CARBON SEQUESTRATION POTENTIAL OF SELECTED SEAWEEDS OF THIKKODI, KERALA

by

SARANYA M.S

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THESIS

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DECLARATION

I, Saranya M.S (2014 – 20 – 124) hereby declare that this thesis entitled **“Carbon sequestration potential of selected seaweeds of Thikkodi, Kerala”** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Vellanikkara **Saranya M.S.**

Date: **(2014– 20 – 124)**

CERTIFICATE

Certified that this thesis entitled **"Carbon sequestration potential of selected seaweeds of Thikkodi, Kerala"**is a record of research work done independently by Ms. Saranya M.S, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Calicut

Date:

Dr. Vinod, K.
(Major Advisor, Advisory Committee)
Principal Scientist, Marine
Biodiversity Division, ICAR-Central
Marine Fisheries Research Institute,
Calicut Research Centre, West Hill
(P.O.), Calicut, Kerala-673005

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Saranya M.S., a candidate for the degree of B.Sc.-M.Sc. (Integrated) Climate Change Adaptation agree that the thesis entitled **"Carbon sequestration potential of selected seaweeds of Thikkodi, Kerala"** may be submitted by Ms. Saranya M.S (2014-20-124), in partial fulfilment of the requirement for the degree.

Dr. Vinod, K.
(Major Advisor, Advisory Committee)
Principal Scientist, Marine Biodiversity Division, ICAR-Central Marine Fisheries Research Institute, Calicut Research Centre, West Hill (P.O.), Calicut, Kerala-673005

Dr. Nameer P.O.
(Member, Advisory Committee)
Special Officer, ACCER, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala- 680656

Dr. P.K.Asokan
(Member, Advisory Committee)
Principal Scientist & Scientist-in-charge, ICAR- Central Marine Fisheries Research Institute, Calicut Research Centre, West hill (P.O), Calicut, Kerala-673005

Dr. Anitha S
(Member, Advisory Committee)
Professor (Agron.), College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala-680656

(EXTERNAL EXAMINER)

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Saranya M.S

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SYMBOLS AND ABBREVATIONS

ANOVA	Analysis of variance
CDM	Clean Development Mechanism
CMFRI	Central Marine Fisheries Research Institute
EEZ	Exclusive Economic Zone
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
GPP	Gross Primary Production
ICAR	Indian Council of Agricultural Research
IPCC AR5	Inter-Governmental Panel on Climate Change 5th Assessment Report
IPCC	Inter-Governmental Panel on Climate Change
MoA	Ministry of Agriculture
NASA	National Aeronautics and Space Administration
NASEM	National Academies of Sciences, Engineering, and Medicine
NETs	Negative Emission Technologies
NGOs	Non-governmental Organizations

NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
ppt	Parts Per Thousand
PRIMER	Plymouth Routines in Multivariate Ecological Research
PUFA	Polyunsaturated fatty acids
SABs	Seaweed Aquaculture Beds
SPSS	Statistical Package for Social Sciences
SST	Sea Surface Temperature
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change

INTRODUCTION

CHAPTER 1
INTRODUCTION

The ocean covers 71% of the earth's surface and plays an important role in the global carbon cycle. The ocean is not only the largest long-term sink for carbon but also stores and redistributes carbon dioxide. The anthropogenic activities since the industrial era have rapidly increased the concentration of greenhouse gases. The increases of these heat-trapping gases lead to temperature rise which may adversely affect the climate around the globe. The concentration of carbon dioxide rise from 280 ppm to 400 ppm over the last 250 years (Bala, 2013). The changes to the climate, as a result of an increase in greenhouse gases' levels in the atmosphere may lead to changes in the ocean which may further put the coastal ecosystem into risk.

Climate change is severe and rapidly impacts the coastal ecosystem which is the largest carbon sink of our planet. The ocean is the major regulating force in the earth's climate system and rapid actions are needed to protect our coastal ecosystem. The mitigation strategies are to be carried out to reduce the greenhouse gas emission, particularly carbon. The coastal ecosystem can store and sequester carbon known as 'Blue carbon'. The coastal blue carbon includes the carbon stored and sequestered in tidal wetlands, mangroves, sea-grass meadows, kelp forest etc.

According to the 2009 UNEP Blue carbon report, fifty-five percent of carbon is captured in the atmosphere by marine organisms and fifty to seventy-one per cent of that is captured by mangroves, seagrass, tidal marshes and seaweed which is 0.5% less than that of the seabed. According to Nellemann *et al*. (2009), about 114 and 328 teragrams ("Tg") of carbon per year is sequestered by vegetated habitats in a coastal region or 1.6 to 4.6% of total anthropogenic emissions (7,2000 Tg per year). In the blue carbon ecosystem majority of carbon is trapped in the soil as above and below ground biomass. Unlike, other blue carbon sectors (mangroves, seagrass and salt marshes); the kelp forests don't have such sedimentary substratum. The kelp is brown seaweed of larger size in the order Laminariales which provides a salubrious coastal environment. The carbon sequestration capacity and storage rates of the blue carbon ecosystem are high and the conservation of these ecosystems may be cost effective to mitigate climate change; particularly in the removal of atmospheric carbon-di-oxide.

India is a tropical country in South Asia with a coastline of about 8000 km, including the islands of Andaman and Nicobar and Lakshadweep. The Indian coastline has an Exclusive Economic Zone (EEZ) of 2.5 million sq.km.and consists of a variety of coastal ecosystem including estuaries, lagoons, backwaters, intertidal areas, salt marshes etc. About 8% of global biodiversity (Oza, 2005) endows the ecological and economic stability of our country. According to Sahoo *et al*. (2001), India ranks among all countries bordering the Indian Ocean ahead of Australia and South Africa in the recorded number of seaweed taxa. The intertidal and shallow subtidal water has magnificent growth of diverse seaweed on the rocky and coralline substrate of those waters.

'Seaweeds' as the name suggest is not an unwanted plant or weed. But it is an important marine ecosystem inherent with rich natural endowments. The seaweeds are accepted as foundation species or "autogenic ecosystem engineers" (Dayton, 1975). The seaweeds or benthic macroalgae are an important member in the blue carbon ecosystem which does not have tube root, stem or leaves.They are auto-trophic non-flowering plants. The thallus consists of holdfast for attachment, stipe and blade. They are mainly categorized into three classes; Chlorophyta, Rhodophyta and Phaeophyta based on the pigmentation and are known as green, red and brown algae respectively.

The seaweed utilizes carbondioxide in the atmosphere for photosynthesis and produce biomass. The solar energy is utilized for bio-fixation of carbon dioxide. They have the capacity for sequestering carbon than terrestrial counterparts (Chung *et al*., 2011). About 90% of marine plant species are algae which contribute about 40% of photosynthesis around the globe (Anderson, 1992). According to (Duarte *et al*., 2005) 2% of the sea surface is covered by macro-vegetated marine habitat and approximately 210-244 Tg/year or 50% of all carbon is sequestered in the global coastal oceans.

The seaweeds are ecologically important primary producers of the coastal ecosystem which acts as ecosystem engineers. The marine macroalgae represent a sink for anthropogenic carbon emissions. The macroalgae are of paramount importance for reducing carbondioxide emissions thereby reducing climate change. The photosynthetic macroalgae have potential to reduce the release of carbon dioxide in the atmosphere by sequestering carbon in sediments and to produce biomass. The rates of carbon sequestered by various seaweed species are different and in some species the increased carbon dioxide concentration may also increase the photosynthetic ability.

The estimation of the carbon sequestration potential of seaweeds would be beneficial for climate change mitigation strategies. Such studies would lay the foundation to understand more about carbon sequestration by coastal ecosystems and in developing incentives for the protection of blue carbon resources. The conservation and effective management of blue carbon is an important step for climate change mitigation. It is also pertinent to mention that these ecosystems when destroyed in any manner may result in the emission of huge amount of carbon back to the atmosphere which may accelerate the climate change. So, sustainable development of the coastal ecosystem is of utmost importance in preserving the biological diversity.

The present study was envisaged to estimate the carbon sequestration potential of selected species of seaweeds found along the Thikkodi coast of Kerala. The study was also intended to understand the distribution and diversity of seaweeds along Thikkodi. The seasonal variation is species diversity and abundance was studied for one year. The carbon sequestration potential of selected seaweeds was evaluated based on laboratory experiments. The results of the present study will be helpful for the planning and implementation processes of policy and management of coastal ecosystems for climate change mitigation.

REVIEW OF LITERATURE

CHAPTER 2
REVIEW OF LITERATURE

A study was conducted along the coast of Thikkodi in Kozhikode district of Kerala to access the carbon sequestration potential of selected species of seaweeds. The assessment of seasonal variation and abundance of seaweeds were also studied. The carbon sequestration potential of different seaweeds was studied, as a strategy for climate change mitigation. The results of the study would be beneficial for the planning and implementation process of the policy and management of coastal carbon ecosystem for climate change. Earlier studies conducted on these aspects are reviewed in this chapter.

2.1. Carbon sequestration

According to Chung *et al*. (2011), carbon sequestration is connected with the provision of an equitable climate in an ecosystem service. The coastal habitats have a greater potential to store carbon and they play a vital role in regulating both local and global climate (Nellemann *et al.*, 2009). Pendleton *et al*. (2012), evaluated that 0.15 -1.02 Pg (billions tons) of CO_2 is released annually by converting the vegetated coastal ecosystem resulting in economic damage of $US 6-42 billion annually. The conversion or degradation may result in the decline of the carbon sequestration potential of the ecosystem.

The National Academics published 'Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration' in 2015 which describes Negative Emission Technologies (NETs) that removes the atmospheric carbon and sequester it. They initially accessed NETs and sequestration technologies. The IPCC Fifth Assessment Report (2014), projected high cost for the reduction of carbondioxide concentration in the atmosphere and extends $1,000 per ton of carbon dioxide emissions by 2100. The natural sinks of carbon in atmosphere are land and ocean. The land sink growth is by two primary causes: CO_2 fertilization of plants that may enhance the photosynthetic rate and cause gain of carbon mass in terrestrial ecosystems, and regrowth of forest following abandonment in agriculture in few locations (Pan *et al*., 2011). In the ocean, the sinking is caused both by the physical dissolution of carbon dioxide in the atmosphere and by uptake of carbon by phytoplankton (Sarmiento and Griber, 2002). The NETs effect on ocean and land sinks for the future intake of carbon was divided into two separate pools based on time scales for carbon retention.Some sinks reach equilibrium quickly with the atmosphere, whereas other sustain and remove carbon dioxide in the atmosphere over the next 10,000 years.In land, sink is short-lived and rapidly decomposed and it quickly reaches equilibrium with the atmosphere. The accumulation of carbon in the Deep Ocean has a residence time of ~ 1,000 years.

In 1992, the UNFCC pledge to "prevent dangerous anthropogenic interference with the climate system" and an international effort to reduce carbon emission was initiated. NET was brought in the framework of the UNFCC which covers reforestation and afforestation as a part of its Clean Development Mechanisms (UNFCC, 2013). The scientific research has ameliorated the comprehension of the concentration of greenhouse gas and the amount of warming that should cause "dangerous anthropogenic interference with the climate system" in two decades since the Kyoto Protocol.

The reports by IPCC (2012,2013) and NASEM (2016) conclude that (1) damages are already occurring due to anthropogenic climate change and will increase greenhouse gases to accumulate continuously (2) the climate system is in danger for catastrophic changes like sea-level rise from loss of majority continental ice sheet etc. The understanding of these catastrophic changes generates consent among non-governmental organization (NGOs), many scientific communities, and governments that the mean global warming should not be exceeded by 2°C above the pre-industrial level. The Cancun agreement under UNFCC committed governments to "hold increase in average global temperature below two degrees" (UNFCC, 2011). This in turn leads to the adoption of article 2 of the UNFCC Paris agreement in 2016 to limit total warming below 2°C, and with an ambitious target of 1.5°C. The 2°C target is challenging as the global mean temperature has already risen about 1°C over the 20th century (Hansen *et al*., 2011). The time lags in the climate system likely mean cycling of carbon that only two-thirds of the warming will gradually occur at current concentration greenhouse gases in atmosphere (Hansen *et al*.,2011). The current concentration of CO_2 is 407 ppm in 2017, would probably needed to remain below 450 ppm to prevent more than 2°C warming (IPCC, 2013). Article 4 of the Paris agreement states that increasing carbon dioxide in the atmosphere would cease "in the second half of the century", even though preventing the atmospheric carbon dioxide increase doesn't need that cease in anthropogenic emissions, only that they are less than or equal in the strength to carbon sinks.

2.1.2 Carbon storage by macroalgae

The macroalgae or seaweeds are rapidly growing aquatic organisms. In the temperate region including the U.S., the macroalgae occur in the largest stands as a kelp forest. In contrast with coastal wetland habitats, the macroalgae are attached to the rocky substratum and don't amass carbon in soils with extensive root systems. According to Krumhansl and Scheibling (2012), about 82% of the kelp productivity is stored as detritus. The carbon sequestration can occur only if the carbon is buried in sediments or it is transported into Deep Ocean and sequestered on long time basis. It is supposed that most of the carbon from macroalgae is return to the Global carbon cycle through herbivory and thus comprehensive study on its carbon storage rate and capacity has not been conducted (Howard *et al*., 2017). Krause-Jensen and Duarte (2016) have conducted studies of macro algal transport and it's occurrence in the Deep Ocean and a rough estimation of macro algal carbon removal potential. The study identifies the potential opportunities for sequestering carbon within algal beds, burial in the mixed ocean layer and to the deep sea. The estimated sequestration of macroalgae is 173 TgC/y, or a removal rate of 11 percent per year using an approximation of 1,521 TgC/y global Net Primary Productions in Deep Ocean.

Many uncertainties remain in valuating macroalgae as an agent of coastal carbon sink because of unknown global area coverage and the amount of carbon sequestered, Timescale of carbon storage. According to Gattuso *et al*. (2006) based on evaluating the ecosystem suitability modeling the maximum potential global area may be as high as 570 million ha. The algal transport and storage is affected by the ocean processes that are not well understood and it would give a more precise assessment of natural carbon sequestration .The carbon sequestration may also be dependent on species of seaweeds and its labiality and carbon content (Trevathan-tackett *et al*., 2015).

The restoration and conservation of kelp beds may increase the carbon sequestration in the deep oceans. However, this floating kelp is made available to the food web and the transportation and impact of which would compete with its potential to food and energy usage. According to Duarte *et al*. (2010), the seaweed aquaculture method may enhance the removal of carbon exponentially by the near surface floating seaweed beds. The seaweed culture is usually taken into account for energy or food rather than as NET (Gaitan-Espitia *et al*., 2014), which says that the warming water and ocean acidification may affect the durability of alive or restored kelp forest through a reduction in germination.

The warming of ocean waters may enhance the grazing of sea urchins (Nabuurs *et al*., 2007). According to Narayan *et al*. (2016) kelp beds give co-benefits of habitat for invertebrate, fishes, and may reduce wave energy for preserving the coastal ecosystem. The coastal ecosystems are already the targets for management and restoration which provide many ecosystem services beyond CO_2 removal,which includes wave attenuation, water quality improvement,coastal storm protection,wildlife and support fisheries (Alongi, 2011; Barbier *et al*., 2011; Lee *et al*., 2014; Nagelkerken *et al*., 2008; Zhang *et al*., 2012). Global restoration is to improve the ecosystem services of the coastal ecosystem. The Intergovernmental Panel on Climate Change GHG Inventory Guidance (IPCC, 2014) and EPA's National Greenhouse Gas Inventory (EPA,2017) as a part of international and national policy action to rein initiate process that may promote the removal of carbon dioxide and thereby reducing the Greenhouse gas burden on the atmosphere. Duarte *et al*. (2013) and Singh and Ahluwalia (2013) says that an alternative way to remove atmospheric carbon-di-oxide is sequestration of carbon by photosynthetic fixation. The long-term organic carbon can act as a crucial sink for mitigating climate change and emission of carbon dioxide (Singh and Ahluwalia, 2013).

According to Nellmann *et al*. (2009) the term 'Blue carbon' refers to carbon sinks in vegetated coastal ecosystems. McLeod *et al*. (2011) refers to blue carbon as the carbon sequestered by salt marshes, mangroves and seagrasses. But, the focus of this review, is mainly on the seaweed population on the coastal ecosystems and their ability to act as carbon sink (Duarte *et al*., 2013). The seaweed doesn't directly contribute to the carbon sequestration due to the lack of soft sediment that accretes due to organic carbon deposition (Geoscience Australia, 2010).

The carbon dioxide levels in atmospheric play a greater role in the carbon assimilation rate in terrestrial plants and a lower concentration of carbon dioxide promote higher photosynthesis (Forrester *et al*., 1996). However, the marine counterparts specifically, seaweeds show a higher rate of GPP (carbon assimilation) in higher carbon dioxide level which shows the unaltered carbon sequestering efficiency at higher carbon dioxide concentration (Kaladharan *et al*., 2009).

The global average atmospheric CO_2 concentration rose from 387 parts per million (ppm) in December 2009 (ESRL/NOAA, 2009) to 409 ppm in September 2018 (NASA, Global Climate Change, 2018). According to Raupach and Canadell (2008), the CO_2 levels are 38% above the pre-industrial value of 280 ppm. The CO_2 level reached the highest over 800000 years (Luthi *et al*., 2018).

According to IPCC (2014) reports, the anthropogenic greenhouse gas emissions in the globe during the year 2000-2010 were highest in history. The CO_2 absorbs and emits infrared radiation of wavelength 4.26μm and it is greenhouse gases which play a greater role in regulating the earth's surface temperature.

2.1.3 Importance of Seaweed Aquaculture Beds (SABs)

The vegetated coastal ecosystem, such as mangroves, seagrasses, tidal marshes are contributors to carbon storage in biomass and sequestration in sediment depositions on a long- time basis (Duarte *et al*., 2013). Murray *et al*. (2011), say that these ecosystems take the atmospheric carbon-di-oxide by photosynthesis and at the same time release oxygen to the air. The respiration and oxidation process releases carbon back into the atmosphere. The carbon sequestration in the coastal ecosystem is promoted by the standing biomass of Seaweed Aquaculture Beds (SABs) that are located in the shallow water (Mitra *et al*., 2014).

According to Littler and Murray (1974), Smith (1981) and Okuda (2008) kelps are important primary producers in the coastal environments. The kelp forest provide many ecosystem services in the coastal environments like facilitating recruitment of marine organisms (Okuda, 2008), absorption of excessive nutrients (Yang *et al*., 2006; Huo *et al*., 2012) dampening waves (Jackson 1984; Anderson *et al*., 1996, Lovas and Totum 2001), act as a buffering agent against ocean acidification (Gao and Zheng, 2010) and also act as a potential carbon sink for anthropogenic CO_2 (Hill *et al*., 2015).

The potential for SABs to catch and sequester anthropogenic CO_2 is significant (N'Yeurt *et al*., 2012; Chung *et al*., 2013). The seaweed can store a huge amount of organic carbon as above and below-ground biomass and can be used as a bioenergy crop (Jansson *et al.*, 2010). According to Nelleman *et al*. (2009) Fourqurean *et al*. (2012), salt marshes, mangroves andseagrasses capture 70% of C in marine ecosystems.

The roles of SABs in CO_2 mitigation was studied at the 5th Asian Pacific Phycological Association (APPA). The Ocean Forestry Global Plan also proposed to bring back atmospheric CO_2 to the 1960's levels by 2200(N'Yeurt *et al*., 2012). The "Ocean healing seaweed forests" play as multidimensional Global plan with political, economic, social, climatic and energy sustainability and it completely reverse global warming while feeding 10×10^9 (people with 200 kg of fish per year per person. The global Net Primary Production (NPP) is 1,521 $TgCy^{-1}$ over an estimated area is 3.5 million square meters (Duarte *et al*., 2005).

In Clean Development Mechanism, the seaweed has an important role in the capture of carbon by photosynthesis and it is a win-win mitigation strategy to promote sustainable and environmental ocean-based production (Laffoley and Grimsditch, 2009). The dominant marine algae, *Laminaria hyperborae* have annual production rates of 3 kg Cm^{-2} (Abdullah and Fredriksen, 2004). According to Turan and Neori (2010), about 0.7 million tonnes of carbon are eliminated every year by commercially harvested seaweeds. Graham *et al*. (2007) and Reed and Brzezinski (2009) calculated Net Primary Production of global kelp forests as 39 Tg C $year^{-1}$and which supplies 16-18.7% of the total marine vegetation sink. Turan and Neori (2010) suggest that a highly productive seaweed species supply an incredible account to an annual biological drawdown of carbon dioxide and the Global Carbon Cycle.

The role of a vegetated coastal ecosystem to sequester carbon led to the development of Blue Carbon and used as a mitigation strategy to climate change (Krause-Jensen *et al*.,2018). The assessments of carbon sequestration in Blue Carbon strategy have so far confined to angiosperm ecosystems like salt marshes, seagrasses and mangrove where carbon is stored as sediment accretion (Duarte *et al.*, 2013). Yet, the potential of macro algae to sequester carbon was suggested by Duarte *et al.* (2016). From 1980 to 2000, the fossil fuel combustion rates amplified by 40%. But, the carbon dioxide accumulated in the atmosphere remains the same over this period as soil, forests, oceans, and other ecosystems remove the excess carbon dioxide released. The process of transfer and secure storage of carbon dioxide from the atmosphere into long-lived C pools is called 'Carbon sequestration'. Otherwise, it may remain or emitted in the atmosphere (Rattan Lal, 2007).

Presently the total annual CO_2 emissions are about 7.4 billion tonnes, about 2 billion tonnes of carbon is sequestered by the terrestrial biosphere, whereas 2±0.8 billion tonnes per year is the net oceanic uptake of carbon. According to Suzuki (1997), 4, 60,000,000 tonnes of carbon a year, is produced by Global marine plant beds. Seigenthaler and Sarmiento (1993) suggest that it is equivalent to 23% of the amount of oceanic carbon dioxide uptake. Mann (1973) showed that some marine plants are the most productive terrestrial ecosystems. According to Denman *et al*. (2007), 7.2 ±0.3 PgC (1Pg= $(10)^{15}$ g or 1 Gigatonne) are released annually from cement production and fossil fuel burning and 1.6±1 Pg C $year^{-1}$ from deforestation, land-use changes. The oceans act as a major sink for anthropogenic carbon-di-oxide and accounts for 48% of emissions since the Industrial revolution (Sabine *et al*., 2004). Behrenfeld *et al*. (2002) estimate that 2±0.8 PgC is the annual oceanic sink for CO_2 with an additional missing sink of 1.8 Pg (which involves both oceanic and terrestrial elements of the biosphere). The atmospheric CO_2 pool increases by ~ 4.1±0.1 Pg C $year^{-1}$ despite the drawdown from abiotic and biotic activities of the oceans. The carbon-di-oxide concentration increased over the last ~200 years from 280 ppm (28 Pa) to ~385 ppm (38.5 Pa) at present and in 1800, most of the increase occuring over 100 years (Denman *et al*., 2007).

The NPP of algae, comprising macroalgae ranges from 400-1900$gCm^{-2}year^{-1}$ whereas, Gross Primary Productivity (GPP) range from 2000-5000$gCm^{-2}y^{-1}$ (Mann, 1982) and with NPP about 60% of GPP. The rooted macroalgae are source of CH_4, CO_2, and other gases through the microbial process of organic matter in sediment and direct emission from leaves (Delaune *et al*., 1990).

The carbon dioxide in seawater is 34-36 ml/l which is higher than in the atmosphere 0.3 ml/l, due to the ability of water to absorb more CO_2 than air, in equal volume (Dawes, 1981). The estimated quantity that macroalgae are capable of sequestering dissolved CO_2 is

80.5 mg/g wet weight/day while only 10 mg/g wet weight/day is the emission rate through respiration as the green and brown seaweeds can make use of the respiratory emission of carbon dioxide in the cells for photosynthesis (Kaladharan *et al*., 2009).

The macroalgae are autotrophic, which by photosynthesis produce organic matter consumed by respiration and are therefore helps in the capture of CO_2 capture in the marine ecosystem. The CO_2 capture potential of seaweed aquaculture is 2.48 million tonnes of CO_2 (0.68 TgC) per year and 27.3 million tonnes fresh weight produced in 2014 be devoted to capturing carbon with 100% yield given by the average carbon content of 24.8% dry weight of seaweeds (Duarte, 1992). By 2050, the seaweed aquaculture by wild seaweed may overshoot 6% of global CO_2 sequestration. The wild seaweed growths over the entire ocean sequester 173 $TgCyear^{-1}$ in the deep sea, and the carbon assisting this flux is produced over 3.5 million square km occupied by seaweed. The area occupied by a typical yield of seaweed aquaculture of 1,604 tonnes $DWKm^{-2}$ (The Fishery Bureau MoA, 2015) globally accounts only about 1,600 Km^2 which is 0.04% of the area covered by wild seaweed beds or around 0.004% which is 43 million Km^2 of agricultural land in 2000 (Ramankutty *et al*., 2008). The seaweed farms have sequestration potential of around 1,500 tons CO_2 $Km^{-2}year^{-1}$ which is greater than 10% of carbon dioxide emissions circumvented by offshore wind farms of around 12,500 tonnes CO_2 $Km^{-2}year^{-1}$.

Not many literatures are available on the climate change effect on macroalgae, but it may significantly report changes in the abundance and distribution of algae. Pedersen *et al.* (2008) during a 28 monthly study in the littoral zone in Long Island Sound found a remarkable change in the community structure of seaweed and connected it with the increase in seawater temperature. Simkanin *et al*. (2005), recorded changes in the sub littoral zone in the abundance of various species of seaweed by revisiting 63 locations along the coast of Ireland after a lapse of 45 years. Even though prudence was made to relate changes with climatic change, long-term trends spotted in these types of surveys can be concealed by short-term variation in the composition of species. Berecibar *et al.* (2004), revisited some location, and it shows that the phytogeographic intertidal regions of the seaweed community have transported northward in concern with the rise in Sea Surface Temperature (SST) along the coast of Portuguese. If these type of changes are detected when the global climate has warmed by an approximated average of 0.65°C in the last half-century, the outcome on species and ecosystem will be more drastic if the temperature rises 6°C by 2100 as predicted (IPCC,2007).

2.2.1 Species diversity around the World

According to FAO (2009), China is the greatest producer of seaweed with 10.9 million tonnes (wet weight) followed by the Philippines (1.5 million tons), Indonesia (0.91 million tonnes), Republic of Korea (0.77 million tonnes) and Japan (0.49 million tonnes).According to Gao *et al.* (1991), higher concentrations amplified the growth of seaweeds especially CO_2 saturated under present day CO_2 levels in ocean and they do not show improved performance in the future.

According to Koch *et al*. (2013), the macroalgae include three divisions: Rhodophyta (red algae), Phaeophyta (brown algae) and Chlorophyta (green algae).There are above 7000 different species of algae live in the oceans, freshwater and also on land.

The log on the benthic algae of the Red Sea by Papenfuss (1968) includes above 500 seaweed taxa and about 9% of endemic species. Walker (1987) splitted familiar species into four geographic regions, The Gulfs (Gulf of Suez and Gulf of Aqaba), Northern, Southern and Central regions, and manifest 8-40% of familiar species from the Red Sea appears in one region only. Ormond and Banaimoon (1994) registered 163 taxa of seaweed from the Southern coast of Yemen. According to Briggs (1974) and Adey and Steneck (2001), the largest coastal biogeography region on Earth is Tropical Indo-West Pacific with 2991 species of seaweed and sub-specific taxa all alone for the Indian Ocean (Silva *et al*., 1996).

A total of 381 taxa of seaweeds of which 73 are Phaeophyta and 186 are Rhodophyta were recorded in Malaysia (Phang *et al*., 2007). According to Cavas and Yurdakoe (2005), algal taxonomy is generally based on pigments, cell wall composition, and number of flagella, growth patterns, branching, holdfast, sporangia type, and photosynthetic products.

The tropical and subtropical waters have a wide diversity of Rhodophyceae, whereas in temperate and cooler water Chlorophyceae and Phaeophyceae is respectively more prevalent (Dawes, 1981). In Chinese literature around 2500 years ago the utilization of seaweed has been quoted (Tseng, 2004).

The foremost research work on some macroalgal geographic distribution is done by Boergesen (1934). The studies on abundance, distribution and dominance of some seaweed were done by Anand (1940, 1943). The biomass variation, tidal variation and abundance of seaweeds were studied by Saifullah (1973) and Qari (1985) done the study on biochemical composition and ecology of seaweeds.

The importance of seaweeds has so far studied by several countries. About 42 countries in the World carry out thorough studies on seaweeds. China holds the first position in the production of seaweed followed by North Korea, South Korea, Japan, Philippines, Chile, Norway, Indonesia, USA and India. Globally, 95% of commercial seaweed volume was furnished by these top ten countries (Sajid and Satam, 2003).

2.2.2 Species diversity around India

According to the Government of India 1985, India which accounts 3,287,263 square kilometer area is Asia's second largest and seventh largest country in the World.Many authors studied the macroalgal biodiversity along the west and east coastal regions of India (Srinivasan, 1946; Gopalakrishnan, 1970; Kalimuthu, 1995; Dhargalkar *et al*., 2001; Sahoo *et al*., 2003; James, 2004; Venkataraman, 2005).The marine algae are mainly classified as Rhodophyceae (Red algae), Phaeophyceae (Brown algae) and Chlorophyceae (green algae) which are comparitively seen in shallow water areas up to 180 metre depth on dead corals, shells, rocks, and plants. Globally, Rhodophyceae encompasses 6000 species followed by Phaeophyceae (1780 species) and Chlorophyceae (920 species) with an approximate production of 21, 65,675 mt/year while India supplies only 3,003 mt/year.

Rao and Mantu (2006) suggest that in India rocky beaches, lagoons, coral reefs and mudflat estuaries furnish a perfect habitat for macroalgal growth. A total of 770 species of seaweeds have been detailed from diverse coastal regions of India, out of those red algae of

420 species; green algae of 184 species and brown algae of 166 species (Sahoo *et al*., 2001).

According to Subba Rao; Vaibhav (2006), the distribution of seaweed species in different maritime states of India are Tamil Nadu (302), Gujarat (202), Maharashtra (152), Lakshadweep (89), Goa (75), Andhra Pradesh (78), Karnataka (39), and Kerala (20).

In the Indian coast, the distribution and diversity studies of seaweed were done by several workers (Untawale *et al.*, 1989; Kalimuthu *et al*., 1995; Selvaraj and Selvaraj, 1997; Jnanendra Adhikary, 2006; Satheesh and Westley, 2012). Krishnamurthy and Joshi (1970) published the first checklist of 520 species of Indian benthic macroalgae. According to Silva *et al*. (1996) and Sahoo (2001) the profuse seaweed beds were seen along Andaman and Nicobar Islands, Lakshadweep,north-western coast of Veraval and Gulf of Kutch, north-eastern coast of Vishakhapatnam, southern coast of Tiruchendur, Mahabalipuram, Tuticorin, Gulf of Mannar and Kerala.

2.2.3 Species diversity around Kerala

The seaweeds are simpler plant that are free-floating or attached to substrates which are extensively distributed from tidal levels to substantial depth (Kaladharan and Reeta, 2003). The surveys for seaweed resources of Kerala was carried out by Nair *et al.* (1982), Nair and Shoba (1983), Silas (1987), Chennubholta *et al*. (1993) and Mathew (1991) which have shown lush growth of many seaweed species across the southern coast of Kerala. Vizhinjam and Varkala have luxuriant growth of seaweed (Kaliaperumal, 2005) .The surveys on seaweed distribution across Thirumullavaram coast was executed by Leena and Prabha Devi (2004).

2.3 Uses of seaweeds

According to (Ronnback *et al*., 2007), the ecosystem goods and services given by seaweeds include storm protection, medicine and food.The edible seaweeds have shown high essential minerals and vitamins.

According to (Mac Artain *et al.,* 2000) the nutritional respects of edible seaweeds are quantified that comprises of minerals (Calcium, Magnesium, Sodium, Potassium, Iron , Zinc, Copper and Iodine) and polysaccharides (alginates, carrageenan, hemicelluloses

,cellulose and xylans), proteins (biliproteins) vitamins (A, B, C and E), polyunsaturated fatty acids (PUFA), and other compounds (Floridoside, Alginic acid, Xylose and Pentoses).

The phytochemical obtained from seaweed are used as thickening,gelling,and stabilizing agents in food, pharmaceutical, varnish, paper, dairy, textile industries etc. (Kolanjinathan *et al.*, 2014). They are also useful as climate change indicator (Vander Strate *et al*., 2002).

In the six states of India evaluated the potential of seaweed is 1,005,000 tons comprising 250,000 tons in Tamil Nadu, 250,000 tons in Gujarat; 100,000 tons in Andhra Pradesh; 100,000 tons in Kerala; 300,000 tons in Andaman and Nicobar Islands and 5,000 tons in Maharashtra (Krishnan and Narayana Kumar, 2010).

According to Dring (1982), 90% of marine plants species are algae and 50% of the global photosynthesis is derived from algae (John, 1994).According to Melkonian (1995), every second molecule of oxygen we inhale is produced by algae, and every second molecule of carbon dioxide we exhale is released by algae.

MATERIALS AND METHODS

CHAPTER 3
MATERIALS AND METHODS

The two most important components of study are namely, assessment of diversity, abundance and seasonal variation of seaweeds along the coast of Thikkodi, Calicut and to estimate the carbon sequestration potential of selected seaweeds.

3.1 Study area

The south-east and south-west coasts of India Andaman & Nicobar and the Lakshadweep archipelago harbor vast variety of seaweeds with rich biomass and species diversity. The state of Kerala is fringed by the Arabian Sea on the west and the Western Ghats on the east. The study area selected for accessing the diversity, abundance and seasonal variation is a rocky intertidal zone, which is an excellent habitat for a rich variety of organisms.

Thikkodi coast lies in the Kozhikode district of Kerala which has a coastline of about 71km ranging from Kadalundinagaram in the South to Mahe (a part of Puduchery U.T) in the North. Thikkodi coast is a long and wide rocky coast with black sand. The rocks were submerged depending on the tides. The laterite rocks are covered by sand and gravel was dispersed at varying depth which provides an ideal substratum for the growth of seaweeds. The waves may cut terrace of laterite.

Thikkodi sports a beautiful rocky intertidal zone with astounding biodiversity which includes seaweeds, fishes, crustaceans, amphipods, zooanthus, gastropods, barnacles, oysters, gastropods, sea cucumbers, sea urchins etc. The gastropods like *Semiricinula tissoti, Turbo bruneus*, *Thais bufo, Gyrineum natator, Planaxis sulcatus* etc were also seen in the rocky stretches.

The field surveys were conducted along the Thikkodi coast, Kozhikode district (11º28’30.8” N, 75º37’04.5”E) from September 2018 to August 2019, during low tide.

Fig.1. Location map of Thikkodi showing the sampling sites

Fig.2. A view of the intertidal region of Thikkodi coast

3.1.1Planning and arrangement before field survey

The intertidal field surveys were done during the low tide periods when a large expanse of the shore was exposed. The tidal data of each month was obtained from the web page (tides.mobilegeographics.com/calendar/month/678.html).

3.1.2 Equipment needed for field survey

- Square quadrates (1 feet*1 feet)
- Tokens
- Scalpels,knives
- Plastic bags of different sizes
- Plastic buckets
- Field diary
- Pen

3.1.3 Sampling Strategies

The study area was visited monthly during low tide from September 2018 to August 2019 and the seaweed samples were collected. A total of six line transects (T1, T2, T3, T4, T5 and T6) were laid perpendicular to the waterline at equal distance .In each of the transects, three quadrats (Q1, Q2, Q3) were laid in such a way that three zones were covered – the area which seldom got exposed even during very high tides (zone 1), the area which gets exposed during the medium tides (zone 2) and the areas which gets exposed during low tides (zone 3). Triplicate quadrat sampling was done in each quadrat site and the size of the quadrat was 1 ft x 1 ft.

Fig.3. Quadrat sampling in zone 1

Fig.4. Quadrat sampling in zone 2

Fig.5. Quadrat sampling in zone 3

To get an understanding of the pattern of zonation, the distribution of the algae in the intertidal region of Thikkodi was examined during one year of study coinciding with the three zones (zone 1, zone 2, zone 3) of the universal scheme of Stephenson & Stephenson (1949).During each survey, the sampling was started an hour before the tide falls,in such a way that the sampling was first done in shallow regions and then moving towards the deeper ends along the transect lines. The quadrats Q1, Q2, Q3 were laid in different transect from T1 to T6.The samples in each quadrat were handpicked with the help of scalpel and collected in polythene bags provided with tokens. The token number and quadrat number in each transect is also noted in the field diary.

A Global Positioning System (Garmin GPS map 76 CSx) was used to mark the exact location of each quad rat along the transects and the geospatial location of each quadrat sampling site is given in Table 1.

Table 1. GPS attributes of different transects

Transect-Quad rat(TQ)	Longitude (°)	Latitude (°)
T1Q1	75.6161	11.4772
T1Q2	75.6153	11.4767
T1Q3	75.6147	11.4761
T2Q1	75.6169	11.4761
T2Q2	75.617	11.4756
T2Q3	75.6181	11.475
T3Q1	75.6181	11.4756
T3Q2	75.6178	11.475
T3Q3	75.6175	11.4744
T4Q1	75.6194	11.4739
T4Q2	75.6197	11.4743
T4Q3	75.62	11.4748
T5Q1	75.6202	11.4737
T5Q2	75.6203	11.474
T5Q3	75.6205	11.4744
T6Q1	75.6211	11.4734
T6Q2	75.6213	11.4738
T6Q3	75.6214	11.4742

The photographs of the seaweed habitat and the nature of the coast were taken using an underwater camera.The seaweed samples collected with holdfast were kept in separate plastic bags for preparing the herbarium. The algal sample collected by detaching a portion from the seaweed bed is then transported to the laboratory.

3.1.4 Studies on seaweed samples in the laboratory

The algal samples collected during the field were fixed in 4% formalin-seawater for further microscopic studies of different species of seaweed. The identification of seaweed was carried out by referring standard taxonomical books (Jha *et al*., 2009) and web page sources (www.algaebase.org) and (www.niobioinformatics.in). The photographs of seaweed species were also taken in the laboratory.

3.1.5 Preparation of Herbarium

The collected samples were kept in a plastic tray filled with filtered seawater and the thalli were cleaned to remove epiphytes, small shells, and sand particles adhering to it using a gentle brush. For mounting the specimen a herbarium sheet of smaller size than the tray is immersed in the water and spread with the help of brush to minimize the overlap of the specimen.

After mounting the specimen on the herbarium sheet it is then slowly lifted and slightly tilted one side to allow gradual draining of water without disturbing the samples. To remove water, a cotton cloth was placed on the specimen and by using a blotting paper excess water was removed. A piece of blotting paper was placed on the top of the specimen in such a way that the entire specimen is covered. Once all the specimens are ready they are kept in between sheets of paper and a counterweight was applied on it.

The specimens were checked continuously by replacing the blotting paper until it is free of moisture. Once the specimen is dried it gets attached to the paper due to the phycocolloid present in the seaweed. Sometimes, the specimens are thick and don't stick to the herbarium sheets. In such cases, the glue was used to stick the specimen. The information regarding the specimen including scientific name, location of collection was written on it and kept in the cupboard for long time preservation.

3.2. Biomass estimation of seaweeds

The seaweeds collected during the field sampling were brought to the laboratory.The different species of each quadrat sample were segregated and weighed separately using a digital balance (top-pan) and wet biomass was recorded. The standing stock of seaweed was determined as per the methods outlined by Baby Ushakiran *et al.* (2017) using the formula:

W= w/a

Where W is the standing stock of a particular species of seaweed,

w, is the wet biomass of seaweeds harvested from 6 quadrats, and

a, is total area studied i.e., 6 square meter.

The standing stock of seaweeds from September 2018 to August 2019 in different zones was calculated during the three seasons namely pre-monsoon (Feb-May), monsoon (Jun-Sep), post-monsoon (Oct-Jan).

3.3 Statistical analysis

The biodiversity indices were studied using PRIMER (Plymouth Routines in Multivariate Ecological Research) software package developed at the Plymouth Marine Laboratory (Clarke & Warwick, 2001). A total of 11 diversity indices were worked out including the taxonomic and phylogenetic taxonomy indices.The total species (S), number of species (N), Pielou's evenness index (J'), Shannon Index (H (loge), Simpson (1-lambda) index, and taxonomic diversity index (delta), total phylogenetic diversity (sPhi+) ,average taxonomic distinctness (Delta +) ,funnel plot for variation in taxonomic distinctness (λ+), Analysis of Similarity (ANOSIM) ,Similarity Percentage Analysis (SIMPER) were calculated.

3.2 Experiment procedures for carbon sequestration potential of selected seaweeds

For the carbon sequestration experiments, seaweeds from Thikkodi intertidal region were collected and maintained in the wet laboratory of ICAR-CMFRI, Calicut. The experiments were conducted at room temperature in the laboratory. The experiments have been conducted on three green algae (*Caulerpa peltata, Caulerpa scalpelliformis,* and *Caulerpa taxifolia*) and two red algae (*Gracilaria corticata*, *Acanthophora spicifera)* at different levels of CO_2 incubation.

Before the experiment, initial CO_2 concentration in the incubating water according to the method of Dye (1958). Required levels of carbon dioxide were dissolved into seawater taken in separate glass containers from a CO_2 cylinder, dispensed through soda maker (Kaladharan *et al*., 2009).

Fig.6. CO2 dispersing unit

The seaweeds were acclimatized overnight in large tanks containing filtered (0.45µ) seawater of 32 ppt.The seaweed samples were washed and the thalli were cleaned thoroughly with excess water to free epiphytes,copepods,amphipods and fine sand particles(Kaladharan *et al*.,2009).

Fig.7. Seaweed culturing tanks

The thalli were cleaned by wiping with a tissue paper, and 0.5 g of seaweed was weighed out using a digital balance (Mctley Sartorins). The weighed seaweed samples were kept in 125 ml and 300 ml bottles respectively for the analysis of oxygen and CO_2.

After determining the initial CO_2, the seaweed taken in duplicates were incubated in 125 ml and 300 ml, light and dark bottles under a water column of 40-50 cm for two hours.

Fig.8. Incubation in 125 ml glass stoppered bottles

3.2.1 Analysis of dissolved carbon-di-oxide

Reagents used:

Phenolphthalein indicator

0.05 g of phenolphthalein was added into a beaker and it is dissolved in 50 ml of 95% ethanol. It is then stirred continuously until phenolphthalein is fully dissolved. Then, 50 ml of distilled water is added and stirred again to get phenolphthalein indicator solution.

Standard sodium hydroxide solution (0.05 N)

2 g of NaOH pellets are dissolved in 1 L distilled water in a volumetric flask.
For estimating dissolved carbon dioxide in seawater, 50 ml burette was taken and filled with 0.05 N NaOH solution. Fifty ml of seawater was gently siphoned out into 250 ml conical flask and to these 2-3 drops of phenolphthalein indicator was addedand titratedagainst 0.05 N NaOH. The sample is titrated until a pink colour appears that is persistent (Dye, 1958).

Calculation:

Quantity of dissolved CO_2 (mg/l) = (ml NaOH used*1000)/vol of sample used

3.2.2 Analysis of dissolved oxygen

The dissolved oxygen in seawater was measured following the Winklers method.

Reagents used:

Sodium thiosulphate solution

1.25 gm of sodium thiosulphate is dissolved in 1litre of distilled water.

Starch solution

1gm of starch is taken and mixed with distilled water to form a paste which is then diluted to 100 ml distilled water. After boiling it, 1 ml of formalin is also added for preserving it.

Winkler A

20gm of manganous sulphate is dissolved in 100 ml of distilled water.

Winkler B

41 gm of sodium hydroxide and 25 gm of potassium iodide is dissolved in 100 ml of distilled water.

Concentrated sulphuric acid

To 125 ml glass bottles, 1 ml of Winkler A and 1 ml of Winkler B solutions are added and shaken well until the precipitate formed was evenly distributed. To the precipitate, 1 ml of concentrated $H_2SO_4$was added and the bottles were shaken thoroughly until the precipitate dissolves completely (Winkler, 1888).

In a conical flask, 10 ml of potassium iodate solution is pipetted out and to that, 1 gm of potassium iodide and 2 ml of cnc.sulphuric acid is also added. Then it is diluted with 100 ml of distilled water and titrated against sodium thiosulphate solution until it becomes pale yellow colour.

The indicator used in starch solution, which is added up to 1 ml which makes the solution into blue. The titration is done until the blue colour disappears. The titration was repeatedly carried out for getting concordant values. (Gaarder and Gran, 1927).

Calculation:

Normality of potassium iodate (N1) = (Weight/litre)/35.67
Normality of sodium thiosulphate (N2) = (N1*10)/titrated volume of sodium thiosulphate
Hence, the amount of dissolved oxygen in ml/hr = (ml of thiosulphate*N2*8*1000*R)/100*1.429

Where, R is the correction factor=1.01
8 is the equivalent weight of oxygen.
1.429 is the conversion factor from ppm to ml/lit

3.1.3 Determination of primary productivity

The water samples were collected in six clear bottles of 125 ml, out of that 2 were dark bottles. Initially, two bottles were fixed immediately with Winkler A and B reagents.

The other two bottles were incubated in the light by covering with transparent polythene bags and the remaining two amber coloured bottles were incubated by wrapping them with black polythene bags, for 2 hours. After 2 hours of incubation, the bottles were fixed with 1ml each of Winkler A and Winkler B reagents.The precipitate was dissolved using concentrated sulphuric acid. The clear solution is then titrated against sodium thiosulphate solution, with starch solution as indicator. The sample is titrated until the blue colour completely disappears.

Calculation:

Let O_2 of light bottle after incubation =x
Let O_2 of dark bottle after incubation =y
The Gross Primary Production= ((x-y)*0.536)/PQ*t mgC/l/hr
The Net Primary Production= ((x-z)*0.536)/PQ*t mgC/l/hr

Where, PQ is the photosynthetic quotient=1.25 (Westlake, 1963)
t is the number of hours of incubation= 2 hours
0.536 is the conversion factor of oxygen into carbon equivalents.

Fig.9. Laboratory set up for determining primary productivity

Fig.10. Digital weighing balance

Fig.11. CO2 titration unit

Fig.12. Filtering unit

RESULT AND DISCUSSION

CHAPTER 4

RESULT AND DISCUSSION

The observed results on the diversity of seaweeds along the Thikkodi coast and carbon sequestration potential of selected seaweeds are discussed in this chapter.

4.1 Seaweed diversity recorded at Thikkodi: Brief description of species

4.1.1 *Caulerpa peltata* J.V.Lamouroux, 1809

DIVISION: CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Bryopsidales

FAMILY : Caulerpaceae

GENUS : Caulerpa

Fig.13. Dense growth of *Caulerpa peltata* at Thikkodi

Fig.14. *Caulerpa peltata*

KEY CHARACTERS:

Plants are small, 1-3 diameter with erect branches of 5-50 mm length. The thallus is ramiform and is of creeping type.The bright green coloured plants grow in patches on sheltered calcareous rocks. The stolons which are freely forked bears rhizoidal branches below and foliar branches above. The plants are coenocytic; with erect branches 5-50 mm tall and bear several peltate branchlets having a slender pedicel of 1-2 mm length and a disc of 3-5mm diameter at its ends.

Habitat: Intertidal zone

IUCN Status: NE

Economic importance: Edible, fodder, manure

4.1.2 *Caulerpa racemosa* (Forsskal) J.Agardh, 1873

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Bryopsidales

FAMILY : Caulerpaceae

GENUS : Caulerpa

Fig.15. *Caulerpa racemosa*

KEY CHARACTERS:

The thallus is ramiform and creeping type.The plants are pale green colourwhich grow as patches on the intertidal rocks or commonly associated with dead corals. The plants are widespread with long, coarse branching stolons which become very densely entangled in old colonies about 1-2m in diameter. Theplants are coenocytic with prostate rhizomes and erect assimilators often much crowded on the rhizomes which are 2-5 cm tall radially and closely arranged ramuli covered with clavate to spherical branchlets.The stalks of the branchlets are short.

Habitat: Intertidal zone

IUCN Status: NE

Economic importance: Edible, fodder

4.1.3 *Caulerpa scalpelliformis* (R.Brown ex Turner) C.Agardh, 1817

DIVISION: CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Bryopsidales

FAMILY : Caulerpaceae

GENUS : Caulerpa

Fig.16. *Caulerpa scalpelliformis* attached to the rocks at Thikkodi

Fig.17. ***Caulerpa scalpelliformis***

KEY CHARACTERS:

The plants are bright yellowish-green to olive green colour attached oncalcareous rocks in the tide pools and streams. The thallus is ramiform and creeping type. The plants are seen in huge association with prostrate rhizome like stolons having roots on lower surface at intervals and erect branches above.The stolon is simple or slightly branched with 15-20 cm length erectile assimilators on the upper face of stolons which are rarely forked. The leaf-like flat bilateral stolon is 8-24 cm or more length, 1 cm or more broad. The closelypinnate branches on the main broad have thickened flat rachis which is alternately linear and plano-compressed of 1-2 cm length, 0.3 mm breadth. The stolon of the thallus have spongy network of anastomosing filaments filled with semi-fluid matter.

Habitat: Intertidal zone

Economic importance: Edible, fodder

4.1.4 ***Caulerpa sertularioides*** **(S.G.Gmelin) M.A.Howe, 1905**

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Bryopsidales

FAMILY : Caulerpaceae

GENUS : Caulerpa

Fig.18. Underwater photograph of *Caulerpa sertularioides*

Fig.19. *Caulerpa sertularioides*

KEY CHARACTERS:

The plants are bright to dark green coloured that commonly grow on stones with fine sediments. The plant forms large colonies, 1-2 m diameter of coarselybranched stolons of thick rhizoid bearing branches below and foliar branches above.The foliar branches are flat and short-stalked of 10-15 cm length and 13-22 mm width. The plants are simple or occasionally branched and closely pinnate. The pinnules are cylindrical up curved about 180-330µ diameter; 3-11mm length with rounded-conical and mucronate tip.

Habitat: Intertidal zone

IUCN Status: NE

Economic importance: Edible, fodder, manure

4.1.5 *Caulerpa taxifolia* (Vahl) C.Agardh, 1817

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Bryopsidales

FAMILY : Caulerpaceae

GENUS : Caulerpa

Fig.20. Underwater photograph of *Caulerpa taxifolia*

Fig.21. *Caulerpa taxifolia* **Fig.22. Close view of *Caulerpa taxifolia***

KEY CHARACTERS:

The plants are yellow to dark green colour. The thallus is a ramiform andcreeping type.The plants have widespread naked stolon with rhizoid-bearing branches below and foliar branches above.The erect branches are closer with stalks of 1-3cm length which ends in flat linear-oblong to linear. The blades are sparingly branched and oppositely pinnate. The pinnules are compressed, sickle shaped with a constricted base which are mucronate and tapering towards the tip. The plant usually grows in tide pools on sheltered rocks.

Habitat: Intertidal zone

IUCN Status: NE

Economic importance: Edible, fodder, manure

4.1.6 *Chaetomorpha antennina* (Bory) Kutezing, 1845

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Cladophorales

FAMILY : Cladophoraceae

GENUS : Chaetomorpha

Fig.23. ***Chaetomorpha antennina*** **attached to the laterite rocks at Thikkodi**

Fig.24. ***Chaetomorpha antennina***

KEY CHARACTERS:

The thallus form is filamentous and brush-like tufts in flocks. The plants are dark green coloured which grows gregariously in tufts. The cylindrical orbarrel-shaped filaments are unbranched and erect. The cells are 200-250µm at upperparts and 2-4 times longer than broad with a thick cell wall. The cell walls of basal cells are thick with annular constrictions. The chloroplast is reticulate, but close together. The filaments are attached by irregularly branched rhizoidal basal cells.

Habitat: Lower mid littoral zone

Economic importance: Raw material for paper manufacturing industries in some countries.

4.1.7 *Chaetomorpha linum* (Muller) Kutezing, 1845

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Cladophorales

FAMILY : Cladophoraceae

GENUS : Chaetomorpha

Fig.25. *Chaetomorpha linum* in the wild

Fig.26. *Chaetomorpha linum*

KEY CHARACTERS:

The plant looks similar to straight green or yellowish hair and sometimes white towards the ends of filaments if spores or gametes are released. It is one of the most delicate forms of green algae. The filaments are unbranched about 5-30 cmlength grown in groups of hundreds or thousands of individuals in sandy areas on rocks or in tide pools. The unattached filaments are yellowish green in colour with cylindrical or slightly swollen cells of 100-375µ diam, 1-2 diameter length.

Habitat: Intertidal (supralittoral)

IUCN Status: LR

Economic importance: Food, fodder

4.1.8 *Chaetomorpha crassa* (Agardh) Kutezing, 1845

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Cladophorales

FAMILY : Cladophoraceae

GENUS : Chaetomorpha

KEY CHARACTERS:

The plants usually grow as entangled form with other seaweeds with filamentous thallus. The plants are bright green coloured. The filaments are unbranched with series of cylindrical to barrel-shaped cells. The cells are slightly constricted near the septa about 400-650µm in diameter.

Habitat: Mid-littoral zone

Economic importance: Paper manufacturing industry. The cellulose of this alga can be modified for developing cellulose-based membranes, to suit for desalination technology.

4.1.9 *Ulva lactuca* Linnaeus, 1753

DIVISION : CHLOROPHYTA
CLASS : Ulvophyceae
ORDER : Ulvales
FAMILY : Ulvaceae
GENUS : Ulva

Fig.27. *Ulva lactuca* attached to the laterite rocks

Fig.28. *Ulva lactuca*

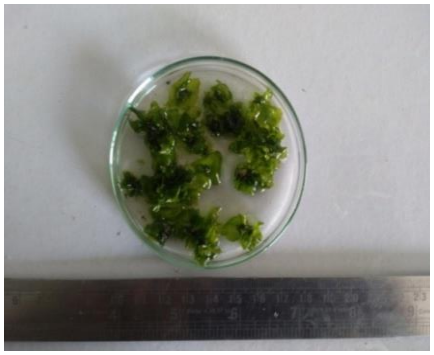

Fig.29. *Ulva lactuca* in petridish

KEY CHARACTERS:

The plants are foliaceous that are bright green to light green, fading to yellowish and sometimes darker when young. The plants are attached to the substratum by a holdfast which consists of rhizoidal outgrowth from the lower cells. The thallus consists of a large expanded sheet of two cell thickness, frequently several meters in length. The stalk is inconspicuous or apparently absent. The margins of the thallus is ruffled and wavy folded with lobes of varying thickness of about 40-45µ at the margins; 60- 65µ at the mid portion. The cross-section of the thallus shows that the cells are isodiametric or vertically elongated to the thallus surface. The cell walls are more or less confluent with one another which form a tough gelatinous matrix. Each cell possesses a single cup-shaped chloroplast which lies next to the outer face of the cell. Each chloroplast contains one pyrenoid.The cell division takes place in a plane perpendicular to the thallus surface. The lower part of the thallus contains certain cells having long colourless rhizoids which grow between the two layers of the cells and intertwine freely with one another.The rhizoids emerge from the thallus near the point of attachment to the substratum and becomes closely intermingled to one another forming a pseudoparenchymatous holdfast.

Habitat: Open coast (intertidal), estuaries and mangroves

IUCN Status: LR

Economic importance: Food, fodder, medicine

4.1.10 *Ulva fasciata* Delile, 1813

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Ulvales

FAMILY : Ulvaceae

GENUS : Ulva

Fig.30. ***Ulva fasciata*** **attached to the laterite rocks**

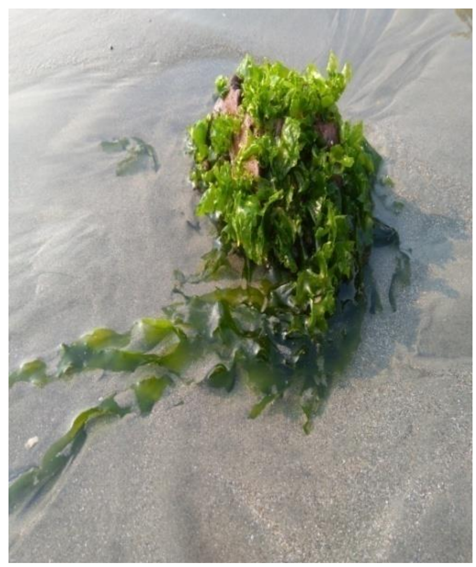

Fig.31. ***Ulva fasciata*** **in plate**

Fig.32. ***Ulva fasciata*** **in habitat**

KEY CHARACTERS:

The thallus is leafy and ribbon-like which are yellow to dark green in colour. The plants are 40 cm in length which divides into a ribbon shaped 1-3 cm broad lobes that are irregular or sometimes divided into lingulate or linear with dichotomous branchlets.The thallus is much thicker, 100 µ or somewhat more and the margins are irregularly ruffled and crenate with a somewhat paler central portion. The margins turn whitish when it releases gametes or zoospores.

Habitat: Open coast (intertidal), estuaries and mangroves

IUCN Status: LR

Economic importance: Food, fodder, and medicine

4.1.11 *Enteromorpha compressa* (Linnaeus) Nees, 1820

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Ulvales

FAMILY : Ulvaceae

GENUS : Enteromorpha

Fig.33. ***Enteromorpha compressa***

Fig.34. ***Enteromorpha compressa*** **in plate**

KEY CHARACTERS:

The thallus form is tubulose and compressed. The plants are attached to intertidal rocks and floating structures in the sea. The plants are usually gregarious. The plants are bright to dark green about 3dm tall,tubular,more or less compressed and expanded above 220 mm width, long and tapering below with several branches from gradually contracted stalk-like base which looks similar to the principal blade. The round subquadrate cells in the adult plants are irregularly placed about 10-15 micron diameter. The walls are not thickened and the whole membrane is 13-20 micron thick in vertically elongate section.

Ecological Status: Intertidal zone, estuaries and mangrove swamps

IUCN Status: LR

USES: Food, fodder, medicine

4.1.12 *Enteromorpha intestinalis* (Linnaeus) Nees, 1820

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Ulvales

FAMILY : Ulvaceae

GENUS : Enteromorpha

KEY CHARACTERS:

The thallus is attached by a basal rhizoidal portion to the substratum. The mature thallus is a dark green coloured hollow tube with a wall that consists of a single layer of cells. The length and width of fronds are 15 cm and 5-6 cm respectively. The older thallii are free-floating. It has simple or branched fronds.

Habitat: Intertidal zone

Economic importance: Edible, medicine, poultry feed

4.1.13 *Cladophora fascicularis* Kutezing, 1843

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Cladophorales

FAMILY : Cladophoraceae

GENUS : Cladophora

KEY CHARACTERS:

The plants are large, about 30-50 cm in length. The fasciculate ramuli are 1.5-3mm in length. The cells of ramuli are 70 to 120 in diameter and 1-3.5 diameters in length. The plants are sparingly branched and crowded near their tips with somewhat pectinate arrangement.

Habitat: Intertidal (supralittoral)

IUCN Status: LR

Economic importance: Food, fodder

4.1.14 *Cladophora prolifera* (Roth) Kutezing, 1843

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Cladophorales

FAMILY : Cladophoraceae

GENUS : Cladophora

Fig.35. ***Cladophora prolifera***

KEY CHARACTERS:

The tufted plants are dark green and it becomes blackish when dried. The coarse and stiff plants are 20 cm tall, with main filaments of 300-475µ diameter. The branchlets are 130-200µ diameter, cells are 4-6 diameters long, and the tips of the cells are blunt.

Habitat: Intertidal (supralittoral)

Economic importance: Food, fodder

4.1.15 *Cladophora herpestica (*Montagne*)* Kutezing, 1849

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Cladophorales

FAMILY : Cladophoraceae

GENUS : Cladophora

Fig.36. *Cladophora herpestica*

KEY CHARACTERS:

The plants are light green which forms cushion like clumps in shallow habitats or entangled with other algae up to 5m depth .The branches are irregular below and unilateral above. The chloroplasts are reticulate with numerous pyrenoids.

Habitat: Intertidal zone

Economic importance: Food, fodder

4.1.16 *Boodlea composita* (Harvey) Brand, 1904

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Cladophorales

FAMILY : Boodleaceae

GENUS : Boodlea

Fig.37. ***Boodlea composita***

KEY CHARACTERS:

The plants are light or yellowish green coloured with bushy and filamentous irregular branches which are fragile, spongy; septate and coenocytes. The unilateral or opposite branches arise from the nodes, but soon it becomes whorled or irregular and in the lesser divisions it is altogether irregular and not flabellate. The main filaments are 200-350 µm in diameter, with 0.2 mm long cell, 70-100 µm in diameter which are devoid of basal cross walls that are acquired later only. The branches and branchlets are arranged to the intertidal rocks, coralline stones by teneculae.

Habitat: Mid littoral zone and infra littoral fringe

IUCN Status: NE

Economic importance: Food

4.1.17 *Valoniopsis pachynema (Martens)* Borgesen, 1934

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Cladophorales

FAMILY : Valoniaceae

GENUS : Valoniopsis

Fig.38. *Valoniopsis pachynema* in habitat

Fig.39. *Valoniopsis pachynema*

KEY CHARACTERS:

The thallus form is cushion or spongy patches. The plants are dark green coloured which are loosely entangled forming wide cushions of 3 cm thickness and 5-7 cm diameter with interlaced ascending coenocytic filaments.

The filaments are repeatedly and often sub-corymbose branched which are attached by septate primary and secondary rhizoids. The younger branchlets are erect whereas the older branchlets are spreading. The branches are unilateral or palmate about 5-7 mm length, 500-750µm diameter, which arises from a few small lenticular cells in the base and other parts of the thallus.

Habitat: Mid littoral zone, exposed rocks

Economic importance: Source of natural antioxidant

4.1.18 *Bryopsis pennata* Lamouroux, 1809

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Bryopsidales

FAMILY : Bryopsidaceae

GENUS : Bryopsis

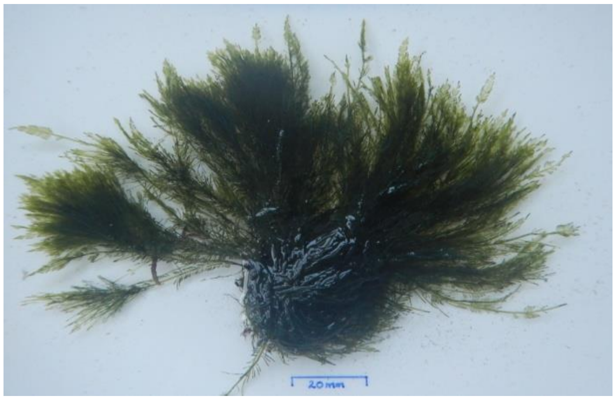

Fig.40. *Bryopsis pennata*

KEY CHARACTERS:

The thallus form is ramiform and feathery. The plants are dark green coloured; sometimes it is iridescent up to 14 cm height. The sparingly branched plants have pinnately divided distichous branchlets of uniform length which gives a linear-lanceolate or oblong aspect to the fronds. They form dense mats in the shade areas below overhanging cliffs.

Habitat: Mid and lower littoral zone

Economic importance: Food, medicine

4.1.19 *Ulothrix flacca* (Dillwyn) Thuret, 1863

DIVISION : CHLOROPHYTA

CLASS : Ulvophyceae

ORDER : Ulotrichales

FAMILY : Ulotrichaceae

GENUS : Ulothrix

KEY CHARACTERS:

It is a thread like algae which are attached to rocks or other solid objects. It is seen as a bright green attached mass. *Ulothrix* comprises 30 species which are seen in a variety of habitats (freshwater, streams, marine etc).*Ulothrix flacca* is a well known marine species. The thallus is unbranched filamentous with a slight differentiation.

Habitat: Intertidal zone

IUCN Status: NE

Economic importance: Food

4.1.20 *Ectocarpus siliculosus* (Dillwyn) Lyngbye, 1819

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Ectocarpales

FAMILY : Ectocarpaceae

GENUS : Ectocarpus

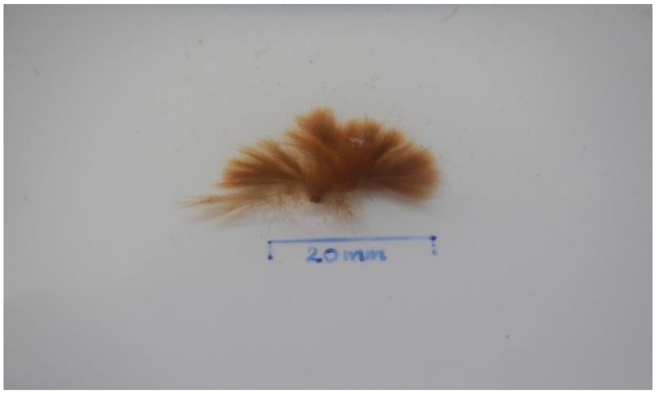

Fig.41. ***Ectocarpus siliculosus***

KEY CHARACTERS:

The plants are dark brown coloured. The thallus is filamentous which tapers towards the apices. The filaments are tufted, up to few cm long with free axes branches and indistinguishable main axis.

Habitat: Intertidal zone

Economic importance: Food, medicine, production of algin

4.1.21 *Dictyota ciliolata* Sonder ex Kutezing, 1859

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Dictyotales

FAMILY : Dictyotaceae

GENUS : Dictyota

Fig.42. ***Dictyota ciliolata***

KEY CHARACTERS:

The thallus form is frondose and bushy type. The plants are yellowish brown coloured with membranous, ribbon like dichotomous branched upper parts up to 15-20 cm height. The plants are attached to the intertidal rocks by a small cuneate disc. The branches are usually of uniform breadth, forking angles between the branches are acute or round, with acute or sub-acute apices. The margins of the branches are subentire or regularly denate with small ascending projections. The tetra sporangia form as a scattered group. Both oogonia and antheridia are distributed all over the surface of the thallus.

Habitat: Intertidal zone

Economic importance: Fodder, production of algin

4.1.22 *Dictyota dichotoma* (Hudson) J.V. Lamouroux, 1809

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Dictyotales

FAMILY : Dictyotaceae

GENUS : Dictyota

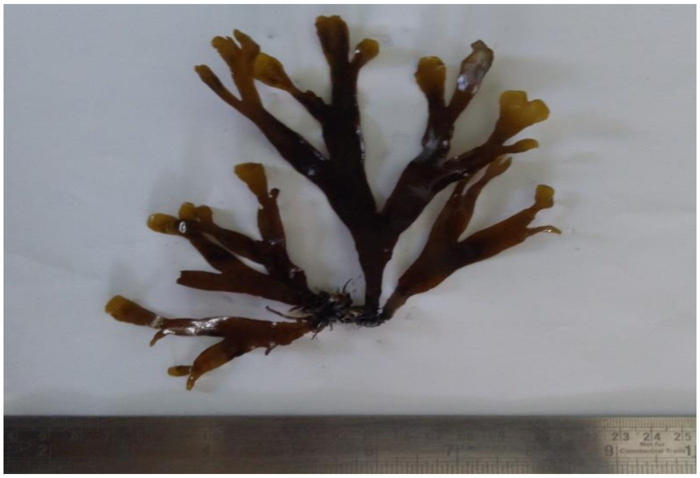

Fig.43. *Dictyota dichotoma*

KEY CHARACTERS:

The thallus form is frondose and bushy type.The plants are yellowish brown in colour about 1diameter tall occasionally, 3.5 diameter bush with ribbon-like upper parts regularly with dichotomous branches attached by a small cuneate disc. The dichotomous branches are forking at an angle of 15-45 degree, usually with narrow sinuses which generally decreases its width from the base to upper branches. The lower segments are little broader below each fork than just about it.The tetra sporangia are single or double which are scattered on both sides of the thallus.

Habitat: Intertidal zone

IUCN Status: NE

Economic importance: Production of alginate, food and animal feed.

4.1.23 *Stoechospermum marginatum* (C.Agardh) Kutezing, 1843

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Dictyotales

FAMILY : Dictyotaceae

GENUS : Stoechospermum

Fig.44. *Stoechospermum marginatum*

KEY CHARACTERS:

The thallus form is frondose and ribbon type.The plant grows as tufts up to 20 cm in height which is yellowish-brown in colour. The thallus is ribbon-shaped which is dichotomously divided with large groups of hair scattered over the surface. The thallus has one-celled thick, pigmented peripheral layers and 4-5 celled medulla at the centre. The margins of the branches are entirely with involute apices. The plants are attached to the substratum by rhizoidal holdfast.

Habitat: Intertidal zone

Economic importance: Source of fertilizer

4.1.24 *Spatoglossum asperum* J.Agardh, 1894

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Dictyotales

FAMILY : Dictyotaceae

GENUS : Spatoglossum

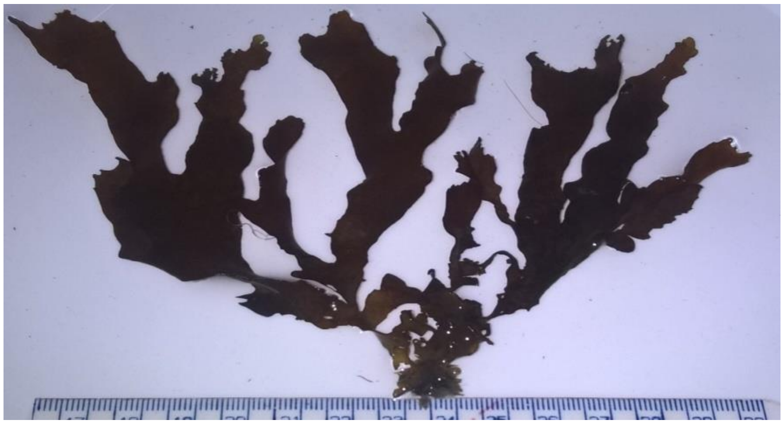

Fig.45. *Spatoglossum asperum*

KEY CHARACTERS:

The plants are dark brown and turn to dirty green when decaying. The thallus is frondose and ribbon type of 400 -500 µ thickness which palmate, sub-dichotomously divided into large and smaller lobes. The lobes are elongate, linear, lanceolate and attenuated towards the base. The apex is acute or rounded with sinuate margin having irregularly dentate larger or smaller proliferations. The plants are extremely variable in size and shape; variously divided into narrow segments of 1-2 mm breadth in 10-20 cm high plants usually seen in the tide pools.

Habitat: Intertidal zone, muddy substratum

IUCN Status: LRnt

Economic importance: Source of alginate, fertilizer etc

4.1.25 *Padina gymnospora* (Kutezing) Sonder, 1871

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Dictyotales

FAMILY : Dictyotaceae

GENUS : Padina

Fig.46. ***Padina gymnospora***

KEY CHARACTERS:

The blades of the plant are 10-12 cm long and broad, but 15 cm long and to 20 cm broad blades may also be found. The frond has three layers of cells except near the unrolled edge where two cell layers occur. The hairlines are alternate on both sides of the blades and just above every second hairline dark lines of sporangia are found. The plants are tufted up to 5-10 cm tall with 5-20 cm broad rounded blades or spilt into narrower portions. The lower parts are stalk-like and stupose which are usually moderately calcified on the upper surface, 2 cells and 50-60 micron thick near the growing margin and 3 cells, 75-110 micron thick below. The cells of the middle layer may be taller than those of the surface, or even 4 cells thick near the stipe.

The hair lines are alternating on the two faces having sterile zones of 24 mm width and alternating fertile zones of 1.5-3.0 mm wide sporangia in discontinuous bonds of 0.5-1.5 mm width, without induria;usually median between alternate hair lines. The gametophytes are dioecious; about 90-125 micron diameter; with 1-2 bands of antheridia in the alternate zones.

Habitat: Commonly seen in the lower half of the intertidal zone

Economic importance: Extraction of alginate, fertilizer

4.1.26 *Padina tetrastromatica* Hauck, 1887

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Dictyotales

FAMILY : Dictyotaceae

GENUS : Padina

Fig.47. *Padina tetrastromatica* in habitat

Fig.48. *Padina tetrastromatica* in plate

KEY CHARACTERS:

The thallus is flabelliform and divided into several small lobes, regularly and distinctly concentric zonate due to regular row of fructiferous organs. The plants are easily recognized due to dark double lines of sporangia, enclosing a line of colourless hair in between. The blades are composed of two layers of cells in the young apical involute portion which is 30-40 µ thick; 80-90 µ thick in the middle three cell layered partitions.

Habitat: Mangrove swamps (attached to mud) /intertidal

IUCN Status: LRnt

Economic importance: Extracting alginate, fertilizer

4.1.27 *Sargassum wightii* Greville ex J.Agardh, 1848

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Fucales

FAMILY : Sargassaceae

GENUS : Sargassum

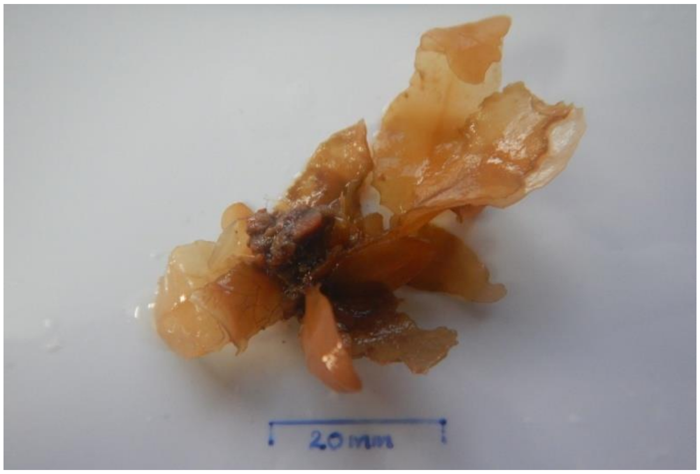

Fig.49. ***Sargassum wightii***

KEY CHARACTERS:

The plants are dark brown coloured about 20-30 cm in height with a well-marked holdfast with rich branched upper portion with cylindrical axes. The leaves are 5-8 cm in length and 2-9 mm in breadth which tapers at the base and apex. The midribs are inconspicuous with large, spherical or ellipsoidal vesicles of 5-8 mm length and 3-4 mm breadth. The stipe of the vesicle is 5-7 mm long seldom which ends into a long tip. The receptacles are in cluster with repeated branches.

Habitat: Intertidal and subtidal

IUCN Status: LRnt

Economic importance: Raw material for sodium alginate production. It also contains 8-10% of mannitol which is used as a substitute for sugar, fertilizer and medicine.

4.1.28 ***Sargassum cinereum,*** **J. Agardh, 1848**

DIVISION : Phaeophyta

CLASS : Phaeophyceae

ORDER : Fucales

FAMILY : Sargassaceae

GENUS : Sargassum

Fig.50. ***Sargassum cinereum***

KEY CHARACTERS:

The thallus form is foliose and bushy type.The plants are dark brown coloured with short, stout main axis which bears terate and smooth primary branches at their upper part. The plant bears membraneous oblong basal leaves which are 2.5-3 cm length, 7-8 mm broad which are rounded at the apices and dentate at the margins. The plants have secondary branches and the leaves of branchlets are lanceolate, 2-2.5 cm long, 3 mm broad, cuneate at the base. The vesicles are spherical, about 4 mm diameter, obovate, rounded which are mucronate at the apices and subcylindrical below.

Habitat: Intertidal zone

IUCN Status: LRnt

Economic importance: Source of alginate, fertilizer and medicine.

4.1.29 ***Gelidium pusillum*** **(Stackhouse) Le Jolis, 1863**

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Gelidiales

FAMILY : Gelidiceae

GENUS : Gelidium

Fig.51. ***Gelidium pusillum***

KEY CHARACTERS:

The plants are small dark red in colour which are solitary or forming loose turfs creeps below which give rise to erect blades of 5-15 mm long subcylindric and flattened about 0.5-0.75 mm.The plants are sparsely pinnately proliferate. The central portion consists of slender colourless filaments with exceedingly thick confluent walls which are surrounded by the inner cortex of short large cells and rounded angular cells of the epidermal layer. The slightly elongated lengthwise of the axis is about 4-10 micron surface diameter. The rhizomes in the stalk-like portions are subcortical in the blade portions invading the medulla, seems absent altogether.

Habitat: Littoral zone

IUCN Status: NE

Economic importance: It is one of the potential species as a source of agar.

4.1.30 *Gracilaria corticata* (J.Agardh) J.Agardh, 1852

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Gracilariales

FAMILY : Gracilariaceae

GENUS : Gracilaria

Fig.52. ***Gracilaria corticata*** **in habitat**

Fig.53. ***Gracilaria corticata*** **in plate**

KEY CHARACTERS:

The thallus form is bushy and cartilaginous consists of bundles of flat and much-divided blades with 2-3 mm broad segments. The colour of the plant varies from deep purple to grass green. The branches are dichotomous in younger blades. The older plants have numerous marginal projections which lines the edges of the segments in a pinnate fashion of 0.5- 2 cm length.

Habitat: Intertidal zone

IUCN Status: NE

Economic importance: Agar, food, animal feed

4.1.31 *Gracilaria corticata* var. *cylindrica* Umamaheswara Rao, 1974

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Gracilariales

FAMILY : Gracilariaceae

GENUS : Gracilaria

KEY CHARACTERS:

The thallus is bushy and cartilaginous. The colours of plants are red to yellowish-red. The fronds are dichotomous with alternate and irregular branches that are compressed at the lower parts and cylindrical close branches above with spinous apices.

Habitat: Lower mid littoral zone

IUCN Status: NE

Economic importance: Agar, food, animal feed

4.1.32 *Grateloupia indica* Borgesen, 1932

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Halymeniales

FAMILY : Halymeniaceae

GENUS : Grateloupia

KEY CHARACTERS:

The thallus form is leafy and lubricous type with subspherical occasionally flattened cystocarp of 250 micron diameter which is dispersed thoroughly. The plants are attached to the substratum by a very small basal disc and a short, compressed, cuneate stipe. The thallus is flat, oblong to linear with extensively divided large ranching of 7-30 cm or more broad at the broadest part and 300-350 µ thickness. The lobes of the thallus are many with an irregular sinuate margin with gradual tapering tips. The rhizoids are 3-4µ thick with many-layered cortex and outer medulla is more compact than the inner one.

Habitat: Intertidal zone

IUCN Status: NE

Economic importance: Food

4.1.33 *Grateloupia lithophila* Borgesen, 1938

DIVISION: Rhodophyta

CLASS : Florideophyceae

ORDER : Halymeniales

FAMILY : Halymeniaceae

GENUS : Grateloupia

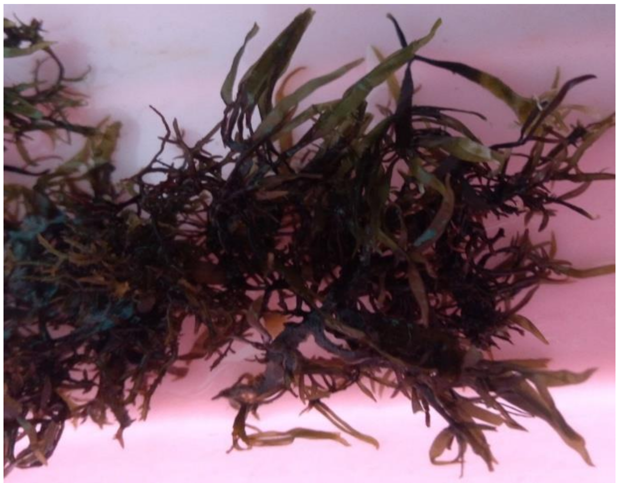

Fig.54. *Grateloupia lithophila*

Fig.55. *Grateloupia lithophila* in plate

KEY CHARACTERS:

The plants are seen on hard substratum in dense tufts. The thallus is flat, simple or irregularly divided about 10-15 cm long,0.5-2 cm broad which is sinuate and undulating with linear lanceolate tapering from the middle to both the ends. The section of the thallus with a central medullary region adjoining cortex is about the same size as cells of the cortex are regular in shape. The tetra sporangia are celled which is seen scattered on the surface of the thallus. The upper ends of the fronds are truncate, becomes more or less broadly rounded. The proliferation arises from the upper end and also from the sides of fronds.

Habitat: Intertidal zone

Economic importance: Food

4.1.34 Amphiroa *fragillissima* (Linnaeus) Lamouroux, 1816

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Halymeniales

FAMILY : Halymeniaceae

GENUS : Amphiroa

Fig.56. *Amphiroa fragillissima* attached to the rocks

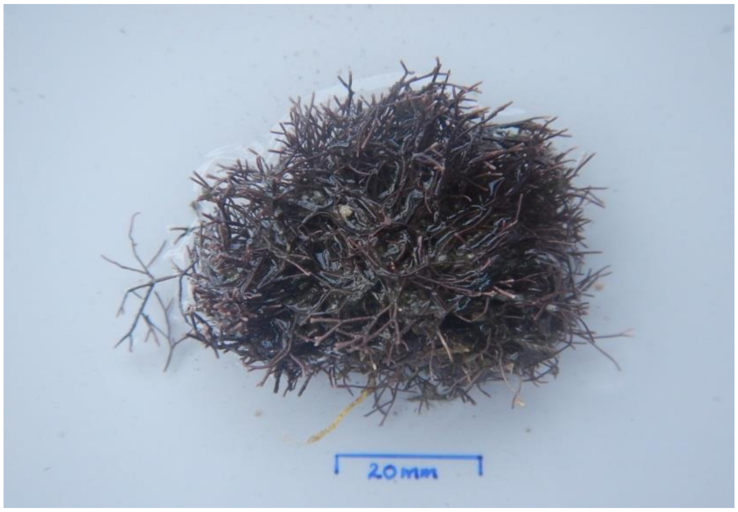

Fig.57. ***Amphiroa fragillissima***

KEY CHARACTERS:

The thallus form is calcified and articulated. The plants are purple red, up to 3 cm tall which is calcified erectile and fragile with regular dichotomous or trichotomous branches. Sometimes it has adventitious branches with obtuse apices. The segments or intergenicula are cylindrical / slightly compressed and sometimes with pad-like swellings at the tip. The conceptacles are lateral, hemispherical and prominent.

Habitat: Lower mid littoral zone, rock pool

Economic importance: Medicine

4.1.35 ***Hypnea musciformis*** **(Wulfen) J.V.Lamouroux, 1816**

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Gigartinales

FAMILY : Cystocloniaceae

GENUS : Hypnea

KEY CHARACTERS:

The thallus form is bushy with apical hooks. The plants are pinkish red which is seen as a common epiphyte on *Laurencia intermedia* and other algae which are easily recognized on the inflated and hooked tips of the main branch. The dense clothing is simple and slender branchlets are about 1 mm length and 80-130 micron thickness. The length of the whole plant is about 10 cm.

Habitat: Mangrove swamps and Intertidal zone

IUCN Status: LRnt

Economic importance: Food, carrageenan yielding plant

4.1.36 *Hypnea valentiae* (Turner) Montagne, 1841

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Gigartinales

FAMILY : Cystocloniaceae

GENUS : Hypnea

Fig.58. *Hypnea valentiae*

KEY CHARACTERS:

The plants are erect and laxly branched with the distinct cylindrical main axis of 680-1700µ thickness. The branches are simple and filiform; but occasionally forked and distinctly oriented at right angle to the axis. The ultimate branchlets are 300-1300 µ long irregularly disposed around the axis. The inflated branches; stichidia are seen as swollen bands at the middle, near the base or rarely near the tips of ultimate branchlets.The plants are greenish to pinkish red in colour. The thallus form is bushy with spinous ramuli.

Habitat: Mangrove swamps and Intertidal zone

IUCN Status: LRnt

Economic importance: Food, carrageenan yielding plant

4.1.37 *Gelidiopsis intricata* (C.Agardh) Vickerns, 1905

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Rhodymeniales

FAMILY : Lomentariaceae

GENUS : Gelidiopsis

Fig.59.*Gelidiopsis intricata*

KEY CHARACTERS:

The thallus form is bushy and wing clumps are usually mixed with other seaweeds. The plants are greenish or purplish brown colour when it is fresh. The plants are attached to the substrate by rhizoids with somewhat creeping and entangled lower branches. The upper ones are erect with filaments of 2-6 m tall, 160-454 μ in diameter and it tapers towards the apices. The branches are spares, irregular and somewhat subdichotomous.The cross-section of branch shows a medulla composed of thick walls and very small rounded cells.

Habitat: Intertidal and subtidal zone

IUCN Status: NE

Economic importance: Food, medicine

4.1.38 *Gelidiopsis variabilis* (C.Agardh) Schmitz, 1895

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Rhodymeniales

FAMILY : Lomentariaceae

GENUS : Gelidiopsis

Fig.60. *Gelidiopsis variabilis*

KEY CHARACTERS:

The thallus form is bushy and cartilaginous. The plants are brownish red in colour about 7-10 cm height with cylindrical, filiform, erect primary axis. The stiff and wiry sparingly branches are simple, cylindrical with obtuse apices.

Habitat: Mid littoral zone

Economical importance: Food, medicine

4.1.39 *Centroceras clavulatum* (C. Agardh) Montagne, 1846

DIVISION : Rhodophyta

CLASS : Florideophyceae

ORDER : Ceramiales

FAMILY : Ceramiaceae

GENUS : Centroceras

Fig.61. *Centroceras clavulatum* attached to the rocks

Fig.62.*Centroceras clavulatum*

KEY CHARACTERS:

The thallus form is filamentous and bushy type.The plants are dark red in colour about 5-8 cm tall, erect, filamentous and rigid. The filaments are regularly dichotomously branched with nodes and fully corticated internodes. The ultimate branches are forcipate, of 500 µm long, 120-180 µm broad have cortical cells quadrate/rectangular arranged in longitudinal rows.

Habitat: Intertidal

Economic Importance: Source of agar

4.1.40 *Acanthophora spicifera* (M.Vahl) Borgesen, 1910

DIVISION : Rhodophyta
CLASS : Florideophyceae
ORDER : Ceramiales
FAMILY : Rhodomelaceae
GENUS : Acanthophora

Fig.63. ***Acanthophora spicifera***

KEY CHARACTERS:

The thallus form is bushy and the wing clumps are usually mixed with other seaweeds. The lower branches are somewhat creeping and entangled which are attached to the substrate by rhizoids. The upper ones are erect, filamentous about 2-6 m tall, cylindrical of 160-454µ in diameter which is tapering towards the apices. The plants are greenish or purplish brown when fresh with spare branches, irregular and somewhat subdichotomous.The cross section of the branches shows a medulla comprising of thick-walled and very small round cells.

Habitat: Intertidal and subtidal zones

Economic Importance: Carageenan yielding plant.

4.2 Diversity of seaweeds along the Thikkodi coast

During the study period from September 2018 to August 2019, a total of 40 species of seaweeds were recorded along the Thikkodi coast which belonged to 23 genera, 18 families and 14 orders (Table 2). Out of the 40 species, 31 species of seaweeds were obtained during the quadrat surveys and the remaining 9 species *viz*., *Caulerpa racemosa, Enteromorpha intestinalis, Ectocarpus siliculosus, Dictyota ciliolata, Dictyota dichotoma, Stoechospermum marginatum, Sargassum cinereum, Gracilaria corticata* var. *cylindrica* and *Hypnea musciformis* were observed outside the quadrats, during the general survey.

Table 2. Checklist of seaweeds recorded from the Thikkodi coast from September 2018 to August 2019

Sl. No.	SCIENTIFIC NAME	FAMILY	ORDER	CLASS	DIVISION
1	*Caulerpa peltata* J.V. Lamouroux, 1809	Caulerpaceae	Bryopsidales	Ulvophyceae	Chlorophyta
2	*Caulerpa racemosa* (Forsskal) J. Agardh,1873	Caulerpaceae	Bryopsidales	Ulvophyceae	Chlorophyta
3	*Caulerpa scalpelliformis* (R.Brown ex Turner) C. Agardh, 1817	Caulerpaceae	Bryopsidales	Ulvophyceae	Chlorophyta
4	*Caulerpa sertularioides* (S.G.Gmelin) M.A.Howe, 1905	Caulerpaceae	Bryopsidales	Ulvophyceae	Chlorophyta
5	*Caulerpa taxifolia* (Vahl) C. Agardh, 1817	Caulerpaceae	Bryopsidales	Ulvophyceae	Chlorophyta
6	*Chaetomorpha antennina* (Bory) Kutezing,1845	Cladophoraceae	Cladophorales	Ulvophyceae	Chlorophyta
7	*Chaetomorpha linum* (Muller) Kutezing,1845	Cladophoraceae	Cladophorales	Ulvophyceae	Chlorophyta
8	*Chaetomorphacrassa*(Agardh)Kutezing,1845	Cladophoraceae	Cladophorales	Ulvophyceae	Chlorophyta
9	*Ulva lactuca* Linnaeus,1753	Ulvaceae	Ulvales	Ulvophyceae	Chlorophyta
10	*Ulva fasciata* Delile,1813	Ulvaceae	Ulvales	Ulvophyceae	Chlorophyta
11	*Enteromorpha compressa* (Linnaeus) Nees,1820	Ulvaceae	Ulvales	Ulvophyceae	Chlorophyta
12	*Enteromorpha intestinalis* (Linnaeus) Nees, 1820	Ulvaceae	Ulvales	Ulvophyceae	Chlorophyta
13	*Cladophora fascicularis* Kutezing,1843	Cladophoraceae	Cladophorales	Ulvophyceae	Chlorophyta
14	*Cladophora prolifera* (Roth) Kutezing,1843	Cladophoraceae	Cladophorales	Ulvophyceae	Chlorophyta
15	*Cladophora herpestica* (Montagne) kutezing, 1849	Cladophoraceae	Cladophorales	Ulvophyceae	Chlorophyta

16	*Boodlea composita* (Harvey) Brand,1904	Boodleaceae	Cladophorales	Ulvophyceae	Chlorophyta
17	*Valoniopsis pachynema* (Martens)Borgesen,1934	Valoniaceae	Cladophorales	Ulvophyceae	Chlorophyta

Table 2. continued

Sl. No.	SCIENTIFIC NAME	FAMILY	ORDER	CLASS	DIVISION
18	*Bryopsis pennata* Lamouroux,1809	Bryopsidaceae	Bryopsidales	Ulvophyceae	Chlorophyta
19	*Ulothrix flacca* (Dillwyn) Thuret, 1863	Ulotrichaceae	Ulotrichales	Ulvophyceae	Chlorophyta
20	*Ectocarpus siliculosus* (Dillwyn) Lyngbye, 1819	Ectocarpaceae	Ectocarpales	Phaeophyceae	Phaeophyta
21	*Dictyota ciliolata* Sonder ex Kutezing,1859	Dictyotaceae	Dictyotales	Phaeophyceae	Phaeophyta
22	*Dictyota dichotoma* (Hudson) J.V. Lamouroux,1809	Dictyotaceae	Dictyotales	Phaeophyceae	Phaeophyta
23	*Stoechospermum marginatum* (C. Agardh) Kutezing, 1843	Dictyotaceae	Dictyotales	Phaeophyceae	Phaeophyta
24	*Spatoglossum asperum* J.Agardh,1894	Dictyotaceae	Dictyotales	Phaeophyceae	Phaeophyta
25	*Padina gymnospora* (Kutezing) Sonder,1871	Dictyotaceae	Dictyotales	Phaeophyceae	Phaeophyta
26	*Padina tetrastromatica* Hauck, 1887	Dictyotaceae	Dictyotales	Phaeophyceae	Phaeophyta
27	*Sargassum wightii* Greville ex J. Agardh, 1848	Sargassaceae	Fucales	Phaeophyceae	Phaeophyta
28	*Sargassum cinereum* J. Agardh, 1848	Sargassaceae	Fucales	Phaeophyceae	Phaeophyta
29	*Gelidium pusillum* (Stackhouse) Le Jolis, 1863	Gelidiaceae	Gelidiales	Florideophyceae	Rhodophyta
30	*Gracilaria corticata* (J.Agardh) J.Agardh, 1852	Gracilariaceae	Gracilariales	Florideophyceae	Rhodophyta
31	*Gracilaria corticata* var. *cylindrica*Umamaheswara Rao, 1974	Gracilariaceae	Gracilariales	Florideophyceae	Rhodophyta
32	*Grateloupia indica* Borgesen, 1932	Halymeniaceae	Halymeniales	Florideophyceae	Rhodophyta
33	*Grateloupia lithophila* Borgesen,1938	Halymeniaceae	Halymeniales	Florideophyceae	Rhodophyta
34	*Amphiroa fragilissima* (Linnaeus) Lamouroux,1816	Lithophyllaceae	Corallinales	Florideophyceae	Rhodophyta
35	*Hypnea musciformis* (Wulfen) J.V.Lamouroux,1816	Cystocloniaceae	Gigartinales	Florideophyceae	Rhodophyta
36	*Hypnea valentiae* (Turner) Montagne,1841	Cystocloniaceae	Gigartinales	Florideophyceae	Rhodophyta
37	*Gelidiopsis intricate* (C.Agardh) Vickerns,1905	Lomentariaceae	Rhodymeniale s	Florideophyceae	Rhodophyta
38	*Gelidiopsis variabilis* (C.Agardh) Schmitz,1895	Lomentariaceae	Rhodymeniale s	Florideophyceae	Rhodophyta
39	*Centroceras clavulatum* (C. Agardh) Montagne,1846	Ceramiaceae	Ceramiales	Florideophyceae	Rhodophyta
40	*Acanthopora spicifera* (M.Vahl) Borgesen,1910	Rhodomelaceae	Ceramiales	Florideophyceae	Rhodophyta

Of the 40 species of seaweeds recorded, 19 species belonged to the Division Chlorophyta, while 12 species belonged to Rhodophyta and 9 species belonged to Phaeophyta (Fig. 64).The studies conducted by Palaniswamy *et al*. (2015) shows a total of 48 species at Thikkodi coast.The Chlorophyta were dominant with 23 species (48%), followed by Rhodophyta with 17 species (35%) and Phaeophya with 8 species(17%). The Division Chlorophyta comprised of seven families *viz*., Caulerpaceae (5 species - *Caulerpa peltata, C. racemosa, C. scalpelliformis, C. sertularioides* and *C. taxifolia*), Cladophoraceae (6 species - *Chaetomorpha antennina, C. linum, C. crassa, Cladophora fascicularis, C. prolifera* and *C. herpestica*), Ulvaceae (4 species - *Ulva lactuca, U. fasciata, Enteromorpha compressa* and *E. intestinalis*), Boodleaceae (1 species - *Boodlea composita*), Valoniaceae (1 species - *Valoniopsis pachynema*), Bryopsidaceae (1 species - *Bryopsis pennata*) and Ulotrichaceae (1 species - *Ulothrix flacca*).

The Division Rhodophyta comprised of 8 families *viz*., Gelidiaceae (1 species - *Gelidium pusillum*), Gracilariaceae (2 species - *Gracilaria corticata* and *G. corticata* var. *cylindrica*), Halymeniaceae (2 species - *Grateloupia indica* and *G. lithophila*), Lithophyllaceae (1 species - *Amphiroa fragilissima*), Cystocloniaceae (2 species - *Hypnea musciformis* and *H. valentiae*), Lomentariaceae (2 species - *Gelidiopsis intricata* and *G. variabilis*), Ceramiaceae (1 species - *Centroceras clavulatum*) and Rhodomelaceae (1 species - *Acanthopora spicifera*).

The Division Phaeophyta was represented by 3 families namely Ectocarpaceae (1 species - *Ectocarpus siliculosus*), Dictyotaceae (6 species - *Dictyota ciliolata, D. dichotoma, Stoechospermum marginatum, Spatoglossum asperum, Padina gymnospora* and *P. tetrastromatica*) and Sargassaceae (2 species - *Sargassum wightii* and *S. cinereum*).

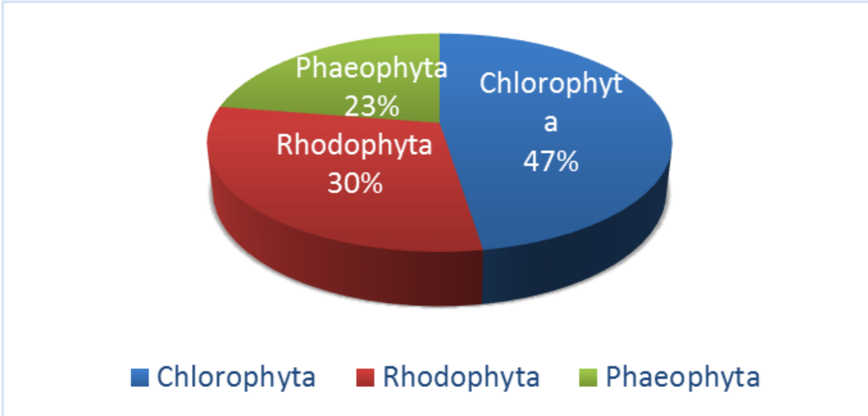

Fig.64. Percentage species composition of seaweeds under different divisions, identified during the quadrat survey

In the quadrat surveys, 31 species were encountered during the study period of which 17 species belonged to Chlorophyta, 10 to Rhodophyta and 4 species belonged to Phaeophyta (Fig. 65).

A total of 37 species of seaweeds were collected during the year 1998-1999 from the stations (Mullur, Dhalavapuram, Thirumallavaram, Manassary, Chettikulam, Thikkodi, Dharmadom, Kannur, Bekal) (Ushakiran *et al*, 2017). Out of 37 species, 13 were grouped under Chlorophyta, 17 were under Rhodophyta and 7 under Phaeophyta. The studies conducted by Palaniswamy *et al*. (2015) suggest the presence of 48 seaweed species along the Thikkodi coast.

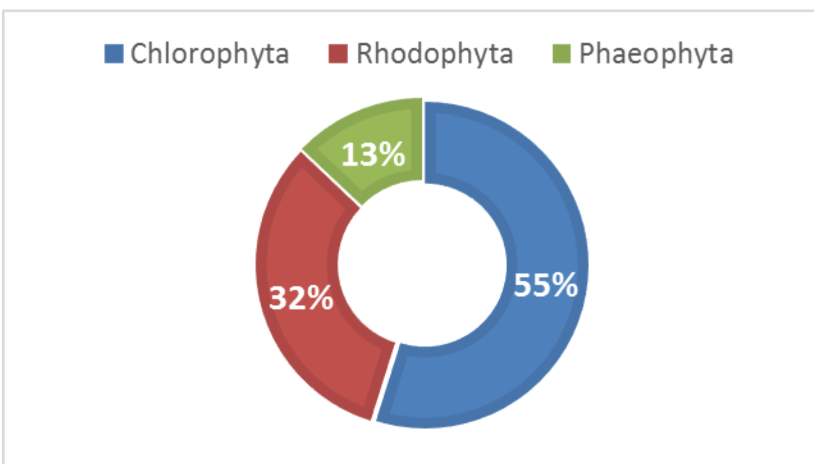

Fig.65. Percentage species composition of seaweeds under different divisions, encountered during the quadrat surveys for different species

4.3 Seasonal variation in abundance of seaweeds at Thikkodi

The average monthly variation (average of three zones) in species abundance of seaweeds along the Thikkodi coast is given in table 3 and the monthly variation in species abundance in different zones is given in tables 4 to 6. The average seasonal abundance of seaweeds for the three study zones is given in tables 7 to 9.

4.3.1Seasonal variation in Zone 1

During the pre-monsoon season, *Caulerpa scalpelliformis* recorded the highest biomass of 2.21 g/sq.m.followed by *Acanthophora spicifera* (2.05 g/sq.m.), *Gracilaria corticata* (1.69 g/sq.m.) and *Centroceras clavulatum* (1.45 g/sq.m.). The seaweed species *Chaetomorpha linum, Ulva fasciata, Enteromorpha compressa, Boodlea composite, Bryopsis pennata* and *Ulothrix flacca* were absent. During the monsoon season, highest biomass of 2.06 g/sq.m. was recorded in the case of *Gracilaria corticata*, which was followed by *Acanthophora spicifera* (1.43 g/sq.m.) and *Centroceras clavulatum* (1.41 g/sq.m.). The species *Enteromorpha compressa, Cladophora fascicularis, Bryopsis pennata*, *Ulothrix flacca* and *Spatoglossum asperum* were absent. During the post-monsoon season too, *Gracilaria corticata* recorded the highest biomass of 1.22 g/sq.m., followed by *Amphiroa fragilissima* which recorded a biomass of 1.04 g/sq.m. The species *Caulerpa scalpelliformis* which recorded the highest biomass in the pre-monsoon season was absent during the post-monsoon season, in zone 1. The average value of three seasons revealed highest representation by *Gracilaria corticata* (1.6523 g/sq. m.), followed by *Acanthophora spicifera* (1.2774 g/sq.m.).

In zone 1, a total of 30 species were recorded. The species *Enteromorpha compressa* was completely absent in zone 1 and was not recorded in any of the seasons.

4.3.2 Seasonal variation in Zone 2

During pre-monsoon, the highest biomass was recorded in the case of *Cladophora herpestica* (2.3170 g/sq.m.), followed by *Valoniopsis pachynema* (1.7517 g/sq.m.) and *Cladophora prolifera* (1.6123 g/sq.m.). The maroalgal species *Chaetomorpha linum, Ulva fasciata, Boodlea composita, Bryopsis pennata, Ulothrix flacca, Spatoglossum asperum, Sargassum cinereum, Grateloupia indica, Grateloupia lithophila, Hypnea valentiae* and

Centroceras clavulatum were absent during the pre-monsoon period. During monsoon, the highest biomass was recorded in the case of *Cladophora herpestica* (1.4407 g/sq.m.), followed by *Gracilaria corticata* (0.5383 g/sq.m.). The species *Caulerpa peltata, Caulerpa scalpelliformis, Caulerpa sertularioides, Caulerpa taxifolia, Chaetomorpha crassa, Ulva fasciata, Cladophora fascicularis, Boodlea composita, Bryopsis pennata, Ulothrix flacca, Spatoglossum asperum, Grateloupia indica, Grateloupia lithophila, Amphiroa fragilissima, Hypnea valentiae* and *Gelidiopsis variabilis* were completely absent during the monsoon season in zone 2. During the post-monsoon season, *Caulerpa peltata* recorded the highest biomass (2.6777 g/sq.m.), followed by *Cladophora prolifera* (2.0580 g/sq.m.) and *Caulerpa sertularioides* (1.1689 g/sq.m.). However 11 seaweed species namely *Caulerpa scalpelliformis, Caulerpa taxifolia, Cladophora fascicularis, Boodlea composita, Spatoglossum asperum, Padina gymnospora, Padina tetrastromatica, Sargassum cinereum, Gelidium pusillum, Grateloupia indica* and *Grateloupia lithophila* were absent during the post-monsoon season in zone 2.The average value of three seasons revealed highest biomass of *Cladophora prolifera* (1.3773 g/sq.m.), followed by *Cladophora herpestica* (1.2774 g/sq.m.).

In zone 2, a total of 27 species were found. Four species of seaweeds *viz*., *Boodlea composita*, *Spatoglossum asperum*, *Grateloupia indica* and *Grateloupia lithophila* did not occur in zone 2 during any of the three seasons.

4.3.3 Seasonal variation in Zone 3

During pre-monsoon, *Valoniopsis pachynema* (0.9324 g/sq.m.) recorded the highest biomass, while during monsoon and post-monsoon seasons, *Cladophora herpestica* (0.7623 g/sq.m.) and *Cladophora prolifera* (1.6633 g/sq.m.) respectively recorded the highest biomass. A total of 21 species were absent during the pre-monsoon season (*Caulerpa scalpelliformis, Caulerpa sertularioides, Chaetomorpha antennina, Chaetomorpha linum, Ulva lactuca, Ulva fasciata, Enteromorpha compressa, Boodlea composita, Bryopsis pennata, Ulothrix flacca, Spatoglossum asperum, Padina gymnospora, Padina tetrastromatica, Sargassum cinereum, Gracilaria corticata, Grateloupia indica, Grateloupia lithophila, Amphiroa fragilissima, Hypnea valentiae, Centroceras clavulatum and spicifera*). During the monsoon season, a total of 21 species namely *Caulerpa peltata,* *Caulerpa scalpelliformis, Caulerpa sertularioides, Caulerpa taxifolia, Chaetomorpha crassa, Ulva fasciata, Enteromorpha compressa, Cladophora fascicularis, Boodlea composita, Bryopsis pennata, Ulothrix flacca, Spatoglossum asperum, Padina gymnospora, Padina tetrastromatica, Sargassum cinereum, Grateloupia indica, Grateloupia lithophila, Hypnea valentiae, Gelidiopsis intricata, Gelidiopsis variabilis* and *Acanthopora spicifera* were completely absent in zone 3. During the post-monsoon season, 9 species namely *Caulerpa scalpelliformis, Caulerpa taxifolia, Chaetomorpha linum, Cladophora fascicularis, Boodlea composita, Spatoglossum asperum, Padina gymnospora, Sargassum cinereum* and *Grateloupia indica* were not recorded. The annual average biomass was highest in the case of *Cladophora prolifera* (0.7561 g/sq.m.).

In zone 3, a total of 27 species were recorded. Four species namely*Caulerpa scalpelliformis, Boodlea composita, Spatoglossum asperum, Padina gymnospora, Sargassum cinereum* and *Grateloupia indica* were absent in this zone.

Prabhakar (2017) recorded a total of 19 species of seaweeds representing 16 genera,15 families and 13 orders from Uran (Navi Mumbai),West coast of India.They observed a maximum species diversity in pre-monsoon,post-monsoon than pre-monsoon phases.The maximum species diversity was identified during post-monsoon than the monsoon phases. The higher species composition was also identified during post-monsoon than pre-monsoon and monsoon phases (Prabhakar,2017).A total of 42 macroalgae taxa (23 Rhodophyta 10 Chlorophyta,and 9 Phaeophyta) which belonged to 18 families were recorded in four seasons autumn, winter, spring and summer in two localities on the eastern coast of the Qeshm Island (Kokabi *et al.*,2016).

By removing a remarkable amount of carbon from the sea during the harvest period (Tang *et al*., 2011),macroalgae are potential aids for biomass production and carbon sequestration (Duarte *et al*., 2005).The macroalgae act as a carbon sink and sequester carbon within their biomass throughout their life span (Chung *et al*., 2013) and beyond (Trevathan-Tackett *et al*., 2015).The macroalgae have been considered as donor of coastal 'blue carbon' in mitigating CO_2 sequestration of CO_2 from seawater by photosynthesis and utilizing it to increase their biomass that can potentially be transeferred to deep sea benthos or deposited to other coastal ecosystems.

Table 3. Average monthly variation in seaweed abundance along the Thikkodi coast (average values of 3 zones; biomass in gm/m^2)

SPECIES	POST-MONSOON				PRE-MONSOON				MONSOON			
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Caulerpa peltata	0	219.85	263.82	555.72	279.94	261.23	25.44	22.5	2.79	0	0	0
Caulerpa scalpelliformis	0	0	0	0	282.16	232.22	2.01	66.24	1.58	0	0.23	0
Caulerpa sertularioides	0	314.97	138.93	1.51	11.95	0	97.14	54.19	0	0	0.11	0
Caulerpa taxifolia	0	0	0	0	0	55.21	0	3.74	2.45	0	0	0
Chaetomorpha antennina	16.77	9.21	7.16	0	0	0	9.22	5.37	11.81	6.28	6.28	8.26
Chaetomorpha linum	2.26	0	1.37	0	3.73	0	0	0	0	0	0	76
Chaetomorpha crassa	0	0	25.52	8.65	4.79	0.16	13.84	0.99	1.33	3.21	0	0
Ulva lactuca	261.26	41.16	163.28	83.36	97.08	23.35	0	0.93	2.08	5.94	15.57	228.5
Ulva fasciata	111.04	19.59	31.92	0	0	0	0	0	0	13.15	0	0
Enteromorpha compressa	0	0	0	4.32	0	0	0	0	0	0	5.65	0
Cladophora fascicularis	0	0	0	0	0	0	80.31	0	0	0	0	0
Cladophora prolifera	0	951.65	24.06	0	33.31	214.01	106.8	280.27	27.14	122.53	12.39	0
Cladophora herpestica	0	196.25	15.7	0	62.68	30.4	118.39	744.77	505.95	155.76	24.98	0
Boodlea composita	0	0	0	0	0	0	0	0	0	8.65	17.59	0
Valoniopsis pachynema	85.43	24.26	169.41	111.49	125.25	141.82	427.07	97.66	21.1	30.21	39.17	0
Bryopsis pennata	0	21.34	31.97	0	0	0	0	0	0	0	0	0
Ulothrix flacca	0	11.55	6.9	0	0	0	0	0	0	0	0	0
Spatoglossum asperum	0	0	0	0	0	15.62	0	0	0	0	0	0
Padina gymnospora		0	0	0	2.46	23.83	14.09	15.01	5.13	0	0	1.21
Padina tetrastromatica	136.04	0	0	0	0	30.49	34.15	0	5.43	0.21	0	0

Table 3. Continued

SPECIES	POST-MONSOON				PRE-MONSOON				MONSOON			
	Oct	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Sargassum cinereum	0	0	0	0	0	50.23	14.25	0.18	0	0	0	25.28
Gelidium pusillum	0	57.83	23.84	76.69	40.14	17.7	131.17	57.08	155.15	83.65	49.41	0
Gracilaria corticata	97.68	236.29	158.38	127.21	388.77	51.2	14.94	188.4	97.76	172.02	0	334.61
Grateloupia indica	0	0	0	0	0	0	0	0	0	32.47	0	64.39
Grateloupia lithophila	124.49	1.33	0	0	0	0	46.33	5.84	5.21	3.96	2.85	0
Amphiroa fragilissima	0	260.04	40.39	49.09	0	16.88	11.04	0	1.59	3.24	0	0
Hypnea valentiae	0	6.45	16.07	0	1.08	0	0	0	7.49	10.9	0.4	0
Gelidiopsis intricata	175.88	2.17	101.46	24.62	0.39	22.05	95.55	7.17	15.02	52.77	9.77	269.11
Gelidiopsis variabilis	0	122.95	56.41	0	63.76	63.43	136.25	72.62	0	19.81	0.66	0
Centroceras clavulatum	260.12	137.74	179.74	162.69	365.33	43.82	28.89	0	57.67	244.6	0.84	107.84
Acanthopora spicifera	60.4	57.3	71.58	65.35	40.88	107.51	153.01	98.23	168.51	89.24	1.6	112.19

Table 4. Monthly variation of seaweed abundance in Zone 1 along the Thikkodi coast (biomass in gm/m^2)

ZONE 1												
	POST-MONSOON				PRE-MONSOON				MONSOON			
SPECIES	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Caulerpa peltata	0	30.45	12.01	27.18	144.49	40.98	25.44	22.5	2.79	0	0	0
Caulerpa scalpelliformis	0	0	0	0	270.44	232.22	2.01	66.24	1.58	0	0.23	0
Caulerpa sertularioides	0	0	51.83	1.51	11.95	0	79.39	54.19	0	0	0.11	0
Caulerpa taxifolia	0	0	2.01	0	0	16.53	0	3.74	2.45	0	0	0
Chaetomorpha antennina	5.4	4.64	0	0	0	0	1.57	1.96	3.72	5.49	5.31	6.88
Chaetomorpha linum	0	0	0	0	0	0	0	0	0	0	0	3.28
Chaetomorpha crassa	0	0	1.22	2.82	1.32	0	0	0.04	1.33	3.21	0	0
Ulva lactuca	39.27	6.88	5.97	35.17	97.08	23.35	0	0	2.08	4.4	3.5	34.97
Ulva fasciata	7.01	8.39	25.95	0	0	0	0	0	0	13.15	0	0
Enteromorpha compressa	0	0	0	0	0	0	0	0	0	0	0	0
Cladophora fascicularis	0	0	0	0	0	0	4.67	0	0	0	0	0
Cladophora prolifera	0	11.99	2.39	0	0	0	0	84.28	13.54	23.14	0	0
Cladophora herpestica	0	57.46	0	0	0	0.31	18.46	239.5	32.06	79.4	5.81	0
Boodlea composita	0	0	0	0	0	0	0	0	0	8.65	17.59	0
Valoniopsis pachynema	22.01	11.14	61.37	0	0	1.26	78.64	18.49	5.34	14.47	7.23	0
Bryopsis pennata	0	21.34	24.13	0	0	0	0	0	0	0	0	0
Ulothrix flacca	0	0	3.19	0	0	0	0	0	0	0	0	0
Spatoglossum asperum	0	0	0	0	0	15.62	0	0	0	0	0	0
Padina gymnospora	0	0	0	0	0	23.83	10.92	15.01	0	0	0	0.49
Padina tetrastromatica	0	0	0	0	0	23.83	25.25	0	0	0.21	0	0
Sargassum cinereum	0	0	0	0	0	50.23	14.25	0.18	0	0	0	20.1

Table 4. Continued

ZONE 1												
	POST-MONSOON				**PRE-MONSOON**				**MONSOON**			
SPECIES	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Gelidium pusillum	0	14.14	1.58	31.08	19.86	17.7	58.58	19.39	56.48	70.58	44.22	0
Gracilaria corticata	77.63	236.29	0	0	181	51.2	14.94	188.4	31.55	172.02	0	327.47
Grateloupia indica	0	0	0	0	0	0	0	0	0	32.47	0	64.39
Grateloupia lithophila	10.77	1.33	0	0	0	0	46.33	5.84	5.21	3.96	2.85	0
Amphiroa fragilissima	0	260.04	7.47	0	0	0	1.95	0	1.59	0	0	0
Hypnea valentiae	0	0	0	0	1.08	0	0	0	7.49	10.9	0.4	0
Gelidiopsis intricata	137.07	0.81	0	0	15.15	22.05	93.83	7.17	15.02	63.7	9.77	169.5
Gelidiopsis variabilis	0	117.23	26.51	0	21.72	63.43	134.24	72.62	0	19.81	0.66	0
Centroceras clavulatum	15.82	90.56	69.67	17.39	222.95	43.82	28.89	0	57.67	244.6	0.75	61.52
Acanthopora spicifera	54.73	0	23.81	13.17	170.92	107.51	153.01	98.23	168.51	89.24	1.6	109.24

Table 5. Monthly variation of seaweed abundance in Zone 2 along the Thikkodi coast (biomass in gm/m^2)

ZONE 2												
	POST-MONSOON				PRE-MONSOON				MONSOON			
SPECIES	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	Aug	**Sep**
Caulerpa peltata	0	0	180.54	511.19	135.45	143.34	0	0	0	0	0	0
Caulerpa scalpelliformis	0	0	0	0	11.72	0	0	0	0	0	0	0
Caulerpa sertularioides	0	234.94	67.03	0	0	0	17.75	0	0	0	0	0
Caulerpa taxifolia	0	0	0	0	0	36.66	0	0	0	0	0	0
Chaetomorpha antennina	6.17	0	0	0	0	0	7.65	3.41	3.78	0.79	0.1	1.38
Chaetomorpha linum	2.26	0	1.37	0	0	0	0	0	0	0	0	31.5
Chaetomorpha crassa	0	0	24.3	3.12	0	0	12.3	0	0	0	0	0
Ulva lactuca	17.82	0	27.71	6.25	0	0	0	1.88	0	1.54	9.03	164.06
Ulva fasciata	83.65	10.25	0	0	0	0	0	0	0	0	0	0
Enteromorpha compressa	0	3.59	0	2.6	0	0	0	0	0	0	5.65	0
Cladophora fascicularis	0	0	0	0	0	0	23.87	0	0	0	0	0
Cladophora prolifera	0	524.11	7.54	0	5.49	118.01	97.03	195.99	13.6	99.39	6.22	0
Cladophora herpestica	0	19.42	5.38	0	48.77	20.02	84.92	444.85	297.18	55.82	19.17	0
Boodlea composita	0	0	0	0	0	0	0	0	0	0	0	0
Valoniopsis pachynema	35.39	0	23.18	58.61	89.37	61.46	301.7	0	0	5.38	7.77	0
Bryopsis pennata	0	0	31.37	0	0	0	0	0	0	0	0	0
Ulothrix flacca	0	11.55	0	0	0	0	0	0	0	0	0	0
Spatoglossum asperum	0	0	0	0	0	0	0	0	0	0	0	0

Table 5. continued

ZONE 2												
	POST-MONSOON				PRE-MONSOON				MONSOON			
SPECIES	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	Aug	**Sep**
Padina gymnospora	0	0	0	0	0	0	3.17	0	5.13	0	0	0.72
Padina tetrastromatica	0	0	0	0	0	6.66	8.9	0	5.43	0	0	0
Sargassum cinereum	0	0	0	0	0	0	0	0	0	0	0	5.18
Gelidium pusillum	0	0	0	0	15.42	0	72.59	37.49	42.75	13.07	5.19	0
Gracilaria corticata	20.05	0	74.41	0	86.93	0	0	0	59.48	0	0	79.58
Grateloupia indica	0	0	0	0	0	0	0	0	0	0	0	0
Grateloupia lithophila	0	0	0	0	0	0	0	0	0	0	0	0
Amphiroa fragilissima	0	0	0	5.17	0	16.88	9.71	0	0	0	0	0
Hypnea valentiae	0	0	5.89	0	0	0	0	0	0	0	0	0
Gelidiopsis intricata	37.1	1.36	33.01	0	71.87	0	0	0	0	3.14	0	27.17
Gelidiopsis variabilis	0	5.72	0	0	42.04	0	0	0	0	0	0	0
Centroceras clavulatum	72.54	17.74	75.54	93.33	0	0	0	0	0	0	0.09	46.32
Acanthopora spicifera	18.75	23.91	31.09	21.09	12.34	0	0	0	0	0	0	2.95

Table 6. Monthly variation of seaweed abundance in Zone 3 along the Thikkodi coast (biomass in gm/m^2)

ZONE 3												
	POST-MONSOON				PRE-MONSOON				MONSOON			
Species	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Caulerpa peltata	0	189.4	71.27	17.35	0	76.91	0	0	0	0	0	0
Caulerpa scalpelliformis	0	0	0	0	0	0	0	0	0	0	0	0
Caulerpa sertularioides	0	80.03	20.07	0	0	0	0	0	0	0	0	0
Caulerpa taxifolia	0	0	0	0	0	2.02	0	0	0	0	0	0
Chaetomorpha antennina	5.2	2.78	5.15	0	0	0	0	0	4.31	0	0.87	0
Chaetomorpha linum	0	0	0	0	0	0	0	0	0	0	0	41.22
Chaetomorpha crassa	0	0	0	8.42	3.47	0.16	1.54	0	0	0	0	0
Ulva lactuca	203.89	30.5	135.57	5.59	0	0	0	0	0	0	3.04	31.61
Ulva fasciata	20.38	3.74	25.39	0	0	0	0	0	0	0	0	0
Enteromorpha compressa	0	0	0	1.72	0	0	0	0	0	0	0	0
Cladophora fascicularis	0	0	0	0	0	0	51.77	0	0	0	0	0
Cladophora prolifera	0	415.55	14.13	0	27.82	96	9.77	0	0	0	6.17	16.53
Cladophora herpestica	0	119.37	10.32	0	13.91	10.07	67.23	49.79	176.71	20.21	0	0
Boodlea composita	0	0	0	0	0	0	0	0	0	0	0	0
Valoniopsis pachynema	28.03	6.38	53.49	17.19	35.88	79.1	46.73	79.17	15.76	10.36	24.17	0
Bryopsis pennata	0	0	7.84	0	0	0	0	0	0	0	0	0
Ulothrix flacca	0	0	3.71	0	0	0	0	0	0	0	0	0
Spatoglossum asperum	0	0	0	0	0	0	0	0	0	0	0	0
Padina gymnospora	0	0	0	0	0	0	0	0	0	0	0	0
Padina tetrastromatica	136.04	0	0	0	0	0	0	0	0	0	0	0
Sargassum cinereum	0	0	0	0	0	0	0	0	0	0	0	0

Table 6. continued

ZONE 3												
	POST-MONSOON				**PRE-MONSOON**				**MONSOON**			
Species	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**
Gelidium pusillum	0	0	22.26	44.82	0	0	0	0.2	55.74	0	0	0
Gracilaria corticata	0	43.69	123.15	127.21	0	0	0	0	6.73	0	0	0
Grateloupia indica	0	0	0	0	0	0	0	0	0	0	0	0
Grateloupia lithophila	113.72	0	0	0	0	0	0	0	0	0	0	0
Amphiroa fragilissima	0	0	32.92	43.92	0	0	0	0	0	3.24	0	0
Hypnea valentiae	0	6.45	10.18	0	0	0	0	0	0	0	0	0
Gelidiopsis intricata	1.71	0	29.27	24.62	0.39	0	1.72	0	0	0	0	0
Gelidiopsis variabilis	0	0	29.9	0	0	0	2.01	0	0	0	0	0
Centroceras clavulatum	158.68	47.18	70.11	168.93	0	0	0	0	0	1.84	0	0
Acanthopora spicifera	0	33.39	0	31.09	0	0	0	0	0	0	0	0

Table 7. Seasonal variation of seaweed abundance in Zone 1 along the Thikkodi coast (biomass in gm/m^2)

Species	Zone 1			Average of three seasons
	Pre-monsoon	Monsoon	Post-monsoon	
Caulerpa peltata	0.9035	0.0108	0.2696	0.3946
Caulerpa scalpelliformis	2.2100	0.0070	0.0000	0.7390
Caulerpa sertularioides	0.5633	0.0004	0.2065	0.2567
Caulerpa taxifolia	0.0785	0.0095	0.0078	0.0319
Chaetomorpha antennina	0.0137	0.0828	0.0389	0.0451
Chaetomorpha linum	0.0000	0.0127	0.0000	0.0042
Chaetomorpha crassa	0.0053	0.0176	0.0156	0.0128
Ulva lactuca	0.4662	0.1740	0.3379	0.3260
Ulva fasciata	0.0000	0.0509	0.1601	0.0703
Enteromorpha compressa	0.0000	0.0000	0.0000	0.0000
Cladophora fascicularis	0.0181	0.0000	0.0000	0.0060
Cladophora prolifera	0.3262	0.1420	0.0557	0.1746
Cladophora herpestica	0.9998	0.4539	0.2224	0.5587
Boodlea composita	0.0000	0.1016	0.0000	0.0339
Valoniopsis pachynema	0.3809	0.1047	0.3659	0.2838
Bryopsis pennata	0.0000	0.0000	0.1760	0.0587
Ulothrix flacca	0.0000	0.0000	0.0123	0.0041
Spatoglossum asperum	0.0605	0.0000	0.0000	0.0202
Padina gymnospora	0.1926	0.0019	0.0000	0.0648
Padina tetrastromatica	0.1900	0.0008	0.0000	0.0636
Sargassum cinereum	0.2503	0.0778	0.0000	0.1094
Gelidium pusillum	0.4472	0.6630	0.1812	0.4305
Gracilaria corticata	1.6860	2.0556	1.2152	1.6523
Grateloupia indica	0.0000	0.3749	0.0000	0.1250
Grateloupia lithophila	0.2019	0.0465	0.0468	0.0984
Amphiroa fragilissima	0.0075	0.0062	1.0355	0.3497
Hypnea valentiae	0.0042	0.0727	0.0000	0.0256
Gelidiopsis intricata	0.5350	0.9987	0.5337	0.6891
Gelidiopsis variabilis	1.1304	0.0792	0.5564	0.5887
Centroceras clavulatum	1.1445	1.4111	0.7488	1.1015
Acanthopora spicifera	2.0503	1.4268	0.3550	1.2774

Table 8. Seasonal variation of seaweed abundance in Zone 2 along the Thikkodi coast (biomass in gm/m^2)

Species	Zone 2			Average of three seasons
	Pre-monsoon	Monsoon	Post-monsoon	
Caulerpa peltata	1.0792	0.0000	2.6777	1.2523
Caulerpa scalpelliformis	0.0454	0.0000	0.0000	0.0151
Caulerpa sertularioides	0.0687	0.0000	1.1689	0.4125
Caulerpa taxifolia	0.1419	0.0000	0.0000	0.0473
Chaetomorpha antennina	0.0428	0.0234	0.0239	0.0300
Chaetomorpha linum	0.0000	0.1219	0.0141	0.0453
Chaetomorpha crassa	0.0476	0.0000	0.1061	0.0512
Ulva lactuca	0.0073	0.6760	0.2004	0.2946
Ulva fasciata	0.0000	0.0000	0.3635	0.1212
Enteromorpha compressa	0.0000	0.0219	0.0240	0.0153
Cladophora fascicularis	0.0924	0.0000	0.0000	0.0308
Cladophora prolifera	1.6123	0.4615	2.0580	1.3773
Cladophora herpestica	2.3170	1.4407	0.0960	1.2846
Boodlea composita	0.0000	0.0000	0.0000	0.0000
Valoniopsis pachynema	1.7517	0.0509	0.4536	0.7521
Bryopsis pennata	0.0000	0.0000	0.1214	0.0405
Ulothrix flacca	0.0000	0.0000	0.0447	0.0149
Spatoglossum asperum	0.0000	0.0000	0.0000	0.0000
Padina gymnospora	0.0123	0.0226	0.0000	0.0116
Padina tetrastromatica	0.0602	0.0210	0.0000	0.0271
Sargassum cinereum	0.0000	0.0201	0.0000	0.0006
Gelidium pusillum	0.4858	0.2362	0.0000	0.2407
Gracilaria corticata	0.3365	0.5383	0.3657	0.4135
Grateloupia indica	0.0000	0.0000	0.0000	0.0000
Grateloupia lithophila	0.0000	0.0000	0.0000	0.0000
Amphiroa fragilissima	0.1029	0.0000	0.0200	0.0410
Hypnea valentiae	0.0000	0.0000	0.0228	0.0008
Gelidiopsis intricata	0.2782	0.1173	0.2767	0.2241
Gelidiopsis variabilis	0.1627	0.0000	0.0221	0.0616
Centroceras clavulatum	0.0000	0.1797	1.0032	0.3943
Acanthopora spicifera	0.0478	0.0114	0.3671	0.1421

Table 9. Seasonal variation of seaweed abundance in Zone 3 along the Thikkodi coast (biomass in gm/m^2)

Species	Zone 3			Average of three seasons
	Pre-monsoon	Monsoon	Post-monsoon	
Caulerpa peltata	0.2977	0.0000	1.0762	0.4580
Caulerpa scalpelliformis	0.0000	0.0000	0.0000	0.0000
Caulerpa sertularioides	0.0000	0.0000	0.3875	0.1292
Caulerpa taxifolia	0.0078	0.0000	0.0000	0.0003
Chaetomorpha antennina	0.0000	0.0201	0.0508	0.0236
Chaetomorpha linum	0.0000	0.1596	0.0000	0.0532
Chaetomorpha crassa	0.0200	0.0000	0.0326	0.0175
Ulva lactuca	0.0000	0.1341	1.4537	0.5293
Ulva fasciata	0.0000	0.0000	0.1917	0.0639
Enteromorpha compressa	0.0000	0.0000	0.0067	0.0002
Cladophora fascicularis	0.2004	0.0000	0.0000	0.0668
Cladophora prolifera	0.5171	0.0879	1.6633	0.7561
Cladophora herpestica	0.5458	0.7623	0.5020	0.6034
Boodlea composita	0.0000	0.0000	0.0000	0.0000
Valoniopsis pachynema	0.9324	0.1947	0.4068	0.5113
Bryopsis pennata	0.0000	0.0000	0.0303	0.0101
Ulothrix flacca	0.0000	0.0000	0.0144	0.0005
Spatoglossum asperum	0.0000	0.0000	0.0000	0.0000
Padina gymnospora	0.0000	0.0000	0.0000	0.0000
Padina tetrastromatica	0.0000	0.0000	0.5266	0.1755
Sargassum cinereum	0.0000	0.0000	0.0000	0.0000
Gelidium pusillum	0.0008	0.2158	0.2597	0.1588
Gracilaria corticata	0.0000	0.0261	1.1383	0.3881
Grateloupia indica	0.0000	0.0000	0.0000	0.0000
Grateloupia lithophila	0.0000	0.0000	0.4402	0.1467
Amphiroa fragilissima	0.0000	0.0125	0.2974	0.1033
Hypnea valentiae	0.0000	0.0000	0.0644	0.0215
Gelidiopsis intricata	0.0082	0.0000	0.2152	0.0745
Gelidiopsis variabilis	0.0078	0.0000	0.1157	0.0412
Centroceras clavulatum	0.0000	0.0071	1.7222	0.5764
Acanthopora spicifera	0.0000	0.0000	0.2496	0.0832

Indices of diversity

Diversity indices were worked out for the seaweed assemblages recorded from three different zones during the study period from September 2018 to August 2019. A total of 11 diversity indices were worked out including the taxonomic and phylogenetic taxonomy indices. Significant differences between the indices among the sites were worked out using Kolmogorov-smirnov two sample tests (since the normality and equality of variance conditions did not meet). The results indicated that among the different diversity indices worked out, total species (S), number of species (N), Pielou's eveness index (J'), Shannon Index (H (loge), Simpson (1-lambda) index, and taxonomic diversity index (delta) and total phylogenetic diversity (sPhi+) varied significantly between the sites ($p<0.05$). All other indices did not vary statistically ($p<0.05$).

Table 10. Diversity indices and taxonomic attributes of zone 1 during the study period

Months	S	N	d	J'	H'(loge)	1-Lambda'	Delta	Delta*	Delta+	Phi+	sPhi+
Sep.'18	10	797.84	1.346921	0.72332	1.665507	0.753491	55.01972	73.01976	88.14814815	70	700
Oct	9	369.71	1.353015	0.800684	1.759281	0.780573	62.26368	79.76666	82.87037037	64.81481	583.3333
Nov	15	872.69	2.067464	0.707023	1.914655	0.803055	62.94812	78.38578	81.74603175	56.66667	850
Dec	15	319.11	2.428222	0.809477	2.192106	0.864328	71.69601	82.95003	79.36507937	55.55556	833.3333
Jan'19	7	128.32	1.23596	0.85699	1.667625	0.798049	69.25642	86.7822	82.53968254	66.66667	466.6667
Feb	12	1157.96	1.559307	0.788502	1.959354	0.839365	68.23573	81.29443	81.06060606	58.33333	700
Mar	16	733.87	2.273302	0.816868	2.26484	0.850292	73.97909	87.0043	87.08333333	56.25	900
April	18	792.37	2.546806	0.829171	2.396612	0.887495	72.26207	81.4225	85.83877996	54.62963	983.3333
May	17	897.78	2.352967	0.756314	2.142799	0.8474	69.80117	82.37099	82.4754902	51.96078	883.3333
June	17	408.41	2.661224	0.680895	1.929122	0.777116	58.37274	75.11456	80.88235294	54.90196	933.3333
July	18	859.4	2.516194	0.755063	2.182414	0.844787	64.40851	76.24227	82.46187364	53.7037	966.6667
Aug	14	100.03	2.82273	0.683171	1.802929	0.757861	65.02036	85.79456	82.05128205	58.33333	816.6667

Table 11. Diversity indices and taxonomic attributes of zone 2 during the study period

Months	S	N	d	J'	H'(loge)	1-Lambda'	Delta	Delta*	Delta+	Phi+	sPhi+
Sep.'18	9	358.86	1.359866	0.682471	1.499543	0.713415	64.5236	90.44333	88.88889	70.37037	633.3333
Oct	9	293.73	1.407791	0.849648	1.866867	0.817305	68.81586	84.19855	81.01852	59.25926	533.3333
Nov	10	852.59	1.333673	0.477527	1.099548	0.544685	38.48333	70.65249	81.11111	58.33333	583.3333
Dec	14	588.36	2.038468	0.822356	2.170244	0.847211	67.46339	79.63001	78.75458	54.7619	766.6667
Jan'19	8	701.36	1.06821	0.449545	0.934802	0.44364	38.87043	87.61707	82.14286	66.66667	533.3333
Feb	10	519.4	1.439384	0.859332	1.978685	0.83941	70.00857	83.40207	81.11111	56.66667	566.6667
Mar	7	403.03	1.000165	0.812979	1.581983	0.75362	47.51664	63.05124	77.77778	64.28571	450
April	11	639.59	1.547789	0.690631	1.65606	0.721971	47.3519	65.58699	76.36364	53.0303	583.3333
May	5	683.62	0.612801	0.521703	0.839648	0.492041	17.2678	35.09426	68.33333	63.33333	316.6667
June	7	427.35	0.990491	0.52288	1.017477	0.48678	43.16536	88.67534	84.12698	61.90476	433.3333
July	7	179.13	1.15649	0.576677	1.122162	0.591715	26.44535	44.69272	74.60317	61.90476	433.3333
Aug	8	53.22	1.761257	0.811889	1.688275	0.800749	51.50452	64.32042	73.80952	58.33333	466.6667

Table 12. Diversity indices and taxonomic attributes of zone 3 during the study period

Zone	S	N	d	J'	H'(loge)	1-Lambda'	Delta	Delta*	Delta+	Phi+	sPhi+
Sep.'18	3	89.36	0.445169	0.943623196	1.036676	0.63497767	36.57889	57.6065819	55.55556	66.6666667	200
Oct	8	667.65	1.0763	0.780058231	1.622085	0.77812761	72.33517	92.9605505	86.90476	70.8333333	566.6667
Nov	12	978.46	1.597449	0.706360743	1.755241	0.75479686	50.98237	67.5444951	78.53535	54.1666667	650
Dec	17	664.73	2.461773	0.852568694	2.415509	0.88525554	74.14818	83.7590673	81.25	54.9019608	933.3333
Jan'19	11	490.86	1.613903	0.772542066	1.852475	0.79022475	58.07161	73.4874614	83.63636	66.6666667	733.3333
Feb	5	81.47	0.909042	0.739303903	1.189864	0.66662992	29.14243	43.7160538	63.33333	60	300
Mar	6	264.26	0.89655	0.700084321	1.254383	0.6948471	40.66786	58.5277895	52.22222	47.2222222	283.3333
April	7	180.77	1.154462	0.703162832	1.368292	0.7135814	27.97539	39.2042075	65.07937	47.6190476	333.3333
May	3	129.16	0.411434	0.616687221	0.6775	0.47938517	24.12507	50.3250273	83.33333	83.3333333	250
June	5	259.25	0.71971	0.574649686	0.924863	0.4863974	42.48832	87.3531014	80	70	350
July	4	35.65	0.839455	0.758726024	1.051818	0.60008265	42.73677	71.2181437	86.11111	79.1666667	316.6667
Aug	4	34.25	0.848972	0.622531807	0.863012	0.47488608	26.3643	55.5171027	55.55556	62.5	250

Table 13. Diversity indices and taxonomic attributes of three zones (mean of all months)

Zones		S	N	d	J'	H'(loge)	1-Lambda'	Delta	Delta*	Delta+	Phi+	sPhi+
Zone 1	Mean	14.00	619.79	2.10	0.77	1.99	0.82	66.11	80.85	83.04	58.48	801.39
	SE	1.07	98.17	0.16	0.02	0.07	0.01	1.68	1.31	0.76	1.63	45.89
Zone 2	Mean	8.75	475.02	1.31	0.67	1.45	0.67	48.45	71.44	79.00	60.74	525.00
	SE	0.67	67.33	0.11	0.05	0.13	0.04	4.91	5.14	1.54	1.44	33.49
Zone 3	Mean	7.08	322.99	1.08	0.73	1.33	0.66	43.80	65.10	72.63	63.59	430.56
	SE	1.23	88.61	0.17	0.03	0.14	0.04	4.93	4.98	3.82	3.31	67.26

The diversity studies conducted by Caniyal et al, 2014 along the Tuticorin coastal waters.The Shannon-Weiner diversity index (H') varied from 3.91 to 4.38. The minimum and maximum value was recorded during September and November respectively. During September the minimum value (11.32) of Margalef richness index (d') was recorded.The minimum and maximum value of Pielou's evenness index (J') were recorded during October (0.97) and July (0.985). The Bray-Curtis similarity was found maximum between July and August (89.92%) followed by August and November (88.11%). The higher the values of diversity indices indicate the healthy nature of seaweed ecosystems along Tuticorin coastal water. Likewise, in Thikkodi coast zone 1 have a higher diversity index, which means healthy nature is found in the area which seldom got exposed even during very high tides.

4.4.1 Species Richness (S)

The diversity indices and taxonomic attributes of zone 1, 2 and 3 are given in tables 9 to 11. In zone 1, the species richness (S) varied between 7 and 18; the lowest being in January 2019 and the highest in April and July 2019. In zone 2, the species richness (S) varied between 5 and 14; the highest being in December 2018 and the lowest being in Many 2019. The species richness (S) in zone 3 varied between 3 and 17; the lowest value was in September 2018 and May 2019; while the highest value was in December 2018. While comparing the three zones, the highest value of species richness (S) was obtained in zone 1 (S=14.00), followed by zone 2 (S=8.75) and zone 3 (S=7.08).

4.4.2 Margalef's Index (d)

The Margalef's index (d) which incorporates the number of individuals (N) and species (S) was the highest in zone 1 (2.10), while it was minimum in zone 3 (1.08). In zone 1, the highest Margalef's index was obtained in August 2019 (2.82), while the lowest value was obtained in January 2019 (1.24). In zone 2, the Margalef's index was highest in December 2018 (2.04), while it was minimum in May 2018

(0.61). The Margalef's index in zone 3 was the highest in December 2018 (2.46), while the lowest value was obtained in May 2019 (0.41).

4.4.3 Pielou's Evenness Index (J')

The equitability or Pielou's evenness index (J') which expresses the evenness of distribution of individuals among the different species showed much variation between the zones and the values ranged from 0.67 (zone 2) to 0.77 (zone 1). Between the months, the Pielou's evenness index varied from 0.68 (June & August 2019) to 0.85 (January 2019) in zone 1. In zone 2, the Pielou's evenness index ranged from 0.45 (January 2019) to 0.86 (February 2019), while in zone 3, it ranged from 0.57 (June 2019) to 0.94 (September 2018).

4.4.4 Shannon Wiener Index (H')

The Shannon Wiener Index is a benchmark measure of biological diversity and is denoted as H'. It is a widely used measure of diversity index for comparing diversity between various habitats (Clark and Warwick, 2001). In the present study, the Shannon Wiener Index (H') showed wide variation between the zones ranging from the lowest value of 1.33 (zone 3) to the highest value of 1.99 (zone 1). In zone 1, the Shannon Wiener Index ranged from 1.67 (September 2018 & January 2019) to 2.40 (April 2019). In zone 2, the Shannon Wiener Index was the lowest in May 2019 (0.84) and the highest value was registered in December 2018 (2.17). The value ranged from 0.68 (May 2019) to 2.42 (December 2018) in zone 3.

4.4.5 Simpson Index (1-Lambda')

The Simpson Index (1-Lambda') showed variations in values ranging from 0.66 (zone 3) to 0.82 (zone 1). In zone 1, the Simpson Index ranged from 0.75 (September 2018) to 0.88 (April 2019); while in zone 2, it ranged from 0.44 (January 2019) to 0.85 (December 2018) and in zone 3, the values ranged from 0.47 (August 2019) to 2.42 (December 2018).

4.5 Taxonomic Distinctness Index

The average taxonomic distinctness (Delta+) is the average taxonomic distance apart of all its pairs of species. The funnel plot created by the values of taxonomic distinctness and the variation in the taxonomic distinctness based on presence/absence of values did not show species assemblages varying significantly from the 90% confidence limit from the master list of assemblages in zone 1.

In zone 2, the taxonomic distinctness values were significantly different in May 2019 whereas all the assemblages were within the limit of the index. In zone 3, the variation in taxonomic distinctness was significantly different in March and April 2019, as it falls outside the confidence funnel.

The average taxonomic distinctness was found maximum in zone 1 (83.04) and minimum in zone 3 (72.63) during the study period. This indicates that the taxonomic distance between species was the highest in zone 1, when compared to zone 2 and zone 3. The taxonomic diversity was found to be the lowest in zone 3 which point out to the availability of more closely related species.

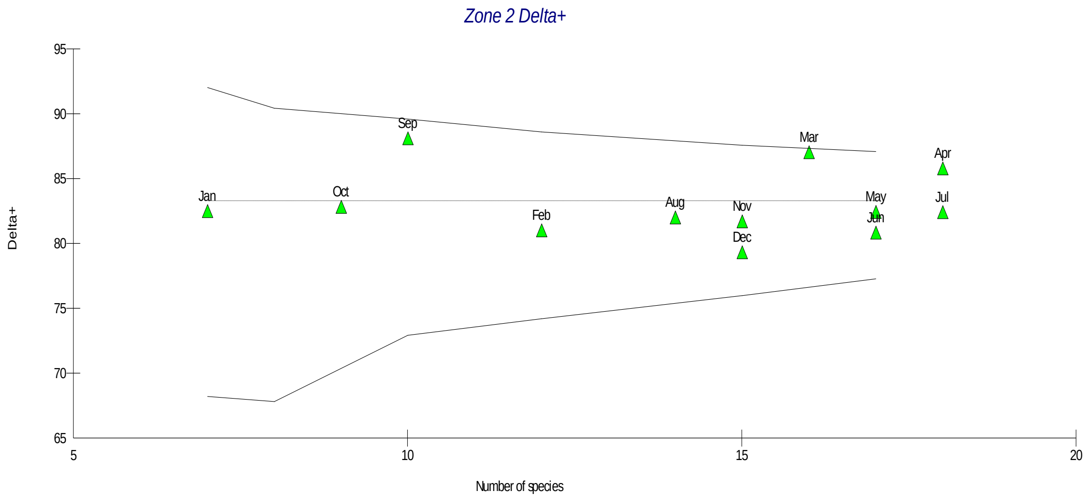

Fig.66. Funnel plot for average taxonomic distinctness (Delta +) showing the diversity of seaweeds during different months in zone 1, and its deviation from the normal distribution.

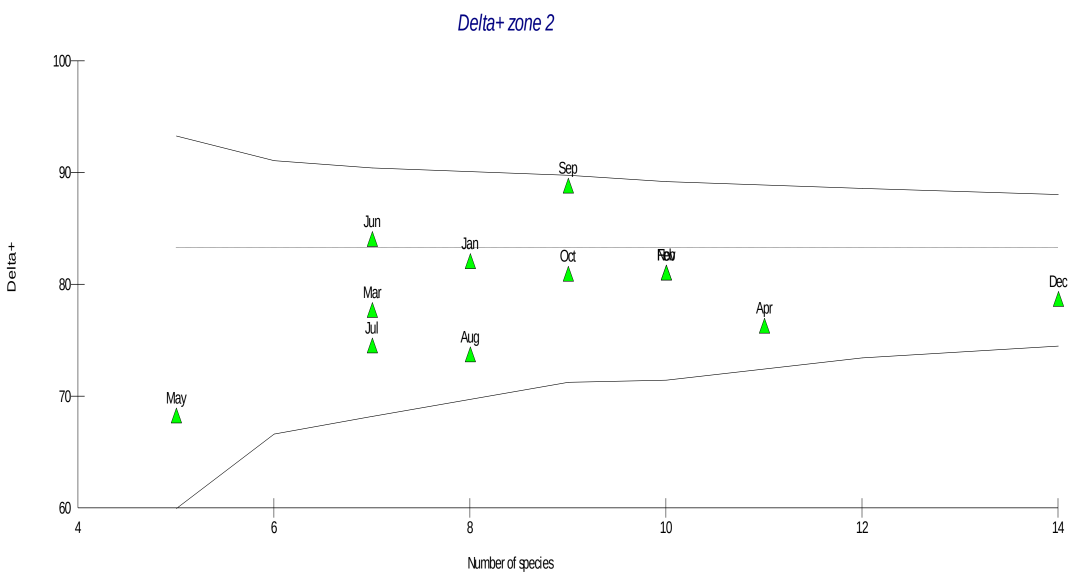

Fig.67. Funnel plot for average taxonomic distinctness (Delta +) showing the diversity of seaweeds during different months in zone 2, and its deviation from the normal distribution.

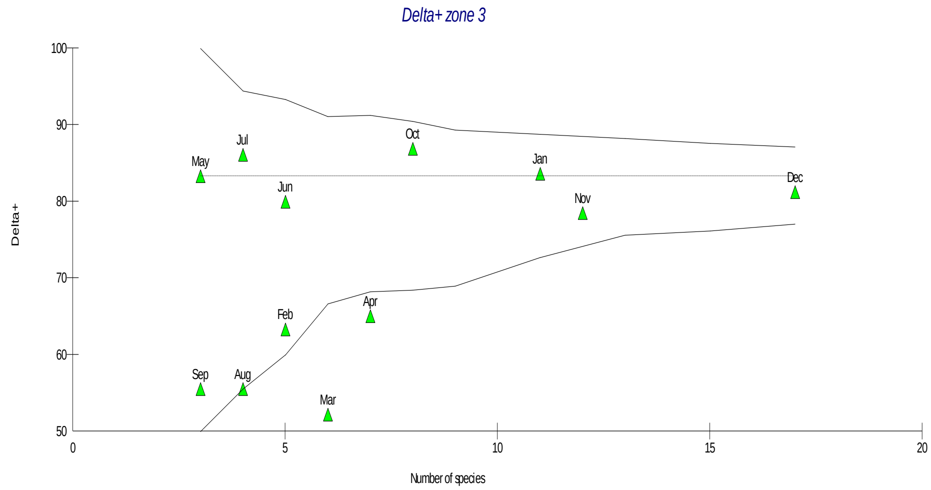

Fig.68. Funnel plot for average taxonomic distinctness (Delta +) showing the diversity of seaweeds during different months in zone 3, and its deviation from the normal distribution.

The taxonomic distinctness (λ) funnel plots indicate that the λ+ values of April was not within the expected limit as the value lies outside the funnel plot in zone 2 and zone 3.

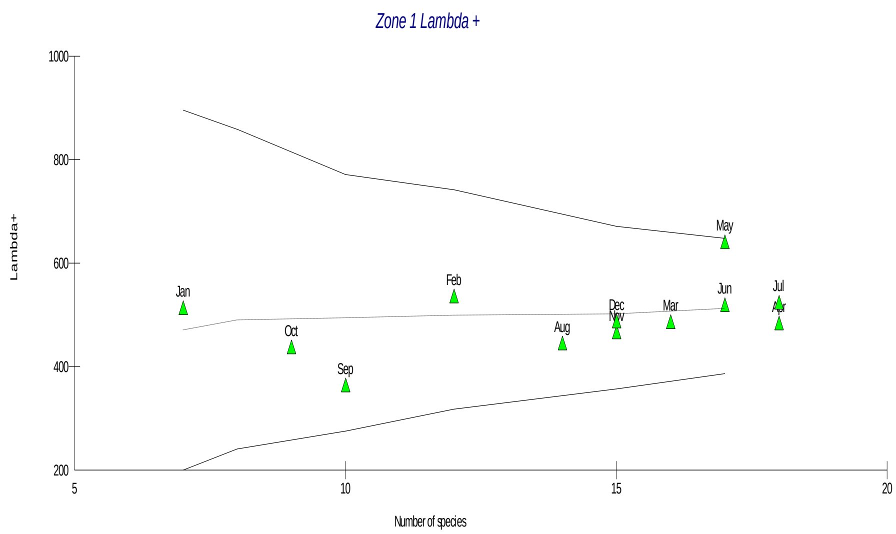

Fig.69. Funnel plot for variation in taxonomic distinctness (λ+) during different months in zone 1.

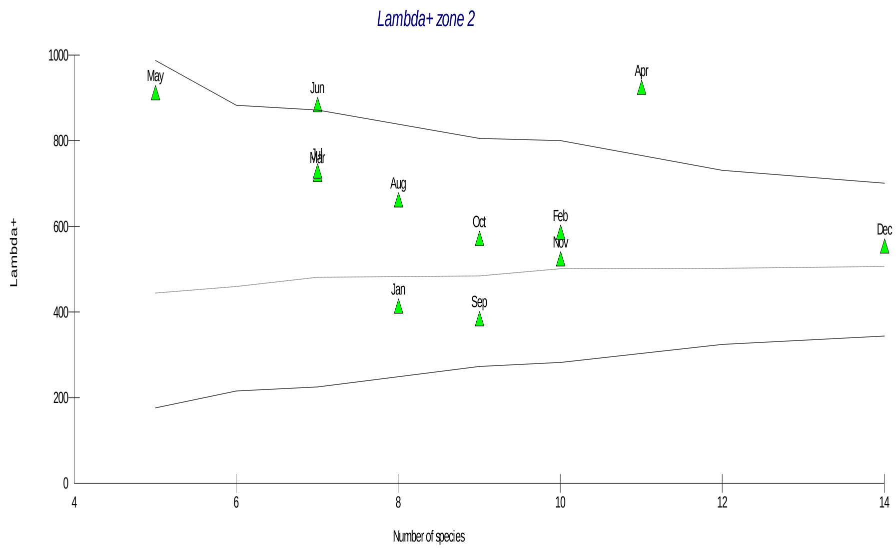

Fig.70. Funnel plot for variation in taxonomic distinctness (λ+) during different months in zone 2.

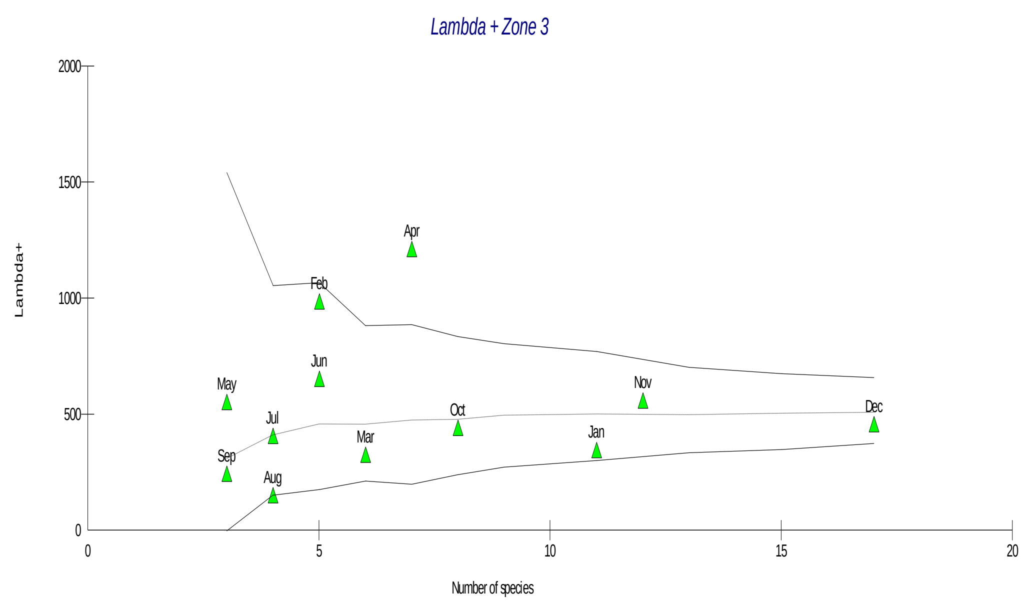

Fig.71. Funnel plot for variation in taxonomic distinctness (λ+) during different months in zone 3.

Total Phylogenetic Diversity (sPhi+)

The total phylogenetic diversity (sPhi+) was the highest in zone 1 (801.39), followed by zone 2 (525) and zone 3 (430.56). This indicates the wider taxonomic breadth in zone 1 when compared to the other zones.

ANOSIM test results

The Analysis of Similarity (ANOSIM) between zone 1 and zone 2 and that of zone 1 and zone 3 showed more similarity within the sites; while between zone 2 and zone 3 showed more similarity between sites than within sites.

Global Test

Sample statistic (Global R): 0.139

Significance level of sample statistic: 0.4%

Number of permutations: 999 (Random sample from a large number)

Number of permuted statistics greater than or equal to Global R: 3

Pairwise Tests

Table 14. Results of Analysis of Similarity (ANOSIM)

R	**Significance Possible**		**Actual**	**Number>=**	
Groups	**Statistic**	**Level%**	**Permutations**	**Permutations**	**Observed**
zone 1,zone 2	0.18	1.	1352078	999	9
zone 1,zone 3	0.304	0.1	1352078	999	0
zone 2,zone 3	-0.06	87.1	1352078	999	870

SIMPER Test results

The Similarity Percentage Analysis (SIMPER) showed an average of similarity of 57.21, 41.69 and 37.69% in the case of species of zones 1, 2 and 3 respectively. The average dissimilarity between species of zone 1 and 2 was 55.21%, while between species of zone 1 and 3 was 61.93% and between species of zone 2 and 3 was 59.0%.

Parameter

Standardise data: No

Transform: Presence/absence

Cut off for low contributions: 90.00%

Factor name: zone

Factor groups

zone 1

zone 2

zone 3

Group zone 1

Average similarity: 57.21

Table 15. Results of the Similarity Percentage Analysis (SIMPER) of zone 1

Species	Av.Abund	Av. Sim	Sim/SD	Conrtib %	Cum %
Centroceras clavulatum	71.14	6.28	1.99	10.98	10.98
Acanthopora spicifera	82.50	6.21	1.98	10.86	21.84
Ulva lactuca	21.60	5.30	1.37	9.27	31.11
Gelidiopsis intricata	44.51	4.77	1.40	8.35	39.45
Gelidium pusillum	27.80	4.69	1.39	8.19	47.64
Gracilaria corticata	106.71	3.81	1.06	6.66	54.30
Valoniopsis pachynema	18.33	3.58	1.07	6.26	60.56

Table 15. Continued

Species	Av.Abund	Av. Sim	Sim/SD	Conrtib %	Cum %
Caulerpa peltata	25.49	2.98	0.83	5.20	65.77
Chaetomorpha antennina	2.91	2.95	0.83	5.15	70.92
Gelidiopsis variabilis	38.02	2.73	0.85	4.78	75.69
Grateloupia lithophila	6.36	2.10	0.67	3.67	79.36
Cladophora herpestica	36.08	1.94	0.68	3.40	82.76
Caulerpa sertularioides	16.58	1.69	0.53	2.96	85.72
Chaetomorpha crassa	0.83	1.64	0.53	0.53	88.58
Caulerpa scalpelliformis	47.73	1.46	0.54	0.54	91.13

Group zone 2

Average similarity: 41.69

Table 16. Results of the Similarity Percentage Analysis (SIMPER) of zone 2

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum %
Cladophora prolifera	88.95	6.45	1.04	15.48	15.48
Cladophora herpestica	82.96	6.45	1.04	15.48	30.96
Valoniopsis pachynema	48.57	4.70	0.84	11.27	42.23
Chaetomorpha antennina	1.94	4.06	0.67	9.75	51.98
Ulva lactuca	19.02	3.85	0.66	9.23	61.21
Gelidium pusillum	15.54	2.92	0.53	6.99	68.20
Centroceras clavulatum	25.46	2.39	0.53	5.74	73.94
Gelidiopsis intricata	14.47	2.35	0.53	5.65	79.58

Table 16. Continued

Species	Av.Abund	Av.Sim	Sim/SD	Contrib%	Cum %
Acanthopora spicifera	9.18	2.30	0.53	5.53	85.11
Gracilaria corticata	26.70	1.58	0.41	3.79	88.90
Caulerpa peltata	80.88	0.96	0.31	2.30	91.19

Group zone 3

Average similarity: 37.68

Table 17. Results of the Similarity Percentage Analysis (SIMPER) of zone 3

Species	Av.Abund	Av.Sim	Sim/SD	Contrib %	Cum %
Valoniopsis pachynema	33.02	12.76	1.66	33.88	33.88
Cladophora herpestica	38.97	6.68	0.76	17.74	51.62
Cladophora prolifera	48.83	4.82	0.61	12.80	64.42
Ulva lactuca	34.18	2.82	0.48	7.55	71.96
Chaetomorpha antennina	1.53	1.85	0.39	4.91	76.87
Gelidiopsis intricata	4.81	1.70	0.40	4.51	81.38
Centroceras clavulatum	37.23	1.56	0.40	4.15	85.53
Chaetomorpha crassa	1.13	1.30	0.31	3.44	88.98
Gelidium pusillum	10.25	1.18	0.28	3.14	92.11

Group zone 1 & zone 2

Average dissimilarity : 55.21

Table 18. Average dissimilarity between zone 1 and zone 2

Species	Group zone 1	Group zone 3	Av.Diss	Diss/SD	Contri%	Cum%
	Av.Abund	Av.Abund				
Gelidiopsis variabilis	38.02	3.98	2.62	1.22	4.74	4.74
Cladophora prolifera	11.28	88.95	2.59	1.03	4.70	9.44
Caulerpa peltata	25.49	80.88	2.53	1.06	4.57	14.01
Gracilaria corticata	106.71	26.70	2.49	1.04	4.51	18.52
Grateloupia lithophila	6.36	0.00	2.48	1.14	4.49	23.01
Acanthopora spicifera	82.50	9.18	2.40	0.95	4.35	27.36
Centroceras clavulatum	71.14	25.46	2.37	0.96	4.30	31.65
Gelidiopsis intricata	44.51	14.47	2.35	0.95	4.25	35.90
Caulerpa sertulariodes	16.58	26.64	2.30	0.95	4.17	40.07
Chaetomorpha crassa	0.83	3.31	2.27	0.95	4.12	44.19
Cladophora herpestica	36.08	82.96	2.26	0.88	4.09	48.28
Gelidium pusillum	27.80	15.54	2.24	0.95	4.06	52.34
Chaetomorpha antennina	2.91	1.94	2.16	0.90	3.91	56.25
Caulerpa scalpelliformis	47.73	0.98	2.11	0.98	3.82	60.07
Valoniopsis pachynema	18.33	48.57	2.01	0.82	3.64	63.70
Ulva lactuca	21.06	19.02	1.99	0.86	3.60	67.30
Padina gymnospora	4.19	0.75	1.85	0.82	3.35	70.65
Amphiroa fragillisima	22.59	2.65	1.82	0.82	3.29	73.94
Ulva fasciata	4.54	7.83	1.75	0.77	3.17	77.10
Padina tetrastromatica	4.11	1.75	1.64	0.75	2.97	80.07
Sargassum cinereum	7.06	0.43	1.57	0.73	2.84	82.91
Hypnea valentiae	1.66	0.49	1.53	0.74	2.77	85.67
Caulerpa taxifolia	2.06	3.06	1.52	0.73	2.75	88.42
Caulerpa linum	0.27	2.93	1.29	0.62	2.34	90.76

Groups zone 1 & zone 3

Average dissimilarity = 61.93

Table 19. Average dissimilarity between zone 1 and zone 3

Species	Group zone 1	Group zone 3	Av.Diss	Diss/SD	Contri%	Cum%
	Av.Abund	Av.Abund				
Acanthopora spicifera	82.50	5.37	4.14	1.59	6.69	6.69
Centroceras clavulatum	71.14	37.23	3.18	1.07	5.14	11.83
Gelidium pusillum	27.80	10.25	3.10	1.15	5.01	16.83
Gracilaria corticata	106.71	25.07	3.03	1.11	4.90	21.73
Gelidiopsis intricata	44.51	4.81	2.93	1.05	4.73	26.46
Gelidiopsis variabilis	38.02	2.66	2.93	1.20	4.67	31.13
Caulerpa peltata	25.49	29.58	2.89	1.03	4.65	35.78
Ulva lactuca	21.06	34.18	2.88	0.93	4.38	40.15
Chaetomorpha antennina	2.91	1.53	2.71	0.99	4.37	44.52
Grateloupia lithophila	6.36	9.48	2.70	1.07	4.36	48.88
Cladophora prolifera	11.28	48.83	2.70	0.95	4.26	53.15
Caulerpa sertulariodes	16.58	8.34	2.64	0.92	4.16	57.31
Chaetomorpha crassa	0.83	1.13	2.58	0.92	4.10	61.41
Cladophora herpestica	36.08	38.97	2.54	0.88	4.10	65.51
Caulerpa scalpelliformis	47.73	0.00	2.54	0.96	4.10	69.19
Ulva fasciata	4.54	4.13	2.28	0.79	3.69	72.43
Amphiroa fragillisima	22.59	6.67	2.00	0.81	3.23	75.53
Valoniopsis pachynema	18.33	33.02	1.92	0.61	3.11	78.41
Hypnea valentiae	1.66	1.39	1.78	0.77	2.87	81.28
Caulerpa taxifolia	2.06	0.17	1.65	0.73	2.67	83.95
Padina gymnospora	4.19	0.00	1.58	0.67	2.55	83.49
Sargassum cinereum	7.06	0.00	1.58	0.67	2.55	89.04
Padina tetrastromatica	4.11	11.34	1.28	0.63	2.06	91.10

Groups zone 2 & zone 3

Average dissimilarity = 59.00

Table 20. Average dissimilarity between zone 2 and zone 3

Species	Group zone 2	Group zone 3	Av.Diss	Diss/SD	Contri %	Cum %
	Av.Abund	**Av.Abund**				
Chaetomorpha antennina	1.94	1.53	3.63	0.95	6.16	6.16
Gelidium pusillum	15.54	10.25	3.50	0.93	5.92	12.08
Ulva lactuca	19.02	34.18	3.49	0.93	5.92	18.00
Centroceras clavulatum	25.46	37.23	3.32	0.95	5.63	23.63
Gelidiopsis intricata	14.47	4.81	3.32	0.95	5.62	29.25
Cladophora prolifera	88.95	48.83	3.19	0.86	5.40	34.65
Acanthopora spicifera	9.18	5.37	3.16	0.95	5.36	40.01
Gracilaria corticata	26.70	25.07	3.03	0.89	5.13	45.15
Cladophora herpestica	82.96	38.97	2.87	0.80	4.87	50.02
Caulerpa peltata	80.88	29.58	2.78	0.84	4.70	54.72
Chaetomorpha crassa	3.31	1.13	2.70	0.81	4.57	59.29
Valoniopsis pachynema	48.57	33.02	2.65	0.71	4.49	63.78
Amphiroa fragillisima	2.65	6.67	2.42	0.72	4.10	67.88
Padina tetrastromatica	1.75	11.34	2.00	0.61	3.39	71.26
Chaetomorpha linum	2.93	3.44	1.92	0.60	3.26	74.52
Ulva fasciata	7.83	4.13	1.90	0.68	3.23	77.75
Enteromorpha compressa	0.99	0.14	1.90	0.62	3.22	80.97
Caulerpa sertularioides	26.64	8.34	1.81	0.68	3.07	84.04
Padina gymnospora	0.75	0.00	1.66	0.55	2.82	86.86
Gelidiopsis variabilis	3.98	2.66	1.62	0.59	2.75	89.61
Caulerpa taxifolia	3.06	0.17	1.11	0.41	1.87	91.48

Non-metric Multidimensional Scaling

The data matrix used for the ANOSIM analysis was subjected to non-metric Multidimensional Scaling (nMDS) to depict the separation of the seaweed assemblages from the three zones. The results of the MDS were in concurrence with the findings of the ANOSIM, which showed separation of species in two-dimensional space. The stress for the ordination was 0.2 for two-dimension, which is an evidence of distinction between the assemblages (Clarke and Warwick, 2001).

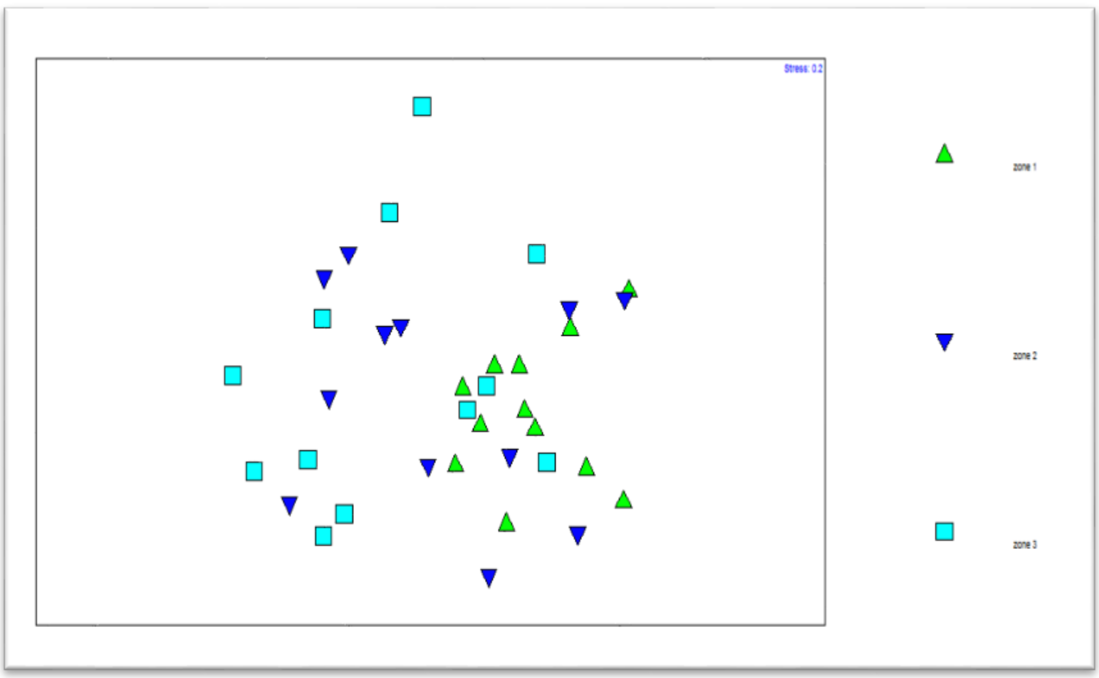

Fig.72. Non-metric Multidimensional Scaling (nMDS) to depict the separation of seaweed assemblages of the three zones

4.6 Carbon sequestration potential of selected seaweeds

4.6.1 Carbon utilization and emission by *Gracilaria corticata*

Eight levels of dissolved CO_2 in seawater were tested to access the rate of carbon utilization in light by *Gracilaria corticata* (Table 21). The utilization efficiency increased from 33.33% at CO_2 level of 26.4 mg/l to 83.33% at CO_2 level of 79.2 mg/l.

At a CO_2 level of 110 mg/l, the utilization efficiency was found to decrease to 48%, and the efficiency further decreased to 26.67% at a CO_2 level of 132 mg/l. With a further increase in CO_2 level (154, 184.8, 330 & 396 mg/l, the utilization efficiency was found to be zero.

Table 21. Carbon-di-oxide uptake by *Gracilaria corticata*

CO_2 concentration(mg/l)	CO_2 utilization(mg/l)	Utilization efficiency (%)
0	0	0
26.4	8.8	33.33
35.2	13.2	37.50
44	22	50.00
79.2	66	83.33
110	52.8	48.00
132	35.2	26.67
154	0	0.00

The effect of increasing levels of dissolved carbon-di-oxide on the Gross Primary Productivity (GPP) and Net Primary Productivity (NPP) of *Gracilaria corticata* at elevated levels of CO_2 in ambient seawater is shown in table 22.The GPP and NPP levels gradually increased from 26.4 mg/l to 132 mg/l CO_2 concentration. After 132 mg/l, the GPP and NPP values decreased. The GPP and NPP levels are highest (2.40 & 2.06 mgC/l/hr respectively) at 132 mg/l CO_2 concentration.

Table 22. Productivity of *Gracilaria corticata*

CO_2 concentration(mg/l)	GPP(mgC/l/hr)	NPP(mgC/l/hr)
0	0	0.03
26.4	0.01	0.25
35.2	0.92	0.40
44	1.00	0.72
79.2	1.27	0.85
110	1.37	1.19
132	2.40	2.06
154	-5.71	-0.30

4.6.2 Carbon utilization and emission by *Caulerpa scalpelliformis*

Seven levels of dissolved carbon-di-oxide in seawater were tested to assess the rate of carbon utilization in light by *Caulerpa scalpelliformis*. The utilization efficiency increased from 25% at CO_2 concentration level of 17.6 mg/l to 42.86%at CO_2 concentration level of 30.8 mg/l. At CO_2 concentration level of 35.2 mg/l, the utilization efficiency decreased to 25 % and at 66 mg/l CO_2 level, the utilization efficiency further decreased to 13.33%. At CO_2 levels of 110 mg/l and above, the carbon utilization efficiency was 0%. The carbon-di-oxide uptake by *Caulerpa scalpelliformis* is given in table 23.

Table 23. Carbon-di-oxide uptake by *Caulerpa scalpelliformis*

CO_2 concentration(mg/l)	CO_2 utilization(mg/l)	Utilization efficiency (%)
0	0	0
17.6	4.4	25.00
26.4	8.8	33.33
30.8	13.2	42.86
35.2	8.8	25.00
66	8.8	13.33
110	0	0.00

The effect of increasing levels of dissolved carbon-di-oxide on the GPP and NPP of *Caulerpa scalpelliformis* at elevated levels of CO_2 in ambient seawater is shown in table 24. At lower concentration of 17.6 mg/l, the GPP and NPP values were 0.37mgC/l/hr and 0.26 mgC/l/hr respectively. The GPP and NPP levels gradually increased at CO_2 levels of 17.6 mg/l to 66 mg/l. The highest GPP and NPP values were 11.76 and 10.63 mgC/l/hr at 66mg/l CO_2 concentration. At higher concentrations beyond 66 mg/l, the productivity decreased. The GPP and NPP values at 110 mg/l CO_2 level were 1.19 mgC/l/hr and 0.82 mgC/l/hr respectively. The least productivity was obtained at 396 mg/l i.e., GPP of -0.97mgC/l/hr and NPP of -1.52 mgC/l/hr.

Table 24. Productivity of *Caulerpa scalpelliformis*

CO_2 concentration(mg/l)	**GPP(mgC/hr)**	**NPP(mgC/l/hr)**
0	0.02	0.08
17.6	0.37	0.26
26.4	1.71	0.52
30.8	3.47	2.50
35.2	4.18	2.65
66	11.76	10.63
110	1.19	0.82

4.6.3 Carbon utilization and emission by *Caulerpa taxifolia*

Five levels of dissolved carbon-di-oxide in seawater were tested to assess the rate of carbon utilization in light by *Caulerpa taxifolia*. The utilization efficiency increased from 33.33% to 57.14%in lower carbon dioxide concentrations of 13.2 mg/l and 30.8 mg/l respectively. The utilization efficiency then decreased to 50 % at 52.8 mg/l CO_2 level and to 30% at 88 mg/l CO_2 concentration (table 25).

Table 25.Carbon-di-oxide uptake of *Caulerpa taxifolia*

CO_2 concentration(mg/l)	CO_2 utilization(mg/l)	Utilization efficiency (%)
0	0	0
13.2	4.4	33.33
30.8	17.6	57.14
52.8	26.4	50.00
88	26.4	30.00

The effect of increasing levels of dissolved carbon-di-oxide on the GPP and NPP of *Caulerpa taxifolia* at elevated levels of CO_2 in ambient seawater is shown in table 26.The least productivity was obtained at 13.2 mg/l i.e., GPP of 0.97mgC/l/hr and NPP of 0.11 mgC/l/hr. The GPP and NPP levels gradually increased at 13.2mg/l to 88 mg/l CO_2 concentration. The GPP and NPP levels were highest at 88 mg/l CO_2 concentration (GPP of 3.46 mgC/l/hr and NPP of 2.50 mgC/l/hr respectively).

Table 26. Productivity of *Caulerpa taxifolia*

CO_2 concentration(mg/l)	GPP(mgC/l/hr)	NPP(mgC/l/hr)
0	0.7	0
13.2	0.97	0.11
30.8	1.01	1.42
52.8	2.20	2.16
88	3.46	2.50

4.6.4 Carbon utilization and emission by *Acanthophora spicifera*

Three levels of dissolved carbon-di-oxide in seawater were tested to assess the rate of carbon utilization in light by *Acanthopora spicifera*. The utilization efficiency was 66.67% at carbon-di-oxide concentration of 13.2 mg/l. The carbon utilization efficiency decreased to 50% and 47.83% at CO_2 levels of 35.2 and 101.2 mg/l (table 27).

Table 27. Carbon-di-oxide uptake by *Acanthopora spicifera*

CO_2 concentration(mg/l)	CO_2 utilization(mg/l)	Utilization efficiency (%)
0	0	0
13.2	8.8	66.67
35.2	17.6	50.00
101.2	48.4	47.83

The effect of increasing levels of dissolved carbon-di-oxide on the GPP and NPP of *Acanthophora spicifera* at elevated levels of CO_2 in ambient seawater is shown in table 28. The least productivity was observed at 13.2 mg/l i.e., GPP of 1.08 mgC/l/hr and NPP of 0.45 mgC/l/hr. The GPP and NPP levels gradually increased at CO_2 levels from 13.2mg/l to 101.2 mg/l CO_2 concentration. The GPP and NPP levels were highest at 101.2 mg/l CO_2 concentration. The GPP and NPP values at 101.2 mg/l CO_2were 2.59 mgC/l/hr and 1.56mgC/l/hr respectively.

Table 28. Productivity of *Acanthopora spicifera*

CO_2 concentration(mg/l)	GPP(mgC/l/hr)	NPP(mgC/l/hr)
0	0.15	0.10
13.2	1.08	0.45
35.2	1.82	1.31
101.2	2.59	1.56

4.6.5 Carbon utilization and emission by *Caulerpa peltata*

Five levels of dissolved carbon-di-oxide in seawater were tested to assess the rate of carbon utilization in light by *Caulerpa peltata*. The utilization efficiency increased from 66.67% to 75% in lower carbon-di-oxide concentration of 13.2 mg/l and 35.2 mg/l respectively. The utilization efficiency decreased to 60% atCO_2 level of 110mg/l.When the ambient CO_2level was 154mg/l and higher, the CO_2 utilization efficiency was nil (table 29).

Table 29. Carbon-di-oxide uptake of *Caulerpa peltata*

CO_2 concentration(mg/l)	CO_2 utilization(mg/l)	Utilization efficiency (%)
0	0	0
13.2	8.8	66.67
35.2	26.4	75.00
110	66	60.00
154	0	0.00

The effect of increasing levels of dissolved carbon dioxide on the GPP and NPP of *Caulerpa peltata* at elevated levels of CO_2 in ambient seawater is shown in table 30. At lower concentration of 13.2 mg/l, the GPP and NPP values were 2.26 mgC/l/hr and 0.90 mgC/l/hr respectively. The GPP and NPP levels gradually increased from 13.2 mg/l to 110 mg/l CO_2 concentration. After 110 mg/l CO_2 level, the GPP and NPP values decreased. The productivity decreased from 110 mg/l to 396 mg/l CO_2 concentration. The GPP and NPP levels were highest at 110 mg/l CO_2 concentration. The least productivity was obtained at 396 mg/l i.e., GPP of -5.43 mgC/l/hr and NPP of -6.78 mgC/l/hr. The highest GPP and NPP values were 14.93 mgC/l/hr and 14.47 mg/C/hr at 110 mg/l CO_2 concentration.

Table 30. Productivity of *Caulerpa peltata*

CO_2 concentration(mg/l)	GPP(mgC/l/hr)	NPP(mgC/l/hr)
0	1.8	0
13.2	2.26	0.90
35.2	6.33	4.98
110	14.93	14.47
154	1.03	2.02

Kaladharan *et al*.(2009) studied the seaweeds commonly seen along the intertidal zone of Indian coast and the potential of the seawweds to utilize the excess CO_2 dissolved in the ambient water levels 5 mg/l higher than the *insitu* levels were also carried out.Amalu *et al*. (2018) studied the carbon sequestration potential of seaweeds at different dissolved CO_2 concentrations (0, 50,100,150 ppm) and their productivity.Their studies have shown that all seaweed species exhibited an increase in their productivity at about 50 ppm of dissolved CO_2 in seawater.Their studies have shown that some species of seaweeds could utilize dissolved CO_2 at higher concentration(100 ppm) and their survival and productivity reduced beyond 150 ppm of dissolved CO_2 concentrations. The present study is in corroboration with the above-cited studies as the CO_2 utilization increased with increase in CO_2 concentration in the medium. However, the increased utilization had a threshold level, beyond which the seaweeds were found to lose their potential to utilize the CO_2 in the ambient medium.

According to Forrester *et al*. (1996) the atmospheric CO_2 plays a greater role in carbon assimilation rate and may enhance photosynthesis in terrestrial plant communities.On the contrary,the marine counterpart like seaweed shows higher rate of GPP in increased levels of ambient CO_2, specifying the possibility of their unaltered efficiency in carbon sequestration even in higher levels of dissolved CO_2.

SUMMARY AND CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

Seaweeds, including kelps are the important primary producers in coastal ecosystems and they provide a livelihood for millions of people and also support many ecosystem services in the coastal ecosystem. The seaweed bed provides shelter to many ecosystem services in the coastal ecosystem. The seaweed bed provides shelter to many organisms, nursery ground for many species, recruitment of marine organisms, absorbing excess nutrients, dampening waves, buffer against ocean acidification. The seaweed also has the potential in serving as carbon sink for anthropogenic carbon dioxide. The salient findings of the study are as follows:

- The carbon utilization of five seaweeds, namely *Gracilaria corticata, Caulerpa scalpelliformis*, *Caulerpa taxifolia*, *Acanthopora spicifera* and *Caulerpa peltata w*as studied.
- Eight levels of dissolved CO_2 in seawater were taken to know the rate of carbon utilization in light by *Gracilaria corticata.*
- The concentration levels were (0, 26.4, 35.2, 44, 79.2,110,132 & 154 mg/l).
- There was an increase in utilization efficiency from 33.33% at 26.4 mg/l to 83.33% at 79.2 mg/l CO_2 level.
- At CO_2 level of 110 mg/l the utilization efficiency was found to decrease by 48% and efficiency decreased further to 26.6% at 132mg/l CO_2 level.
- The utilization efficiency was found to be zero when the CO_2 levels were increased (154,184.8, 330 & 396 mg/l).
- The GPP and NPP levels increased gradually from 26.4 mg/l to 132 mg/l CO_2 concentration.
- The GPP and NPP values decreased after 132 mg/l.
- The GPP and NPP values were highest at 132 mg/l CO_2 which was 2.40 & 2.06 mgC/l/hr.

- Seven levels of dissolved CO_2 in seawater were taken to know the rate of carbon utilization in light by *Caulerpa scalpelliformis.*
- The concentration levels were (0, 17.6, 26.4, 30.8, 35.2,66 and 110 mg/l).
- There was an increase in utilization efficiency from 25% at 17.6 mg/l to 42.86% at 30.8 mg/l.
- At CO_2 level of 110 mg/l the utilization efficiency was zero.
- The GPP and NPP levels increased gradually from 17.6 mg/l to 66 mg/l CO_2 concentration.
- At concentrations beyond 66 mg/l, the productivity decreased.
- Five levels of dissolved CO_2 in seawater were taken to know the rate of carbon utilization in light by *Caulerpa taxifolia.*
- The concentration levels were (0, 13.2, 30.8, 52.8 & 88 mg/l).
- There was an increase in utilization efficiency from 33.33% at 13.2 mg/l to 57.14% at 30.8 mg/l CO_2 level.
- The utilization efficiency then decreases to 50% at 52.8 mg/l CO_2 level and to 30% at 88 mg/l CO_2 concentration.
- The GPP and NPP levels were highest at 88 mg/l CO_2 which were 3.46 mgC/l/hr and 2.50 mgC/l/hr respectively.
- Three levels of dissolved CO_2 in seawater were taken to know the rate of carbon utilization in light by *Acanthopora spicifera.*
- The concentration levels were (0, 13.2, 35.2 & 101.2 mg/l).
- The utilization efficiency was 66.67 % at 13.2 mg/l of CO_2 concentration and it decrease to 47.83% at 101.2 mg/l CO_2 concentration.
- The GPP and NPP levels were highest at 101.2 mg/l CO_2 which were 2.59 mgC/l/hr and 1.56 mgC/l/hr respectively.
- Five levels of dissolved CO_2 in seawater were taken to know the rate of carbon utilization in light by *Caulerpa peltata.*
- The concentration levels were (0, 13.2, 35.2,110 & 154 mg/l).

- There was an increase in utilization efficiency from 66.67% at 13.2mg/l to 75% at 35.2 mg/l CO_2 level.
- At CO_2 level of 110 mg/l the utilization efficiency was found to decrease by 60% and efficiency reduces to zero at 154 mg/l CO_2 level.
- The highest GPP and NPP values were 14.93 mgC/l/hr and 14.47 mg/C/hr at 110 mg/l CO_2 concentration.
- A total of 40 species of seaweeds which belongs to 23 genera, 18 families and 19 orders were recorded along the Thikkodi coast during the study period from September 2018 to August 2019.
- Out of the 40 species recorded from Thikkodi, 19 species belonged to the division Chlorophyta, while 12 species belonged to Rhodophyta and 9 species belonged to Phaeophyta.
- The seasonal variations in abundance of seaweed at Thikkodi in different zones were also studied.
- In zone 1, a total of 30 species were recorded.
- The species *Enteromorpha compressa* was completely absent in zone 1 and was not recorded in any of the seasons (pre-monsoon, monsoon and post-monsoon).
- In zone 2, a total of 27 species were found.
- Four species of seaweeds *viz*., *Boodlea composita, Spatoglossum asperum, Grateloupia indica* and *Grateloupia lithophila* did not occur in zone 2 during any of the three seasons.
- In zone 3, a total of 27 species were recorded.
- Four species namely *Caulerpa scalpelliformis, Boodlea composita, Spatoglossum asperum, Padina gymnospora, Sargassum cinereum*and *Grateloupia indica* were absent in this zone.
- A total of 11 diversity indices were worked out for the seaweed assemblages recorded from three different zones.

- The Shannon Wiener Index (H’) showed wide variation between the zones ranging from the lowest value of 1.33 (zone 3) to the highest value of 1.99 (zone 1).
- The Simpson Index (1-Lambda’) showed variations in values ranging from 0.66 (zone 3) to 0.82 (zone 1).
- The highest value of species richness (S) was obtained in zone 1 (S=14.00), followed by zone 2 (S=8.75) and zone 3 (S=7.08).
- The Margalef’s index (d) was the highest in zone 1 (2.10), while it was minimum in zone 3 (1.08).
- The equitability or Pielou’s evenness index (J’) showed much variation between the zones and the values ranged from 0.67 (zone 2) to 0.77 (zone 1).
- The average taxonomic distinctness (Delta +) was found maximum in zone 1 (83.04) and minimum in zone 3 (72.63) which indicates that the taxonomic distance between species was the highest in zone 1, when compared to zone 2 and zone 3.
- The total phylogenetic diversity (sPhi+) was the highest in zone 1 (801.39), followed by zone 2 (525) and zone 3 (430.56) which indicates the wider taxonomic breadth in zone 1 when compared to the other zones.
- The Similarity Percentage Analysis (SIMPER) showed an average of similarities of 57.21, 41.69 and 37.69% in the case of species of zones 1, 2 and 3 respectively.
- The average dissimilarity between species of zone 1 and 2 was 55.21%, while between species of zone 1 and 3 was 61.93% and between species of zone 2 and 3 was 59.0%.
- Zone 1 has the highest diversity indices and taxonomic attributes as compared to zone 2 and zone 3, which indicates that healthier vegetation is found in zone 1.

The seaweed capture the atmospheric CO_2 through photosynthesis and it can store huge amounts of organic carbon in above ground biomass. The carbon sequestration process in the seaweed biomass can be considered as potential climate change mitigation against increase in atmospheric CO_2.

REFERENCES

REFERENCES

Abdullah, M. I. and Fredriksen, S. 2004. Production, respiration and exudation of dissolved organic matter by the kelp *Laminaria hyperborea* along the west coast of Norway. *J. Mar. Biol. Ass. UK.* 84: 887–894.

Adey, W. H. and Steneck, R. S. 2001. Thermo geography over time creates bio geographic regions: a temperature/space/time-integrated model and an abundance-weighted test for benthic marine algae. *J. Phycol.* 37: 677–698.

Alongi, D. M. 2011. Carbon payments for mangrove conservation: Ecosystem constraints and uncertainties of sequestration potential. *Environ. Sci.* 14(4): 462-470.

Amalu, A. M. 2018. Carbondioxide fixation by seaweeds and their role in De-acidyfying ocean-an experimental approach.MSc (Fs) dissertation, Kerala University of Fisheries and Ocean Studies (KUFOS), Kochi. 87 p.

Amalu, A. M., Revathy, S. and Kaladharan, P. 2018. CO_2 fixation by seaweeds and their role in De-acidifying ocean- an experimental approach. [abstract]. In: Abstracts, Conservation and Sustainability of Aquatic Resources, 19-20 June, 2018, Thoothukudi, p.130. Abstract No. 07.

Anand, P. L. 1940. Marine Algae from Karachi. Part I. Chlorophyceae. Punjab University Botany Publisher, Lahore, pp.1-76.

Andersen, K. H., Mork, M. and Nilsen, J. E. O. 1996. Measurement of the velocity profile in and above a forest of Laminaria hyperborae. *Sarsia.* 81: 193–196.

Andersen, R. A., 1992. Diversity of eukaryotic algae. *Biodivers. Conserv*. 1: 267-292.

Baby Ushakiran, M. S., Treesa, M. V. M., Sathanandan, T. V. and Kaladharan, P. 2017. Marine macroalgal resources from nine beaches along the Kerala coast, India. *J. Mar. Biol. Ass. India*. 59(1): 73-81.

Bala, G. 2013. Digesting 400 ppm for global mean CO_2 concentration. *Curr. Sci.* 104: 1471–1472.

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C. and Silliman, B. R. 2011. The value of estuarine and coastal ecosystem services. *Ecol. Monogr.* 81(2): 169-193.

Behrenfeld, M. J., Esais, W. E., Turpie, K. R. 2002. Assesment of primary production at th global scale. In: Willims, P. J. le B., Thomas, D. N., Reynolds, C. S. (eds.), *Phyttoplankton Productivity Carbon assimilation in marine and freshwater ecosystems*, Blackwell, Oxford, pp.156-186.

Bereribar, E., Wynne, M. J., Barbara, I. and Santos, R. 2004. Records of Rhodophyta new to the flora of the Iberian Atlantic coast. *Bot. Mar*. 52: 217-218.

Boergesen, F. 1934. *Some marine algae from the Northern part of the Arabian Sea with remarks on this geographical distribution.* Kongelige Danske Vidensk Selskab, Biological Meddelelser. 11(6): 72 p.

Briggs, J. 1974. *Marine zoogeography*. McGraw Hill Book Company, New York, 475p.

Cavas, L. and Yurdakoc, K. 2005. An investigation on the antioxidant status of the invasive algae Caulerpa racemosa var. cylindracea (Sonder) Verlaque, Huisman, et Boundouresque (Caulerpales, Chloropphyta*). J. Exp. Mar. Biol.Ecol.* 325: 189-200.

Chennubhotla, V. S. K., Ramachandrudu, B. S., Kaladharan, P. and Dharmaraja, S. K. 1988. Seaweed resources of Kerala Coast. *Aquat. Biol*.7: 69-74.

Chung, I. K., Beardall, J., Mehta, S., Sahoo, D., and Stojkovic, S. 2011. Using Marine Macroalgae for Carbon Sequestration: A Critical Appraisal. *J. Appl. Phycol.* 23:877-886.

Chung, I. K., Oak, J. H., Lee, J. A., Shin, J. A., Kim, J. G. and Park, K. S. 2013. Installing kelp forest/seaweed beds for mitigation and adaptation against global warming: Korean project overview. *ICES J.Mar. Sci*. 70(5): 1038-1044.

Clarke, K. R. and Warwick, R. M. 2001. A further biodiversity index applicable to species lists:variations in taxonomic distinctness. *Mar. Ecol. Prog. Ser.* 216: 265-278.

Dawes, C. J. 1998. *Marine Botany* (2nd Ed.). John Wiley & Sons, Inc, New York. 48p.

DeLaunce, R. D., Pezeshki, S. R., Pardue, J. H., Whitcomb, J. H. and Patrick, W. H. 1990. Some influences of sediment addition to a deteriorating salt marsh in th Mississippi River deltaic plain: a pilot study. *J.Coast.Res*. 6: 181-188.

Denman, K. L., Brasseur, G., Chidthaisong, A., Ciais, P., Dickinson R. E., Hauglustaine, D., Heinze, C., Holland, E., Jacob, D., Lohmann, U., Ramachandran, S., da Silva Dias, P. L., Wofsy, S. C. and Zhang, X. 2007. Couplings between changes in the climate system and biogeochemistry. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. (eds.), *Climate change 2007: the physical science basis.* Contribution of Working Group I to the Fourth Assessment

Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, United Kingdom and New York, NY, USA, pp.501-587.

Dhargalkar, V. K., Untawale and Jagtap, T. G. 2001. Marine and macroalgal diversity along the Maharastra coast; Past and present status. *Indian J. Mar. Sci*. 30(1): 18-24.

Dring, M. J. 1982. *The biology of marine plants*. Edward Arnold publishers limited, London, 199p.

Duarte, C. M., Marba, N., Gacia, E., Fourqurean, J. W., Beggins, J., Barron, C. and Apostolaki, E. T. 2010. Seagrass community metabolism: Assessing the carbon sink capacity of seagrass meadows. *Glob.Biogeochem*.24(4): 1-8.

Duarte, C. M, Middelburg, J. J., Caraco, N. 2005. Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences.* 2: 1–8.

Duarte, C. M., Losada , I. J., Hendriks, I. E., Mazarrasa, I. and Marba., N. 2013. The role of coastal plant communities for climate change mitigation and adaptation. *Nat. Clim. Chang.* 3: 961-968.

Duarte, C. M. 1992. Nutrient concentration of aquatic plants: patterns across species. *Limnol*. *Oceanogr.* 37: 882–889.

Dye, J. F. 1958. Correlation of the two principal methods of calculating the three kinds of alkalinity. *J. Am. Assoc*.50: 812-814.

EPA [Environmental Protection Agency]. 2017. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2015. Washington, DC: US Environmental Protection Agency.

ESRL/NOAA [Earth Systems Research Laboratory/National Oceanic and Atmospheric Administration]. 2009. ESRL/NOAA home page[on line]. Available: http;//www.esrl.noaa.gov. [19 Nov.2019].

FAO [Food and Agriculture Organization]. 2009. The State of World Fisheries and Aquaculture 2008[e-book]. Food and Agriculture Organization of the United Nations, Rome, Italy. Available: http://www.fao.org/3/i0250e/i0250e00.htm. [19 Nov.2019].

Forrester, M. L., Krotkov, G. and Nelson, C. D. 1966. Effect of oxygen on photosynthesis, photorespiration and respiration in detached leaves 1. Soybean. *Plant Physiol*. 41: 422-427.

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marba, N., Holmer, M., Mateo, M. A., Apostolaki, E. T., Kendrick, G. A., Krause Jensen, D., McGlathery, K. J. and Serrano, O. 2012. Seagrass ecosystems as a globally significant carbon stock. *Nat Geosci.* 5(7): 505-509.

Gaarder, T. and Gran, H. M. 1927. Investigation of the production of plankton in the Olso Fjord. *Int. Explor.Mer.* 42: 3-7.

Gaitán-Espitia, J. D., Hancock, J. R., Padilla-Gamiño, J. L., Rivest, E. B. , Blanchette, C. A., Reed, D. C. and Hofmann, G. E. 2014. Interactive effects of elevated temperature and pCO_2 on early-life-history stages of the giant kelp Macrocystis pyrifera. *J. Exp. Mar. Biol. Ecol.* 457:51-58.

Gao, K. and McKinley, K. R. 1994. Use of macroalgae for marine biomass production and CO_2 remediation: a review. *J. Appl. Phyco.* 6: 45–60.

Gao, K. and Zheng, Y. 2010. Combined effects of ocean acidification and solar UV radiation on photosynthesis, growth, pigmentation and calcification of the coralline alga Corallina sessile (Rhodophyta). *Glob Chang Biol.*16: 2388–2398.

Gao, K., Aruga, Y., Asada, K., Ishihara, T., Akano, T. and Kiyohara, M.1991. Enhanced growth of the red alga Porphyra yezoensis Ueda in high CO_2 concentrations. *J. Appl. Phycol.* 3: 356–362.

Gattuso, J. P., Gentili, B., Duarte, C. M., Kleypas, J. A., Middelburg, J. J., and Antoine, D. 2006. Light availability in the coastal ocean: impact on the distribution of benthic photosynthetic organisms and their contribution to primary production. *Biogeosciences.* 3(4): 489-513.

Geoscience Australia. 2010. Coastline lengths. Australian Government. Available fromhttp://www.ga.gov.au/scientific-topics/geographic-information/dimensions/bolder-lengths. [Acessed 12.Nov.2019].

Gopalakrishnan, P. 1970. Some observations on the Shore Ecology of Okha Coast. *J. Mar. Bio.Ass. India*. 12: 15-34.

Graham, M. H., Kinlan, B. P., Druehl, L. D., Garske, L. E., and Banks, S. 2007. Deep-water kelp refugia as potential hotspots of tropical marine diversity and productivity. *Proc.Nat. Acad. Sci.U.S.A.*104: 16576–16580.

Guiry, M. D. and Guiry, G. M. 2019. Algaebase[online]. World-wide electronic publication, National University of Ireland, Galway. Available:http://www.algaebase.org. [22 Sep.2019].

Gujarat Ecological Commission (GEC). 2012. Seaweed Diversity along the Gulf of Kutch, 81p.

Hansen, J., Sato, M., Kharecha, P. and Von Schuckmann, K. 2011. Earth’s energy imbalance and implications. *Atmos. Chem.Phy*. 11(24): 13421-13449.

Hill, R., Bellgrove, A., Macreadie, P. I., Petrou, K., Beardall, J., Steven, A., Ralph, P. J. 2015. Can macroalgae contribute to bluecarbon? An Australian perspective. *Limnol Oceanogr*. 60: 1689–1706.

Howard, J. A., Sutton-Grier, D., Herr, J. Kleypas, E., Landis, E., Mcleod, E., Pidgeon, and Simpson, S. 2017. Clarifying the role of coastal and marine systems in climate mitigation. *Front. Ecol. Environ.* 15(1): 42-50.

Huo, Y. Z., Wu, H. L., Chai, Z. Y., Xu, S. N., Han, F., Dong, L. and He, P. M. 2012. Bioremediation efficiency of Gracilaria verrucosa for an integrated multi-trophic aquaculture system with Pseudosciaena crocea in Xiangshan harbor, China. *Aquac.* 326(329): 99–105.

IPCC [Intergovernmental Panel on Climate Change]. 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Cambridge, United Kingdom, NY, UK, 582p.

IPCC [Intergovernmental Panel on Climate Change]. 2013. Climate Change 2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, United Kingdom and New York, NY, USA, 1585p.

IPCC. 2007. Synthesis Report. 2007. Available from http://www.ipcc.ch/report/ar4/syr. [18 Nov.2019].

IPCC. 2014. 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T. G. (eds.), IPCC, Switzerland.

IPCC. Climate Change 2014: Synthesis Report. 2014. Available from http://www.ipcc.ch/report/ar5/syr. [18 Nov.2019].

James, J. E., Kumar, R. A. S. and Raj, A. D. S. 2004. Marine algae Flora from some Localities of southeast coast of Tamil Nadu, *Seaweed Res. Utiln.* 26(1&2): 3-39.

Jansson, C., Wullschleger, S. D., Kalluri, U. C. and Tuskan, G. A. 2010. Phytosequestration: Carbon biosequestration by plants and the prospects of Genetic Engineering. *Bioscience.* 60(9): 685-696.

Jha, B., Reddy, C. R. K., Thakur, M. C. and Umamaheswara, R., 2009. *Seaweeds of India-The Diversity and Distribution of Seaweeds of the Gujarat Coast.* Springer Dordrecht Heidelberg London New York, 216p.

John, D. M. 1994. Biodiversity and conservation:an algal perspective. *Phycologist.* 38:3-15.

Kaladharan, P. and Reeta, J. 2003. Seaweeds. In: Joseph, M. M. and Jayaprakash, A. A. (eds.), *Status of exploited marine fishery resources of India*, Cent. Mar. Fish. Res. Inst., Cochin, pp. 228-239.

Kaladharan, P., Veena, S., and Vivekanandan, E. 2009. Carbon Sequestration by a Few Marine Algae: Observation and Projection. *J. Mar. Biol. Ass. India.* 51(1): 107-110.

Kaliaperumal, N. 2005. *Conservation of seaweed resources for sustainable utilizations*. SDMRI research Publication, Regional centre of Central Marine Fisheries Research Institute Marine Fisheries, Tamilnadu, 9: 49-53.

Kalimuthu, S., Kaliperumal, N. and Ramalingam, J. R. 1995. Distribution of algae and sea grasses in the estuaries and backwaters of Tamil Nadu and Pondicherry. *Seaweed Res. Utiln*. 17 (1&2): 79-86.

Koch, M., Bowes, G., Ross, C., zhang, X. H. 2015. Climate change and ocean acidification effects on seagrasses and marine macroalgae of Iran. *Bot. Mar.* 58: 307-320.

Kokabi, M., Yousetzadi, M., Razaghi, M. and Feghhi, M. A. 2016. *Mar. Biodivers Rec*. 9:96.

Kolanjinathan, K., Ganesh, P. and Saranraj, P. 2014. Pharmacological Importance of Seaweeds: A Review. *World J. Fish. Mar. Sci*. 6: 01-15.

Krause-Jensen, D. and Duarte, C. M. 2016. Substantial role of macro algae in marine carbon sequestration. *Nat. Geosci.* 9(10): 737-742.

Krause-Jensen, D., Lavery, P., Serrano, O., Marba, N., Masque, P. and Duarte, C. M. 2018. Sequestration of macroalgal carbon: The elephant in the Blue Carbon room. *Biol Lett*. 14(6).

Krishnamurthy, V. 1969. Seaweed drifts on the Indian coast. *Bull. Nat. Inst. Sci.* 38 (2): 657-666.

Krishnan, M. and Narayankumar, R. 2010. Socio economic dimensions of Seaweed Farming in India. CMFRI Special Bulletin No.102, 78 p.

Krumhansl, K. A., and Scheibling, R. E. 2012. Production and fate of kelp detritus. *Mar. Ecol. Prog. Ser.* 467: 281-302.

Laffoley, D. d'A. and Grimsditch, G. 2009. *The management of natural coastal carbon sinks.* IUCN, Gland,Switzerland. 53p.

Lal, R. 2007. Carbon sequestration. *Phil.Trans. R. Soc. B.* 363: 815-830.

Lee, S. Y., Primavera, F., Dahdouh-Guebas, F., McKee, K. Bosire, J. O., Cannicci, S., Fromard, N., Marchand, C., Mendelssohn, I., Mukherjee, N. and Record, S. 2014. Ecological role and services of tropical mangrove ecosystems: A reassessment. *Glob. Ecol. Biogeogr*. 23(7): 726-743.

Leena, T. and Prabhadevi, L. 2004. Seaweeds and the associated fauna of the Thirumullavaram coast, Kerala. *Seaweed Res. Utiln.* 26 (1&2): 23-28.

Littler, M. M. and Murray, S. N. 1974. The primary productivity of marine macrophytes from a rocky intertidal community. *Mar. Biol.* 27: 131–135.

Lovas, S. M, Totum, A. 2001. Effect of the kelp Laminaria hyperborean upon sand dune erosion and water particle velocities. *Coast. Eng.* 44: 37–63.

Lüthi, D., Le Floch, M., Bereiter, B., Blunier, T., Barnola ,J., Seigenthaler, U., Raynaud, D., Jouzel, J., Fischer, H., Kawamura, K. and Stocker, T. F. 2008. High resolution carbon dioxide concentration record 650000–800000 years before present. *Nat.* 453: 379–382.

MacArtain, P., Christopher, I. R. G., Mariel, B., Ross, C. and Ian, R. 2007. Nutritional value of Edible Seaweeds. *Nutri. Rev.* 65: 535-543.

Mann, K. H. 1973. Seaweeds-their productivity and strategy for growth. *Sci*. 182: 975–981.

Mann, K. H.1982. *Ecology of coastal waters-A system approach studies in Ecology*. University of California Press, Berkeley. 322pp.

Mathew, S. S. and Chennubhotla, V. S. K. 1993.Some observations on the ecology and biochemical aspects of the seaweeds of Kerala coast. *CMFRI. Spl. Publ.* 56: 133-136.

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H. and Silliman, B. R. 2011. A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Front. Ecol. Environ.* 9(10): 552-560.

Melkonian, M. 1995. introduction. In: Wiessner, W., Schnepf, E., Starr, R. C. (eds.), *Algae, Environment and Human Affairs*, Bristol, Biopress Ltd. pp.11-13.

Mitra, A., Zaman, S., Pramanick, P., Bhattacharyya, S. B, Raha, A. K. 2014. Stored carbon in dominant seaweeds of Indian Sundarbans. *Pertanika J. Trop. Agric. Sci.* 37: 263–274.

Munda, M. I. 1981. Tide pool associations of Benthic algae in Icelandic waters.In: Levring,T. (ed.), *X^{th} International Seaweed Symposium*, 11-15 August 1980, New York, pp. 327-332.

Murray, B. C., Pendleton, L., Jenkins, W. A. and Sifleet, S. 2011 . *Green payment for blue carbon: economic incentives for protecting threatened coastal habitats*. Nicholas Institute for Environment Policy Solutions Report. Durham, North Carolina, USA, 42p.

N'Yeurta, A. D. R,, Chynoweth, D. P., Capron , M. E., Stewart, J. R., and Hasan, M. A. 2012. Negative carbon via Ocean Afforestation. *Process. Saf. Environ. Prot*. 90: 467–474.

Nabuurs, G. J., Masera, O., Andrasko, K., Benitez-Ponce, P., Dutschke, R. B. M., Elsiddig, E., Ford-Robertson, J., Frumhoff, P., Karjalainen, T., Krankina, O., Kurz, W. A., Matsumoto, M., Oyhantcabal, W., Ravindranath, N. H., Sanchez, M. J. S. and Zhang. X. 2007. Forestry. In: Metz, B., Davidson, O. R., Bosch, P. R., Dave, R. and Meyer, L. A. (eds.), *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University press, United Kingdom and New York, NY, USA, pp.542-584.

Nagelkerken, I., Blaber, S. J. M., Bouillon, S., Green, P., Haywood, M., Kirton, L. G., Meynecke, J. O., Pawlik, J., Penrose. M., Sasekumar, A. and Somerfield, P. J. 2008. The habitat function of mangroves for terrestrial and marine fauna: A review. *Aquat. Bot.* 89 (2): 155-185.

Nair, N. B. and Shobha, V. 1983. Marine Algae of Kerala II: Report on a collection from Varkala, Kovalam, Poovar and Cape Comorin. *Mahasagar.* 16 (4): 469-471.

Nair, N. B., Shobha, V. and Arunachalam, M. 1982. Algae from southern Kerala coast. *Indian J. Mar. Sci*. 11: 266-269.

Narayan, S., Beck,M. W., Reguero, B. G., Losada, I. J. Wesenbeek, B. V., Pontee, N., Sanchirico, J. N., Ingram, J. C., Lange, G. M. and Burks-Copes, K. A. 2016. The effectiveness, costs and coastal protection benefits of natural and nature-based defences. *Plos One*.11 (5): 1-17.

NASA. 2018. Retrived on 13.09.2019 from https://climate.nasa.gov.

NASEM [National Academies of Sciences, Engineering, and Medicine] . 2016. *Attribution of Extreme Weather Events in the Context of Climate Change.* Washington, DC; National Academies Press.187p.

Nellemann, C., Corcoran, E., Duarte, C. M., Valde´s, L., De Young, C., Fonseca, L. and Grimsditch, G. 2009. *Blue Carbon: The role of healthy oceans in binding carbon*. Grid-Arendal, Norway.78p.

NIO bioinformatics. 2019. Available from:http://www.niobioinformatics.in. [22 Nov.2019].

Okuda, K. 2008. Coastal environment and seaweed-bed ecology in Japan. *Kuroshio Sci.* 2(1): 15–20.

Ormond, R. F. G. and Banaimoon, S. A. 1994. Ecology of intertidal macroalgal assemblages on the Hadramout coast of southern Yemen, an area of seasonal upwelling. *Mar. Ecol. Prog. Ser.*105: 105-120.

Orr, M., Zimmer, M., Jelinski, D. E., Mews, M. 2005. Wrack deposition on different beach types: spatial and temporal variation in the pattern of subsidy. *Ecol. Soc. Am.* 86: 1496–1507.

Oza, Rohit, M. 2005. Biodiversity of Benthic Marine Algae along the Indian Coast. Handbook of Biotechnology, 48p.

Palanisamy, M., Yadav, S. K. and Murthy, G. V. S. 2017. Distribution and Diversity of Seaweeds at Thikkodi Coast, Kerala. In: Rajendran, A. and Aravindhan, V. *Biodiversity Conservation: Aspects and Prospects*, LAP LAMBERT Academic Publishing, Germany, pp.51-62.

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S. and Hayes, D. 2012. A large and persistent carbon sink in the world’s forests. *Sci.* 333(6045): 988-993.

Papenfuss, G. F. 1968. A history,catalogue and bibliography of benthic Red Sea algae. *Israel J. Bot.* 17: 1-118.

Pawar, P. R. 2017. Distribution pattern & species diversity of seaweeds at Uran (Navi Mumbai), West Coast of India. *Int. J. Appl. Zool.* 5(1): 25-32.

Pendleton, L., Donato, D. C., Murray, B. C., Crooks, S., Jenkins, W. A., Siflect, S., Craft, C., Fourqurean, J. W., Kauffman, J. B., Marba, N., Megonigal, P., Pidgeon, E., Herr, D., Gordon, D. and Baldera, A. 2012. Estimating global “Blue carbon” emissions from conversion and degradation of vegetated coastal ecosystems. *Plos One.* 7(9): 435-442.

Phang, S. W., Hino, T., Abdullah, M. H. and Karamoto, N. 2007. Applications of polyaniline doubly doped with p-toluene sulphonic acid and dichloroacetic acid as microwave absorbing and shielding materials. *J. Phy. Chem.*104: 327-335.

Phillips, J. A. 2001. Marine macro algal biodiversity hotspots: Why is there high species richness and endemism in southern Australian marine benthic flora? *Biodivers. Conserv*. 10: 1555–1577.

Qari, R. 1985. Seasonal variation in biomass and biochemical composition of some edible seaweeds from Karachi coast. M.Phil thesis, Centre of Excellence in Marine Biology, Karachi University.

Ramankutty, N., Evan, A. T., Monfreda, C. and Foley, J. A. 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year. 2000. *Glob. Biogeochem. Cycles.* 22:1-9.

Rao, P. V. S. and Mantri, V. A. 2006. Indian seaweed resources and sustainable utilization: scenario at the dawn of a new century. *Curr. Sci.* 91: 161-174.

Rath, J. and Adhikary, S. P. 2006. Marine macro-algae of Orissa, east coast of India. *Algae.* 21(1): 49 - 59.

Raupach, M. R. and Canadell, J. G. 2008. Observing a vulnerable carbon cycle. In: Dolman, A. J, Valentini, R., and Freibauer, A. (eds.), *The continental scale greenhouse gas balance of Europe.* Ecological studies, Springer, New York, pp.5-32.

Reed, D. C. and Brzezinski, M. A. 2009. Kelp forest. In: Laffoley, D.d' and Grimsditch, G. (eds.). *The Management of Natural Coastal Carbon Sinks.* IUCN, Gland, Switzerland, pp. 31–37..

Ritschard, R. L. 1992. Marine algae as a CO_2 sink. *Water Air Soil Pollut.* 64: 289-303.

Ronnback, P., Kautsky, N., Pihl, L., Troell, M., Soderqvist, T. and Wennhage, H. 2007. Ecosystem goods and services from Swedish coastal habitats: identification, valuation, and implications of ecosystem shifts. *Ambio. J. Hum. Environ.* 36: 534–544.

Sabine, C. L., Feely, R. A., Gruber, N., Key, R. M., Lee, K., Bullister, J. L., Wanninkhof, R., Wong, C. S., Wallace, D. W. R., Tilbrook, B., Millero, F. J., Peng, T. H., Kozyr, A., Ono, T. and Rios, A .F. 2004. The oceanic sink for anthropogenic CO_2. *Sci.* 305:367–371

Sahoo, D. 2001. *Seaweeds of Indian coast.* A.P.H. Publishing Corporation, New Delhi, 283p.

Sahoo, D., Sahu, N. and Sahoo, D. 2003. A Critical Survey of Seaweed Diversity of Chilika Lake, India. *Algae*.18(1): 1-12.

Saifullah, S. M. 1973. A Preliminary Survey of the Standing Crop of Seaweeds from Karachi Coast. *Bot. Mar*.16(3): 139-144.

Sarmiento, J. L. and Gruber, N. 2002. Sinks for anthropogenic carbon. *Phys.* 55(8): 30-36.

Satheesh, S. and Wesley, S. G. 2012. Diversity and distribution of seaweeds in the Kudankulam coastal waters, south-eastern coast of India. *Biodivers. J.* 3(1): 79 - 84.

Selvaraj, R. and Selvaraj, R. 1997. Distribution and diversity of seaweeds in Tiruchendur and Idinthakarai. Seaweed. *Res. Utiln*. 19: 115-123.

Siegenthaler, U. and Sarmiento, J. L. 1993: Atmospheric carbon dioxide and the ocean. *Nat.* 365: 119-125.

Silas, E. G. 1987. Prospects of seaweed research and utilization. *CMFRI Bull*. 41: 81-111.

Silva, P. C., Basson, P. W. and Moe, R. L. 1996. *Catalogue of the benthic marine algae of the Indian Ocean*. University of California publications in botany, USA. 1259 p.

Simkanin, C., Power, A., Myers, A., McGranth, D., Southward, A., Mieszkowska, N., Leaper, R. and O'Riordan, R. 2005. Using historical data to detect temporal changes in the abundances of intertidal species on Irish shores. *J. Mar. Ass. UK*. 85: 1329-1340.

Singh, U. B., and Ahluwalia, A. S. 2013. Microalgae: A promising tool for carbon sequestration. *Mitig. Adapt. Strateg. Glob. Chang.* 18: 73–95.

Smith, S. V. 1981. Marine macrophytes as a global carbon sink. *Sci.* 211: 838–840.

Srinivasan, K. S. 1946. Ecology and seasonal succession of the Marine algae Mahabalipuram (Seven pagodas) Near Madras. Indian Bot. Soc. M.O.P. Iyengar Commemo.Vol.pp. 267-278.

Stephenson, T. A. and Stephenson, A. 1949. The Universal Features of Zonation between Tide-Marks on Rocky Coasts. *J. Ecol.* 37(2): 289–305.

Suzuki, Y. 1997. *Marine biota and global carbon cycling.* (1st Ed.). University of Tokyo press, Tokyo, 208p.

Tang, Q., Zhang, J., Fang, J. 2011. Shellfish and seaweed mariculture increase atmospheric CO_2 absorption by coastal ecosystem. *Mar. Ecol. Prog. Ser.* 429: 97-104.

The Fishery Bureau MoA. 2015. *China Fishery Statistical Yearbook.* China Agriculture Press, Beijing, China, 155 p.

Trevathan-Tackett, S. M., Kelleway, J., Macreadie, P. I., Beardall, J., Ralph, P. and Bellgrove, A. 2015. Comparison of marine macrophytes for their contributions to blue carbon sequestration. *Ecol.* 96(1): 3043-3057.

Tseng, V. 2004. Family Interdependence and Academic Adjustment in College: Youth From Immigrant and U.S.-Born Families. *Child. Dev.* 75(3): 966-983.

Turan, G. and Neori, A. 2011. Intensive seaweed aquaculture :a potent solution against global warming. In: Israel, A., Einav, R., Seckbach, J. (eds.), *Seaweed and their role in globally changing environment*,. Springer, Dordrecht, pp. 359–372.

UNFCC.2011.Retrived on 8.09.2019 from https.//unfcc.int/resource/docs/2011/cop17/eng/07.pdf.

UNFCC.2013. Retrived on 8.09.2019 from https.//unfcc.int/resource/docs/2015/sb/eng/inf01.pdf.

UNFCCC [United Nations Framework Convention on Climate Change]. 2011. The Paris Agreement.Available from:http://www.unfcc.int. [18 Nov.2019].

Untawale, A. G., Reddy, C. R. K. and Deshmukhe, G. V. 1989. Ecology of intertidal benthic algae of northern Karnataka coast. *Indian J. Mar. Sci*. 18(2): 73-81.

Vander, S. H. J., Boele-Bos, S. A., Olsen, J. L., deZande, L. V. and Stam, W. T. 2002. Phylogeographic studies in the tropical seaweed Cladophoropsis membranacea (Chlorophyta, Ulvophyceae) reveal a cryptic species complex. *J. Phycol.* 38: 572-582.

Venkatraman, K. 2005. Coastal and Marine Biodiversity of India. *J. Mar. Sci.* 34(1): 57-75.

Walker, D. I. 1987. Benthic algae. In: Edwards, A. J. and Head, S. M (eds.), Red Sea. Pergamon Press, Oxford, pp 152-168.

Wellman, B. 1998. Doing it ourselves: The SPSS Manual as Sociology's Most Influential Recent Book. In: Amherst, D. C. (ed.). *Required Reading: Sociology's Most Influential Book*, University of Massachusetts Press, pp.71-78.

Westlake, D. F. 1963. Comparisons of plant productivity. *Biol. Rev.* 38: 385-425.

Winkler, L. W. 1888. *Ber. Dtsch. Chem. Ges.* 21(2): 2843-2854.

WORMS [World Register of Marine Species]. 2019. Available from: http://www.marinespecies.org. [21 Nov. 2019].

Yang, Y. F., Feixg, Song, J. M., Hu, H. Y., Wang, G. C. and Chung, I. K. 2006. Growth of Gracilaria lemaneiformis under different cultivation conditions and its effects on nutrient removal in Chinese coastal waters. *Aquac*. 254: 248–255.

Zhang, J., Fang, J., Wang, W., Du, M., Gao, Y. and Zhang, M. 2012. Growth and loss of mariculture kelp Saccharina japonica in Sungo Bay, China. *J. Appl. Phycol.* 24: 1209–1216.

Zou, D. 2005. Effects of elevated atmospheric CO_2 on growth, photosynthesis and nitrogen metabolism in the economic brown seaweed, Hizikia fusiforme (Sargassaceae, Phaeophyta). *Aquac*. 250(3-4): 726-735.

CARBON SEQUESTRATION POTENTIAL OF SELECTED SEAWEEDS OF THIKKODI, KERALA

by

SARANYA M.S.

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THESIS ABSTRACT

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VELLANIKKARA, THRISSUR – 680 656

KERALA, INDIA

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ABSTRACT

The coastal blue carbon is the carbon sequestered by mangrove, tidal marshes, seagrasses and macroalgae which account for less than 0.5% of the seabed. Unlike, other blue carbon sectors (mangroves, tidal marshes and seagrasses), the macroalgae do not have sedimentary substratum. The macroalgae are commonly known as seaweeds. The ‘seaweeds’ as the name suggest is not an unwanted plant or weed. It has an important role in the marine ecosystem by acting as a sink for carbon emissions. The present study is based on the carbon sequestration potential of selected seaweeds of Thikkodi coast, Kerala. The state of Kerala has a long coastline of about 580 km, ranking only third among all the maritime states of the country. Some of these coastline stretches are pegged with areas of seaweed resources. The Thikkodi coast (11º28’30.8” N, 75º37’04.5”E) in the Kozhikode district of Kerala is well known for its rocky intertidal coast with a luxuriant growth of seaweeds of diverse species. An extensive study of seaweeds and their species diversity was carried out for a period of one year from September 2018 to August 2019 along the Thikkodi coast of Kerala. A total of 40 species of seaweeds were recorded which belonged to 23 genera, 18 families and 14 orders. A total of 19 species belonged to Chlorophyta, while 12 species belonged to Rhodophyta and 9 species belonged to Phaeophyta. The distribution and seasonal abundance of different species along the Thikkodi coast was also studied. The biodiversity indices were studied using PRIMER (Plymouth Routines in Multivariate Ecological Research). The biodiversity indices such as Shannon-Wiener diversity (H’), Pielou’s evenness (J’), Margalef species richness (d) were calculated. The seaweeds collected from Thikkodi coast were used to carry out the carbon sequestration potential studies. While comparing the three zones, the highest value of species richness (S) was obtained in zone 1 (S=14.00), followed by zone 2 (S=8.75) and zone 3 (S=7.08). The Margalef’s index (d) which incorporates the number of individuals (N) and species (S) was the highest in zone 1 (2.10), while it was minimum in zone 3 (1.08). The equitability or

individuals among the different species showed much variation between the zones and the values ranged from 0.67 (zone 2) to 0.77 (zone 1). In the present study, the Shannon Wiener Index (H') showed wide variation between the zones ranging from the lowest value of 1.33 (zone 3) to the highest value of 1.99 (zone 1). The Simpson Index (1-Lambda') showed variations in values ranging from 0.66 (zone 3) to 0.82 (zone 1). The experiments were conducted on selected seaweeds particularly *Gracilaria corticata*, *Caulerpa scalpelliformis* and *Caulerpa peltata*. Carbon dioxide was dissolved in seawater at different concentrations using a soda maker by adjusting the fizz. After determining the initial CO_2, the seaweeds were incubated in 125ml light bottles under a water column of 50-60cm for 2 hours. The initial CO_2 concentration

(mg/l) and the CO_2 utilization were examined by titrating the seawater against 0.5N Sodium hydroxide solution using Phenolphthalein indicator. The Gross Primary Production (GPP) and Net Primary Production (NPP) were also estimated. For *Gracilaria corticata*, the utilization efficiency increased from 33.33% to 83.33% in lower CO_2 concentration of 26.4mg/l and 79.2mg/l respectively. For *Caulerpa scalpelliformis*, the utilization efficiency increased from 25% to 42.86% in a lower CO_2 concentration of 17.6mg/l and 30.8mg/l respectively. For *Caulerpa peltata*, the utilization efficiency increased from 66.67% to 75% in a lower CO_2 concentration of 13.2mg/l and 35.2 mg/l respectively. When the concentration of $CO_2$was increased beyond a threshold level, the CO_2 utilization efficiency decreases and cease down to zero .Same is the case for productivity. Therefore the study implies that the carbon sequestration potential of different species of seaweeds varies. The macroalgae have a greater potential to act as carbon sink and based on the sequestration potential of seaweeds, selection of different species of seaweeds can be made possible for developing Seaweed Aquaculture Beds (SABs). The SABs provide important structure in coastal ecosystem and play an incredible role in climate change mitigation aspects.