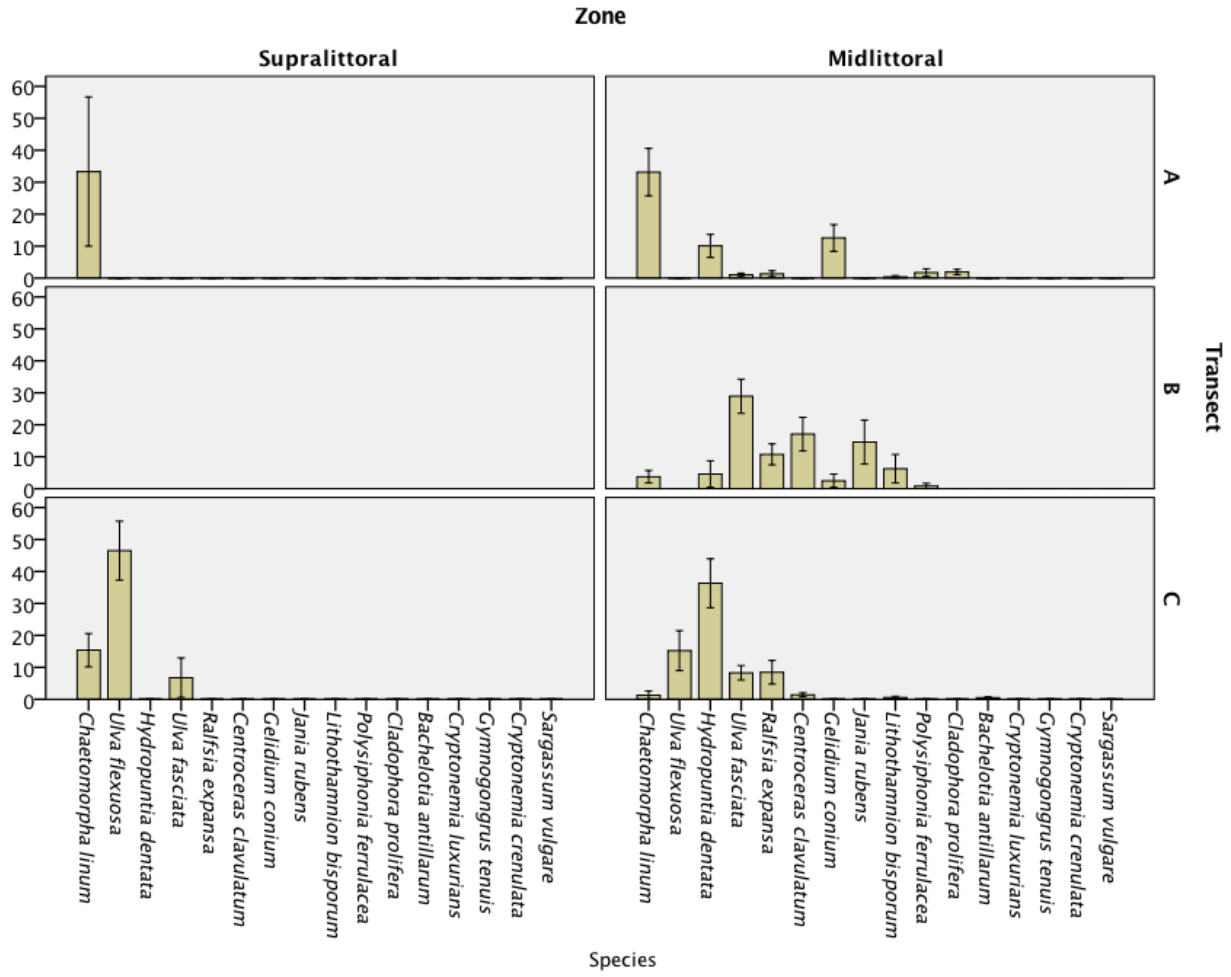
Appendix B

Distribution of macroalgal species within respective transects at each sampling locations.

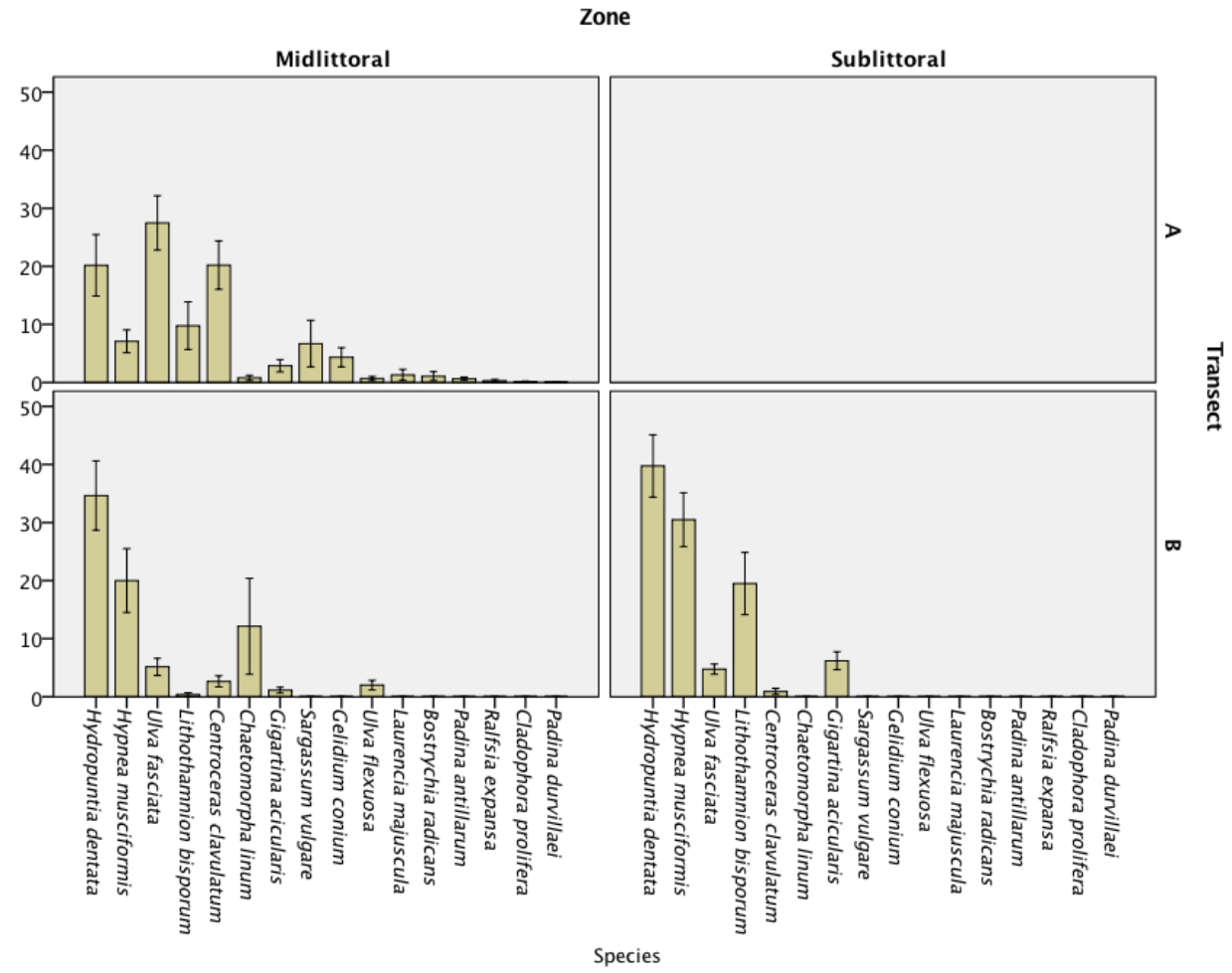
a). Dixcove



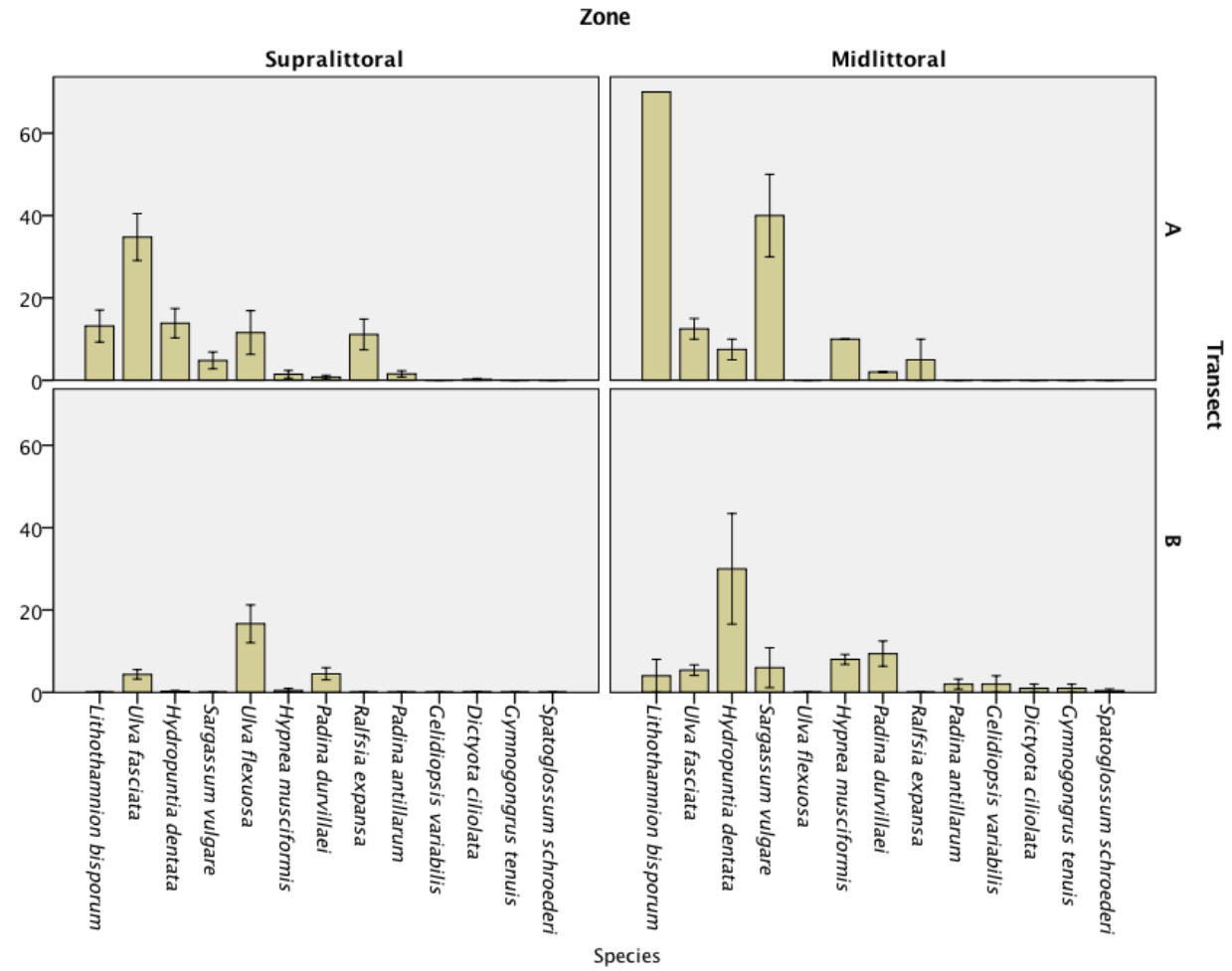
b). Takoradi


Zone
Supralittoral
Midlittoral
Transect
A
B
C
60
50
40
30
20
10
0
Chaetomorpha linum
Ulva flexuosa
Hydropuntia dentata
Ulva fasciata
Ralfsia expansa
Centroceras clavulatum
Gelidium conium
Jania rubens
Lithothamnion bisporum
Polysiphonia ferrulacea
Cladophora prolifera
Bachelotia antillarum
Cryptonemia luxurians
Gymnogongrus tenuis
Cryptonemia crenulata
Sargassum vulgare
Species

c). Aminano


Zone
Midlittoral
Sublittoral
Transect
A
B
50
40
30
20
10
0
Hydropuntia dentata
Hypnea musciformis
Ulva fasciata
Lithothamnion bisporum
Centroceras clavulatum
Chaetomorpha linum
Gigartina acicularis
Sargassum vulgare
Gelidium conium
Ulva flexuosa
Laurencia majuscula
Bostrychia radicans
Padina antillarum
Ralfsia expansa
Cladophora prolifera
Padina durvillaei
Species

d). Mumford


Zone
Supralittoral
Midlittoral
Transect
A
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60
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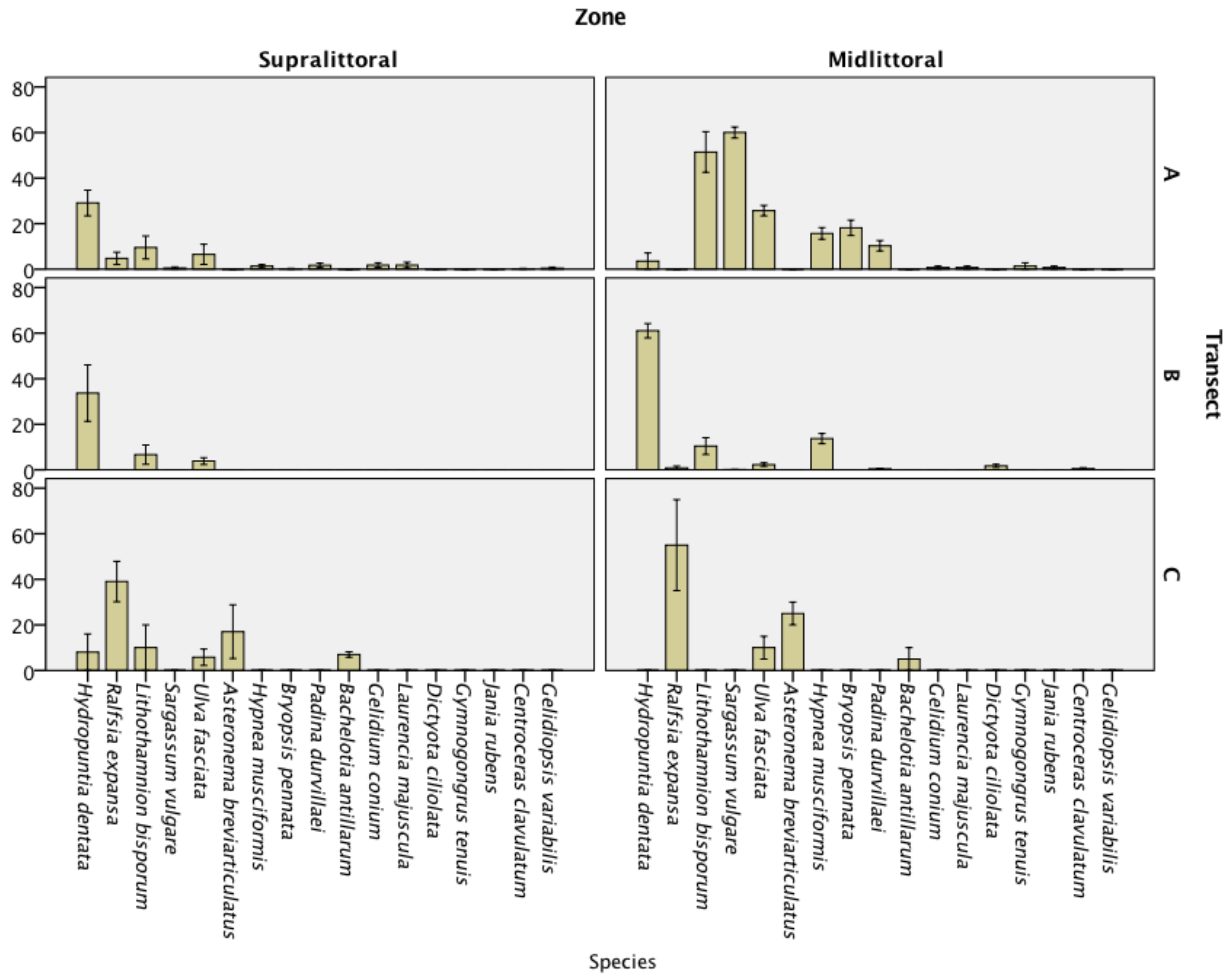
0
Lithothamnion bisporum
Ulva fasciata
Hydropuntia dentata
Sargassum vulgare
Ulva flexuosa
Hypnea musciformis
Padina durvillaei
Ralfsia expansa
Padina antillarum
Gelidiopsis variabilis
Dictyota ciliolata
Gymnogongrus tenuis
Spatoglossum schroederi
Species

e). Kokrobite


Zone
Supralittoral
Midlittoral
Transect
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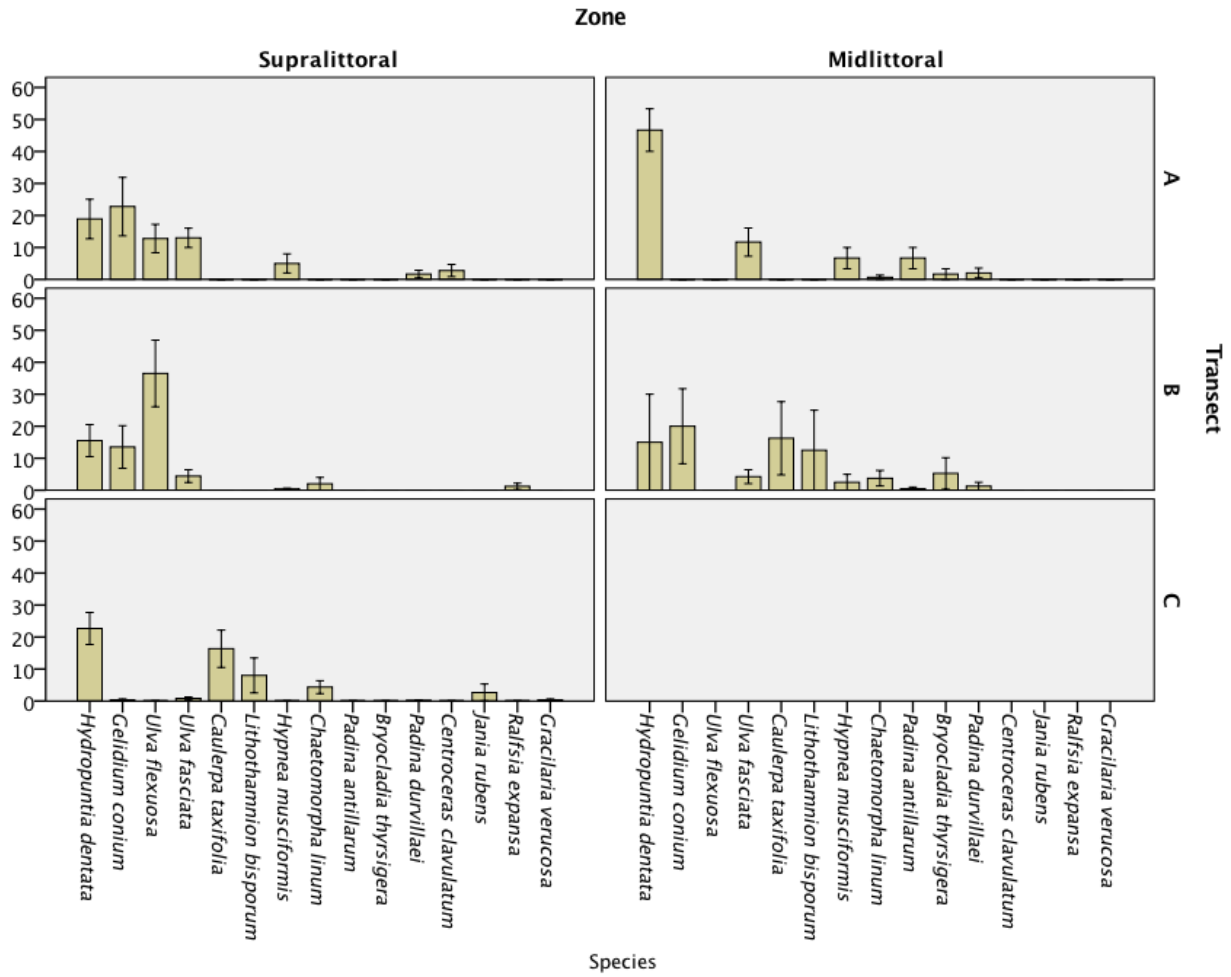
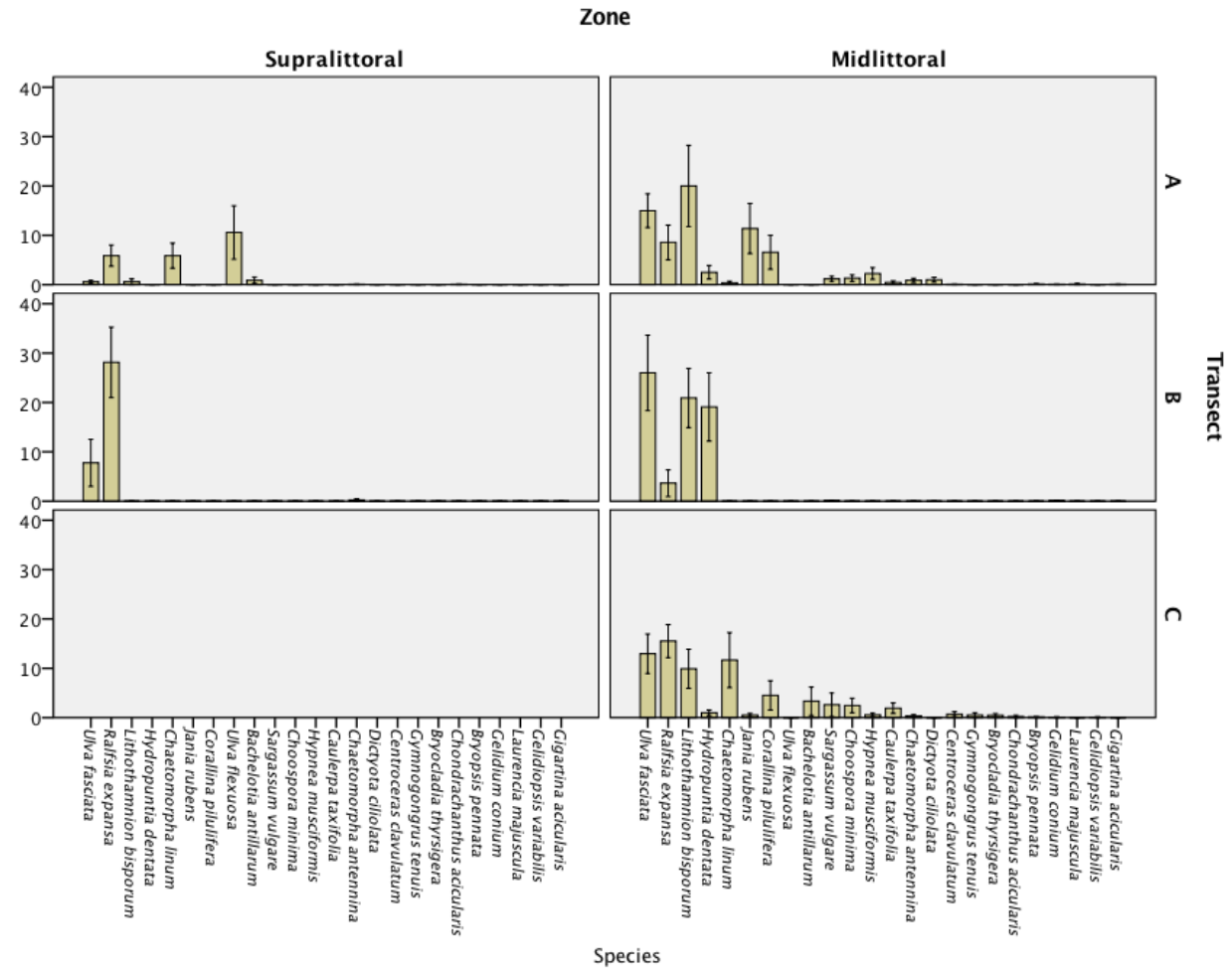
Hydropuntia dentata
Ralfsia expansa
Lithothamnion bisporum
Sargassum vulgare
Ulva fasciata
Asteronema breviarticulatus
Hypnea musciformis
Bryopsis pennata
Padina durvillaei
Bachelotia antillarum
Gelidium conium
Laurencia majuscula
Dictyota ciliolata
Gymnogongrus tenuis
Jania rubens
Centroceras clavulatum
Gelidiopsis variabilis
Species

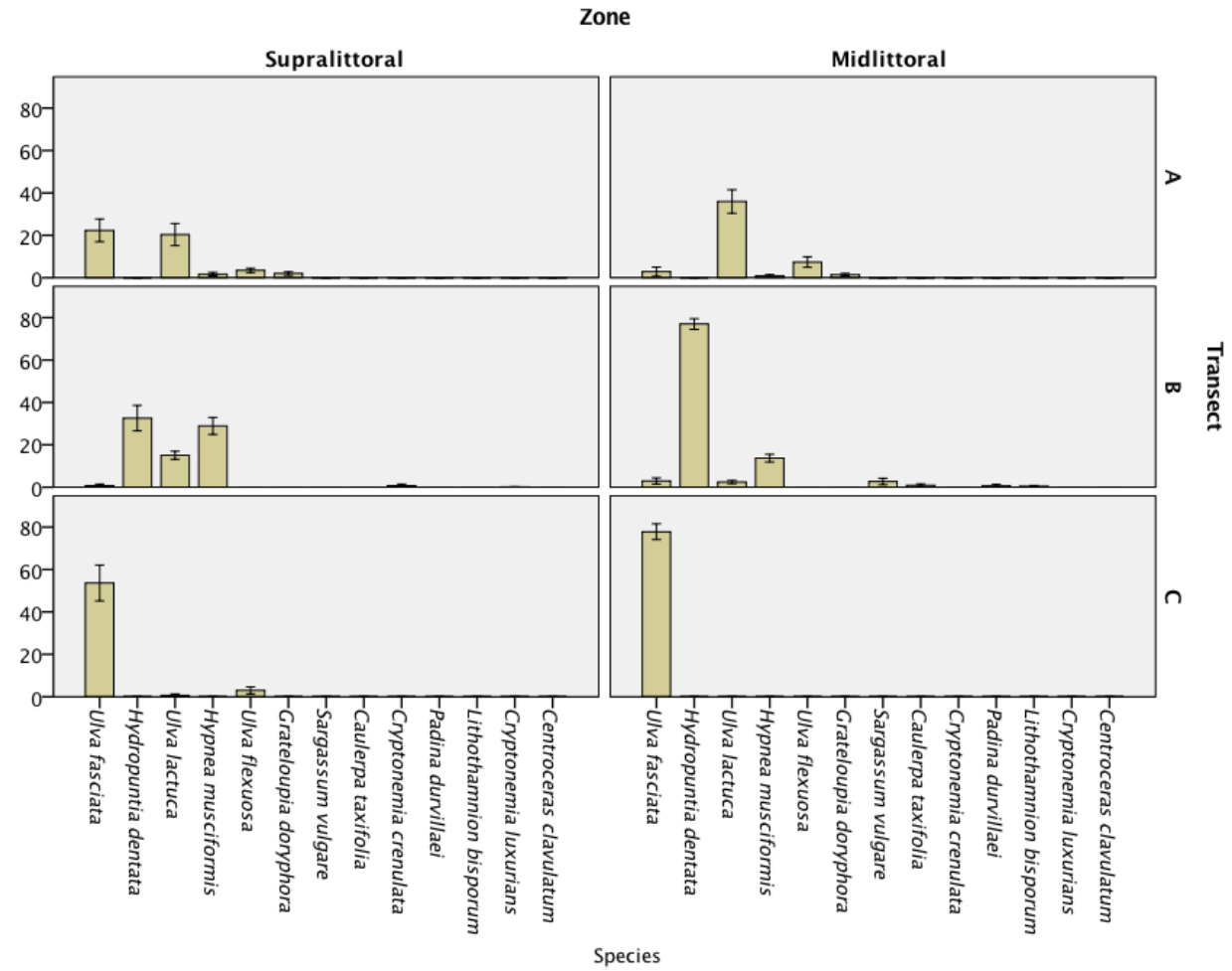
f). Christianborg Castle



g). Teshie (Next Door)



h). Tema


Zone
Supralittoral
Midlittoral
Transect
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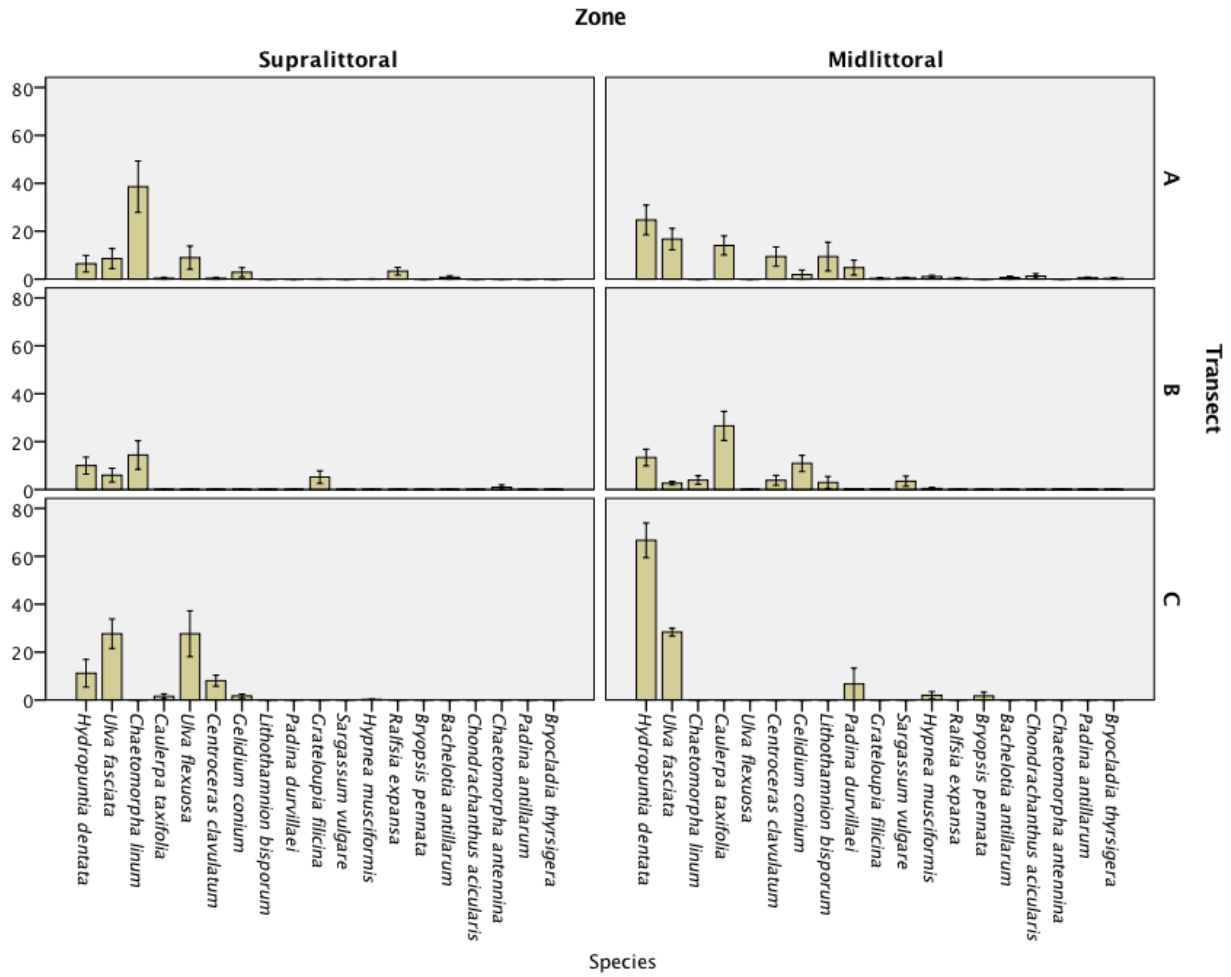
80
Ulva fasciata
Hydropuntia dentata
Ulva lactuca
Hypnea musciformis
Ulva flexuosa
Grateloupia doryphora
Sargassum vulgare
Caulerpa taxifolia
Cryptonemia crenulata
Padina durvillaei
Lithothamnion bisporum
Cryptonemia luxurians
Centroceras clavulatum
Species

i). Prampram


Zone
Supralittoral
Midlittoral
Transect
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Hydropuntia dentata
Ulva fasciata
Chaetomorpha linum
Caulerpa taxifolia
Ulva flexuosa
Centroceras clavulatum
Gelidium conium
Lithothamnion bisporum
Padina durvillaei
Grateloupia filicina
Sargassum vulgare
Hypnea musciformis
Ralfsia expansa
Bryopsis pennata
Bachelotia antillarum
Chondrachanthus acicularis
Chaetomorpha antennina
Padina antillarum
Bryocladia thyrsigera
Species

j). Old Ningo

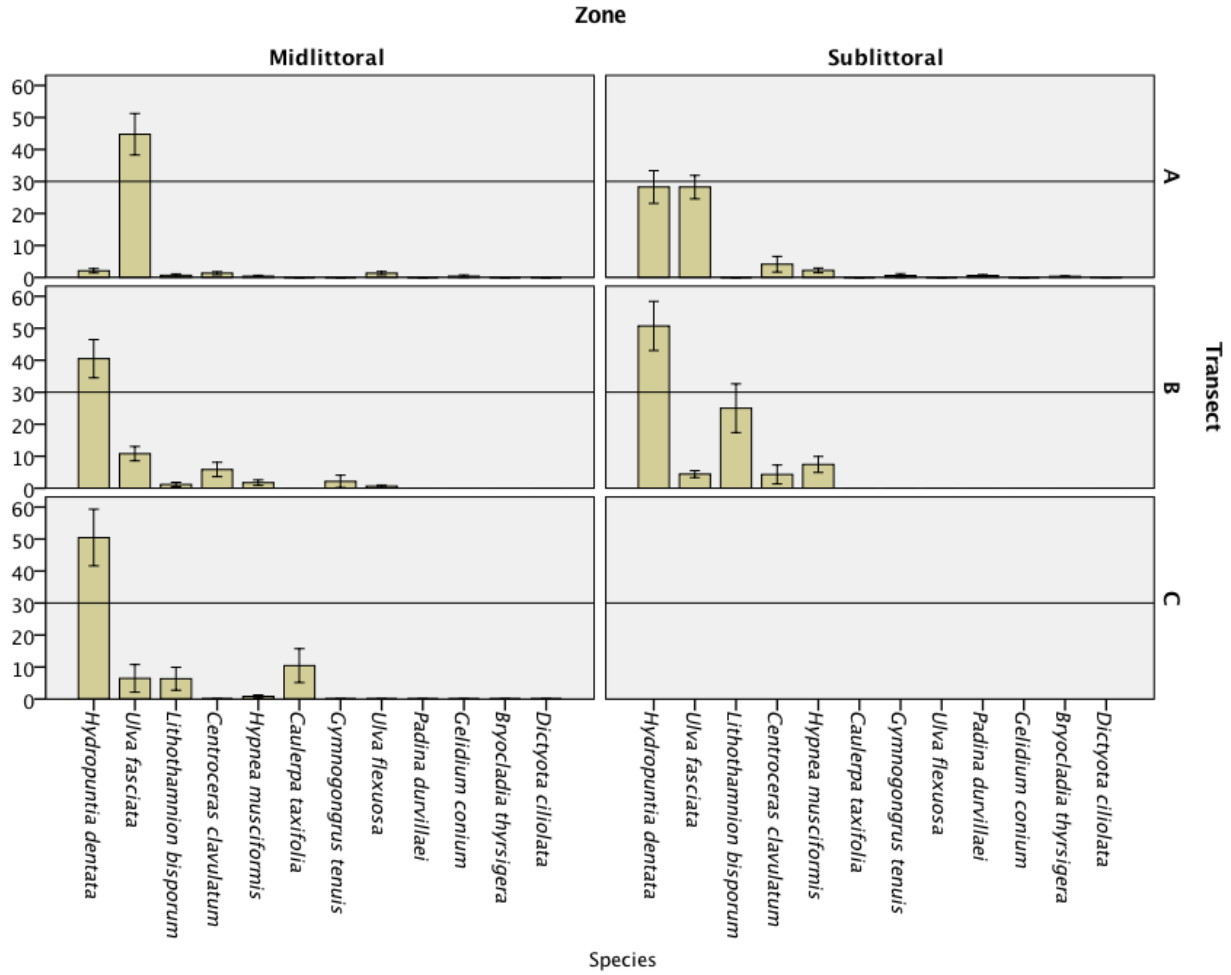

Figure 30 Horizontal distribution (supra-, mid-, sub-littoral) of macroalgal species abundance (% cover) per transect at each sampling location