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Seasonal variations in seagrass biomass and productivity in Palk Bay, Bay of Bengal, India

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Seagrass meadows are valuable habitats having economic and ecological importance in coastal ecosystem. The major seagrass meadows in India exist along the southeast coast of India, particularly in Palk Bay region. The dominant seagrass species of this region was *Cymodocea serrulata* and *Syringodium isoetifolium* and these two species were taken for the survey. In this study, a survey was carried out for a period of two years from August 2009 to November 2011 on the seasonal and spatial variability of these two seagrass species. There was a distinct seasonal and spatial variation in the total biomass, productivity and above ground biomass, leaf canopy height and shoot density of these two species between the stations. The seasonal variation in the biomass, productivity, leaf canopy height and shoot density could be influenced by the abiotic variables and the nutrient factors. Results conclude that the particulate organic carbon, inorganic phosphate and total organic nitrogen (p>0.001 level) influenced the enhancement of biomass, productivity, leaf canopy height and shoot density. Increase in seagrass growth was observed in the monsoon season, due to optimum temperature, low salinity, pH and addition of nutrients.

Key words: Seagrasses, seasonal changes, biomass, productivity, leaf canopy height.

INTRODUCTION

Seagrasses are flowering plants (angiosperms) living their full lifecycle submerged in marine environment. They are found in all coastal areas of the world except in Antarctic (Green and Short, 2003; Duarte and Gattuso, 2010). They comprise less than 0.02% of the angiosperm species and have relatively fewer species than other marine organisms (Short et al., 2007). Despite their low diversity, seagrass beds are ecologically and economically highly important. They are among the world's most productive coastal ecosystems (Duarte and Chiscano, 1999). Seagrasses are not only supportive to marine biota, but also to human populations, especially in the tropical regions where people along the coasts depend largely on the seagrass ecosystem for their daily subsistence in terms of food and per capita income (de la Torre-Castro and Ronnback, 2004). *Cymodocea serrulata* and *Syringodium isoetifolium* belongs to the family Potamogetonaceae, commonly found along the coastal area of the tropical Indo-West Pacific region. Out of the twelve species of seagrasses identified in the east coast of India and among twelve species, two species were selected for this study. *C. serrulata* can be distinguished from other seagrass species by their shoots with distinctive open leaf scars, triangular, flat leaf sheath,

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fibrous roots on the shoot and serrated leaf tips (Oliviera et al., 2005). *S. isoetifolium* can be distinguished by its tubular leaf, scars in rhizome, root and flowers.

A number of general parameters are critical to whether seagrass will grow and persist. These include physical parameters that regulate the physiological activity of seagrasses (temperature, salinity, waves, currents, depth, day length, substrate, etc.), natural phenomena that limit the photosynthetic activity of the plants (light, nutrients, epiphytes and diseases) and anthropogenic inputs that inhibit the access to available plant resources (nutrient and sediment loading). Seagrasses as any other plants require nutrients for their growth, development and metabolism, but too much of some nutrients and environmental factors may limit rather than promote growth. The nutrients most commonly limiting seagrass growth in natural systems are nitrogen and phosphorus (Duarte, 1990; Romero et al., 2006). These essential nutrients may be derived from the decomposition of organic matter in the water column and sediments (Holmer and Olsen, 2002; Kilminster et al., 2006), in which seagrass litters are the main source (Holmer and Olsen, 2002; Romero et al., 2006). Various combinations of these parameters will permit, encourage or eliminate seagrass from a specific location. Although many studies have investigated how light, temperature and salinity affect the seagrass beds, little work has been done regarding the relationships between seagrass biomass, productivity, leaf canopy height and shoot density in the Palk Bay region. Fong and Harwell (1994) have attempted to model seagrass communities and temperature, salinity and light as three of the primary environmental factors affecting seagrass growth. Recently, Govindasamy and Arulpriya (2011) reported that the reduction and degradation of the seagrass beds occurs due to the increase intemperature and salinity in northern part of Palk Bay region. This investigation, therefore, attempts to examine the effects of both environmental factors and nutrients on the biomass, above ground biomass, productivity, leaf canopy height and shoot density of *C. serrulata* and *S. isoetifolium* in Palk Bay region, the eastcoast of India.

MATERIALS AND METHODS

Study sites

Palk Bay is situated in the southeast coast of India encompassing the sea between Point Calimere in the north and the northern shores of Mandapam to Dhanushkodi in the south. It is situated between Latitude 9°55' - 10°45'N and Longitude 78°58' - 79°55'E. The Palk Bay itself is about 110 km long and is surrounded on the northern and western sides by the coastline of the State of Tamilnadu in the mainland of India. The present study was conducted for the period of two years from August 2009 to November 2011 in the Palk Bay region of India. The saline water and the muddy substratum coupled with seasonal rains and discharge from Vaigai and Cauvery rivers has created a good breeding ground for pelagic and demersal fishes.

Manamelkudi (Site I; Lat. 10°2'3"N and Long. 79°15'39"E) is located in the middle part of the Palk Bay (Figure 1). The coastal region is muddy in nature and the muddy bottom of this area provides a suitable substratum for the rich growth of seagrasses. Thondi (Site II) was popular as the historical port in ancient times. Here the coastal region was muddy, swamp in nature and Manimutharu River drain into the sea. Human population was high in the coastal region due to high fishing activity. Devipattinam (Site III; Lat. 9°28'11"N and Long. 78°54'4"E) is located at a distance of 45 km south of Thondi. Here, the littoral zone is muddy and clay in nature thereby it support the luxuriant growth of seagrasses (Sriramkumar et al., 2011). Devipattinam is characterized by channel environment where the southwest monsoon is able to push the waves much into this Bay (Suresh Gandhi and Rajamanickam, 2004). Small patches of mangroves are present in this coastal region. When compared with other two sites in Devipattinam region, human population is high and in addition tourist activities are also high.

Water column characteristics

Water temperature, salinity, pH were measured at the sampling sites itself once in three months using a mercury thermometer, refractometer (Model 2491 Master- S/Milla) and pH meter (Model pH-873), respectively. For the analysis of nutrients, surface water samples were collected in clean polyethylene bottles and kept in an ice box and immediately transported to the laboratory. The samples were filtered using Whatman glass filter paper (70mmø; GF/C) for particulate organic carbon analysis by adapting standard method of Strickland and Parson (1972). The nutrients such as total inorganic phosphate, nitrate, nitrite, reactive silicate, total dissolved organic nitrogen were analyzed by adopting the standard methods described by Strickland and Parson (1972).

Seagrass biomass and productivity

The abundance of seagrasses was quantified by estimating the total biomass and above ground biomass. All the collections were made by using SCUBA diving equipment in the seagrass meadows with its average depth of 3 to 5 m. For biomass estimation, a quadrat (0.25 m^2) was placed ten times at random and seagrass materials found in the quadrat were collected and washed thoroughly with the habitat water to remove debris. Moisture from the samples was removed using adsorbent paper and weighed to get the total biomass. The mean of ten quadrat samplings was considered for computing the seagrass biomass per square meter and the mean values were expressed in terms of gram fresh weight per square meter ($g.fr.wt.m^{-2}$). For the estimation of above ground biomass samples, leaves and sheaths were oven dried at 60°C for 48 h and weighed and the values were expressed in terms of dry weight per square meter ($g.drywt.m^{-2}$). Changes in dissolved oxygen concentration in the water surrounding a plant community was used by several workers as measurements of the products of photosynthesis. Dissolved oxygen was measured by light and dark bottle method and productivity of seagrasses was estimated (Qasim et al., 1972).

Leaf canopy height and shoot density

Prior to drying of samples, the shoot density and leaves canopy height was recorded. For the sake of convenience and interpret-

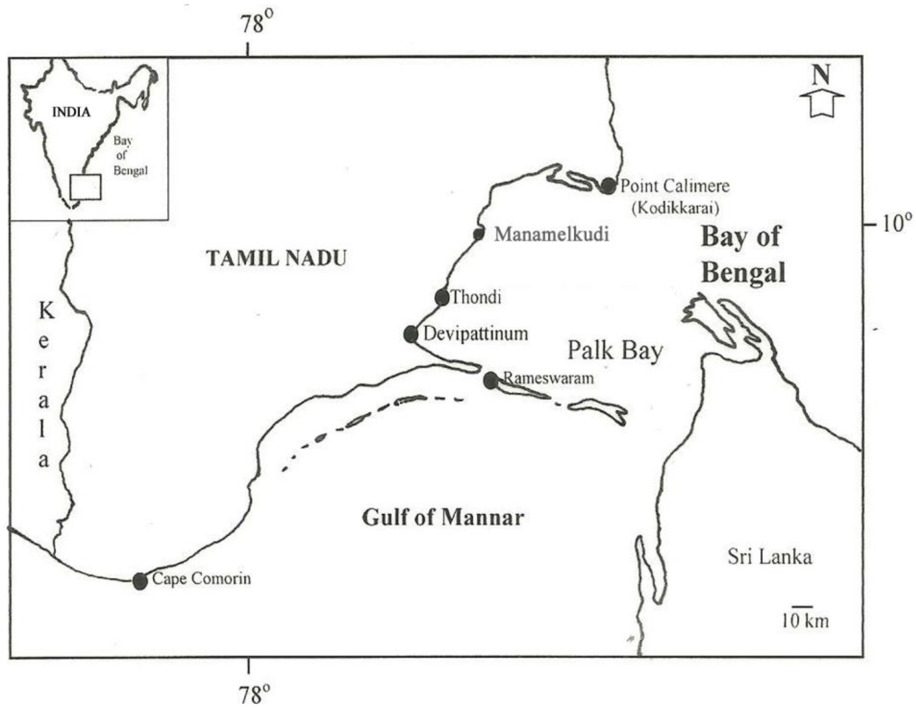

Figure 1. Map showing the study areas.

tation, a calendar year was divided into four seasons based on the northeast monsoon which alone brings bulk rain fall to the southeast coast of India where the present study area is situated. The seasons are: Post monsoon season (January-March), summer season (April-June), premonsoon season (July-September) and monsoon season (October-December). Pearson's correlation co-efficient was employed for the statistical interpretation of data. One-way analysis of variance (ANOVA) tests were used to compare the environmental parameters with biomass, above ground biomass, productivity, shoot density and leaf canopy height between the sites. Two way ANOVA were used to compare the seasonal variation in the physico-chemical, biomass, productivity, leaf canopy height and shoot density.

RESULTS

Water column characteristics

Air and surface water temperatures values were varied from 24 to 31°C at all the sites (Figure 2a and 2b). Minimum temperature was observed during the monsoon season due to monsoonal clouds and maximum temperature was observed during the summer due to solar radiation (Santhanam and Perumal, 2003; Vengadesh Perumal et al., 2009). Salinity values ranged from 29 to 38 ppt during the study period at all the sites (Figure 2c). Both parameters were found to be high in the summer season and low in the monsoon season. Salinity also showed same trend as that of temperature. The high values recorded in the summer season could be attributed to a higher degree of evaporation, reduction of rainfall with decreased fresh water inflow and drainage (Govindasamy et al., 2000). Lowest pH was recorded between monsoon and post monsoon season and highest pH falls in the summer season (Figure 2d). Particulate organic carbon (POC) values ranging from 0.136 to 1.555 mg dry wt.l^{-1} recorded high and low in the monsoon and summer season, respectively at all the sites (Figure 2e). The hydrogen ion concentration (pH) is changed with time due to the changes in temperature, salinity and biological activity. These three physiological parameters were closely related and positively correlated. Higher POC and nutrients content was recorded during the monsoon season, perhaps due to runoff from the land, but was lower in the summer season (Govindasamy and Arulpriya, 2011).

Nitrate and silicate showed significant variation between the sites. One way ANOVA results showed that the nitrate concentration at site I was high than other two sites with an average of 6.425 µM and site III had a lower average silicate of 16.428 µM. Highest nitrate concentration was recorded during rainy season and it was significantly higher than during the dry season (Figure 2f). Nitrite value ranged between 0.302 and 3.146 µM with the maximum in post monsoon at site I (Figure 2g) and III (Figure 2c) and pre monsoon season at site II. Inorganic phosphate concentration in all the seasons ranged from

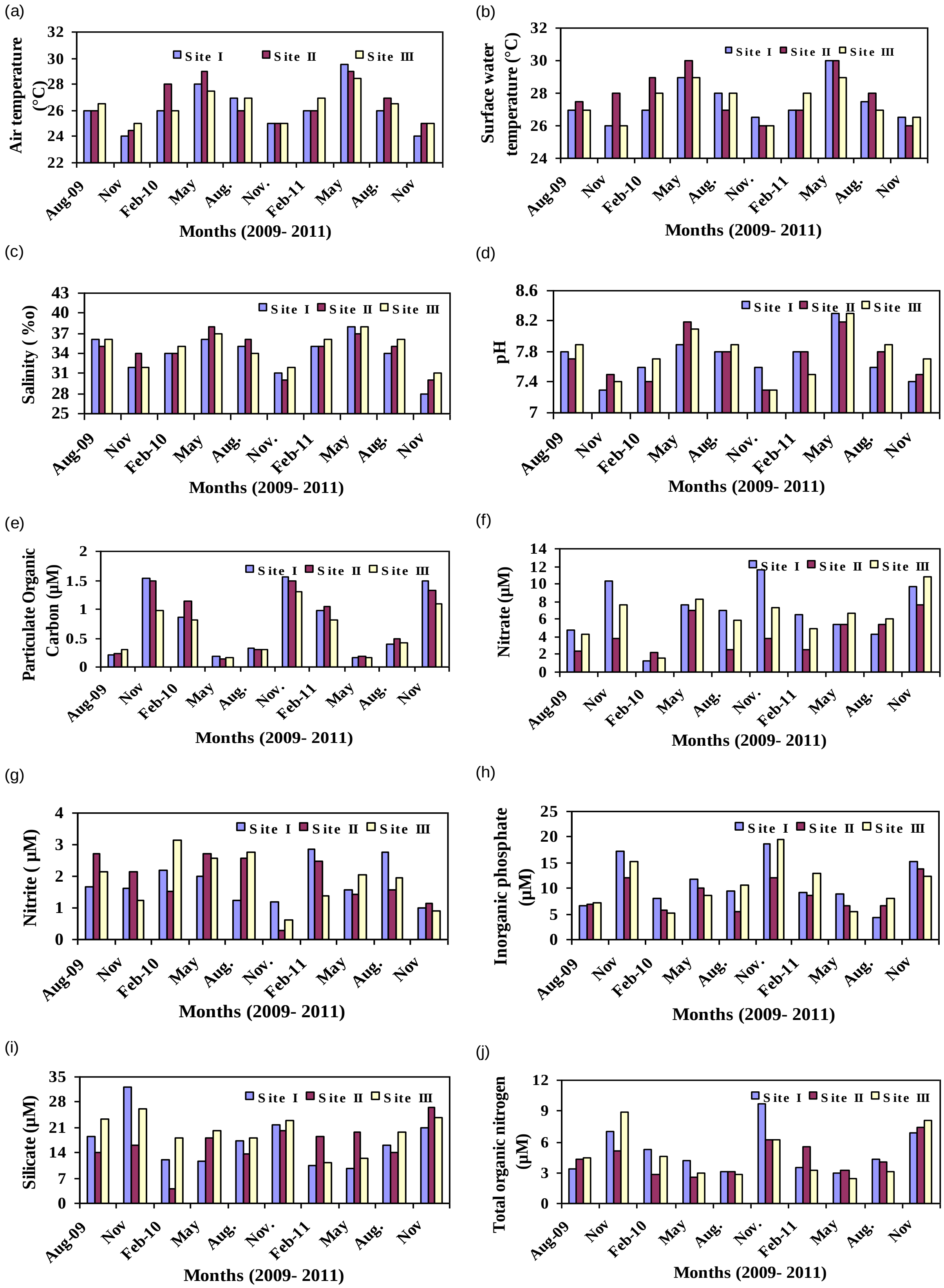

Figure 2a to j. Seasonal changes in water column characters at sites I, II and III during the study period from August 2009 to November 2011.

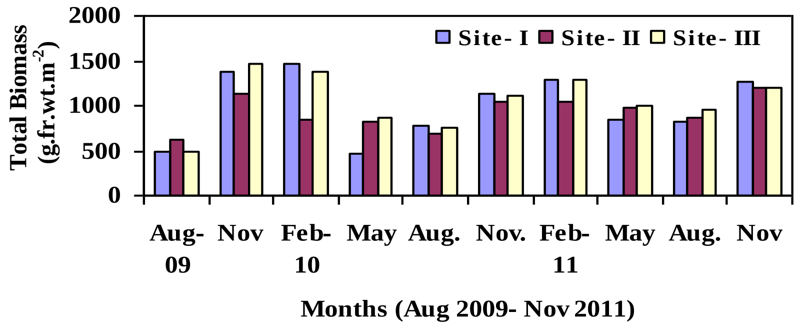

Figure 3a. Seasonal changes in total biomass of *C. serrulata* at sites I, II and III.

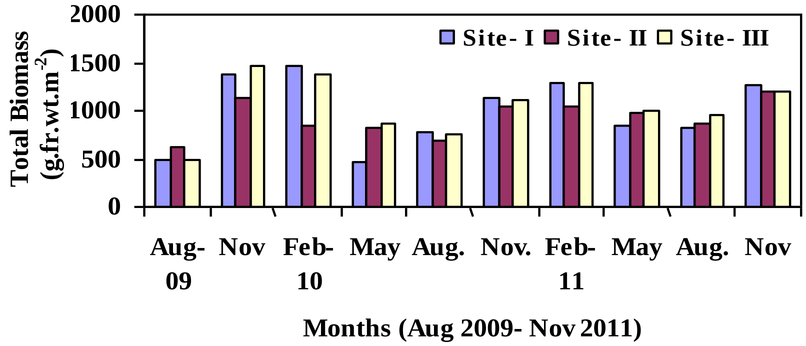

Figure 3b. Seasonal changes in total biomass *S. isoetifolium* at sites I, II and III.

4.318 to19.504 µM in all the sites (Figure 2h). Silicate concentration ranged between 3.984 and 32.267 µM with the maximum in monsoon and minimum in post monsoon at sites I and II (Figure 2i). Total organic nitrogen value ranged from 2.384 to 9.659 µM with maximum in monsoon and minimum in summer (Figure 2j). Two ANOVA results revealed a significant variation among seasons but not between sites. Nutrients showed distinct seasonal variation due to fresh water inflow from land sources, nutrients utilization by phytoplankton, tidal action, mixing of water column and increase in the microbial population (Chandran and Ramamoorthy, 1984; Rajasekar, 2003; Das et al., 2007; Sudaramanickam et al., 2008; Govindasamy et al., 2012).

Biomass

Total biomass of *C. serrulata* ranged between 619 and 1429 g.fr.wt.m^{-2} (Figure 3a). *C. serrulata* above ground biomass (AGB) varied between 20.6 and 60.6 g dry wtm^{-2} (Figure 4). Maximum and minimum biomass of *C. serrulata* was observed during the post monsoon (February 2010) and pre monsoon seasons (August 2009) at site III. One way ANOVA results showed there is no significant variation in the total biomass, between the sites. At site I *C. serrulata* total biomass and AGB was negatively correlated with salinity and positively correlated with POC ($r = 0.668$; $r = 0.650$) at all $p< 0.01$ level of significance. At site II, the total biomass and AGB of *C. serrulata* at site II was highly influenced by salinity ($r = -0.528$; $r = -0.575$; $p<0.05$), pH ($r = -0.574$; $r = -0.593$; $p<0.02$), POC ($r = 0.695$; $r = 0.723$; $p<0.01$), nitrite ($r = -0.533$; $r= -0.554$; $p<0.05$) and total organic nitrogen ($r = 0.488$; $r = 0.506$; $p<0.05$). At site III total biomass and AGB was negatively correlated with air temperature ($r =-0.412$; $r = -0.422$)and pH ($r = -0.544$; -0.455). POC ($r = 0.667$; $r = 0.425$) was positively correlated. Seagrass production and biomass maxima and minima attributed to seasonal changes in temperature and salinity is common (Durate, 1989) in temperate and tropical seagrasses (Van Tussenbroek, 1998). In *C. serrulata* the photosynthetic characters were higher in leaves devoid of epiphytes (younger leaves) (Ruiz et al., 2009). *C. nodosa* and *S. isoetifolium* net productivity increased continuously during monsoon season and reached a distinct maximum at

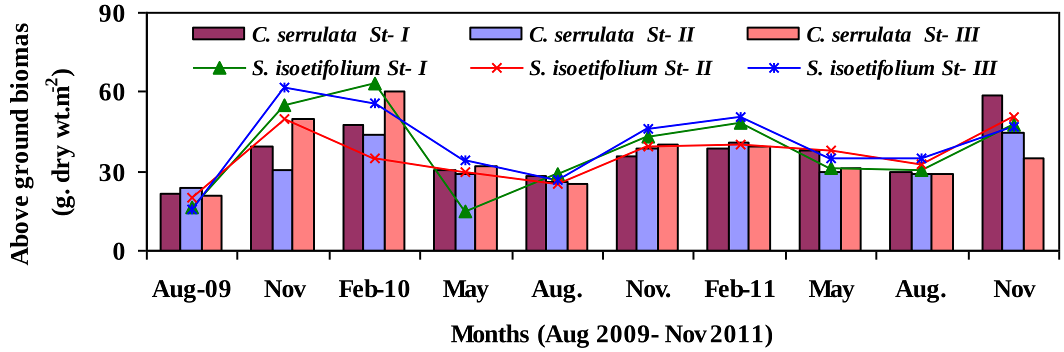

Figure 4. Seasonal changes in above ground biomass of *C. serrulata* and *S. isoetifolium* at sites I, II and III.

post monsoon season (Peduzzil, 1990; Daby, 2003).

In general, during the monsoon and post monsoon season, the seagrasses growth and production was high due to the availability of nutrients. In both species, above ground biomass was significantly decreased in the wet season (May and August), when low tide occurred in day time and only slow recovery took place until the monsoon season (October). Generally, temperature is a critical factor that would affect plant growth, survival and distribution (Padla, 2001). As Responte (2009) pointed out, temperature regulates the range dissolved oxygen and carbon dioxide as well as salinity in the water column. High temperature enhances evaporation rate in sea (Govindasamy et al., 2000).

Total biomass of *S. isoetifolium* was varied from 457.06 to 1473.16 g.fr.wt.m^{-2} (Figure 3b). *S. isoetifolium* AGB varied from 29.2 to 62.88 g dry wt m^{-2} (Figure 4). Total biomass and AGB was recorded maximum during the monsoon season (November 2009) at site III and minimum was recorded during the summer season (May 2010) at site I. In the present study, total biomass and AGB showed there were no significant differences between the sites. Salinity, temperature and pH significantly influenced ($p<0.01$) the biomass and AGB of *S. isoetifolium* at all the sites. At site I, total biomass and AGB of *S. isoetifolium* was highly influenced by the nutrients POC ($p<0.001$), inorganic phosphate ($r = 0.512$; $r = 0.540$) and total organic nitrogen was at ($r = 0.524$; $r = 0.503$); $p<0.05$ level of significance. At site II, total biomass and AGB was influenced by POC, inorganic phosphate ($r = 0.760$; $r = 0.723$; $p<0.001$) and total organic nitrogen ($r = 0.708$; $r = 0.695$; $p<0.01$). Total biomass and AGB of *S. isoetifolium* was increased by the influence of the nutrients POC ($r = 0.688$; $r= 0.727$) and total organic nitrogen ($r = 0.625$; $r = 0.524$) at site III. Campbell et al. (2006) reported that temperature affects the growth and production rate of *S. isoetifolium*. The susceptibility of *S. isoetifolium* to temperature may be associated with its cylindrical morphology, the presence of a thin leaf cuticle and thin vascular-bundle cell walls (Kuo, 1993). Such leaf anatomy and ultra structure is advantageous for nutrient uptake and gaseous exchange and this species has been found to have a relatively high production rate when compared with other species (Duarte and Chiscano, 1999). It is a species that previously has been restricted to subtidal waters because of in tolerance to high temperatures in intertidal reef habitats (Bridges and McMillan, 1986; McMillan, 1983). Lirman and Cropper (2003) found that *S. filiforme* was a seagrass species susceptible to higher salinity levels. The maximum growth rate of seagrass biomass dropped dramatically when salinity increased.

The total biomass of both the seagrass species and seagrass coverage area was reduced at site III. In Devipattinam region, the seagrass beds are erased to some meters during the study period.

Leaf canopy height

Leaf canopy height of *C. serrulata* ranged from 23.07 to 30.95 cm (Figure 5). Leaf canopy height varied between the season, growth and environmental variables. Maximum Leaf canopy height was recorded in the monsoon and minimum was recorded during the pre monsoon season. Leaf canopy height was negatively correlated with air temperature ($r = -0.513$), salinity ($r = -0.567$), pH ($r = -0.597$) all at 0.02 level. At site II, leaf canopy height was mainly affected by salinity ($r = -0.416$; $p<0.1$). At site III, *C. serrulata* leaf canopy height was influenced by air temperature ($r = -0.601$), salinity ($r = -0.521$), pH ($r = -0.511$).

Leaf canopy height of *S. isoetifolium* ranged from 24.52 to 34.306 cm (Figure 5). Maximum leaf canopy height was recorded during the post monsoon season at site II and minimum leaf canopy height was recorded during the pre monsoon season at site II. One way ANOVA results interestingly states that the leaf canopy height of *S.*

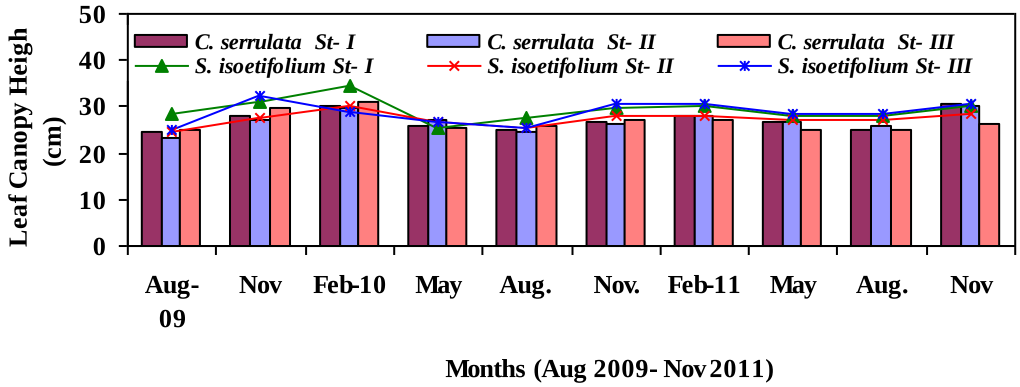

Figure 5. Seasonal changes in leaf canopy height of *C. serrulata* and *S. isoetifolium.*

isoetifolium showed significant variation between the sites. Average leaf canopy height was maximum at site III (251.592 ± 135.010). Leaf canopy height of *S. isoetifolium* was affected by air temperature, surface water temperature, salinity and pH in all the sites. Leaf canopy height was maximum in the monsoon and post monsoon season due to the presence of POC, inorganic phosphate, total organic nitrogen and these parameters are positively correlated for both species at all sites. Mellors et al. (1993) found that *C. serrualta* standing crop declined from May to August, increased from September to December in seagrass meadows of Green land. In Northern Indian River, temperature affects *S. isoetifolium* leaf growth and lead to leaf abscission (Pomeroy, 1963). Leaf canopy height of *S. isoetifolium* was maximum during the monsoon season. Same result was observed by McKenzie (1994) in *Zosteria marina*, leaf canopy heights were highest between October and February and lowest around midyear.

Shoot density

Maximum (526.8 shoots m^{-2}) and minimum ((65.9 shoots m^{-2}) shoot density was recorded during the monsoon and minimum was recorded during the pre-monsoon season at site I (Figure 6). Shoot density of *C. serrulata* was highly influenced by temperature, salinity and pH at 0.01 significant levels in all the three sites. POC (r = 0.647) and inorganic phosphate (r = 0.613) influence shoot density at site I. At site II, shoot density was influenced by nitrite (r= -0.67), inorganic phosphate (r = 0.628) and total organic nitrogen (r = 0.629) all at p<0.01 level. At site III, shoot density of *C. serrulata* was positively influenced by POC (r = 0.774), inorganic phosphate (r = 0.743) and total organic nitrogen (r = 0.786).

Shoot density of *S. isoetifolium* varied between 70.94 and 528.39 shoots m^{-2}. Maximum and minimum shoot density was observed during the monsoon and summer season at site II and I, respectively (Figure 6). At all the sites, shoot density was highly affected by air temperature, surface temperature, salinity and pH. At site I, shoot density of *S. isoetifolium* was significantly influenced by the nutrients total organic nitrogen (r = 0.582), POC (r = 0.810) and inorganic phosphate (r = 0.630). silicate (r = 0.605), nitrite (r = -0.608), inorganic phosphate (r = 0.703), total organic nitrogen (r = 0.700) was significant at 0.01 level and POC (r = 0.798) was shown at 0.001 level significance in the shoot density of *S. isoetifolium* at site II. At site III, shoot density was highly influenced by total organic nitrogen (r = 0.696) at p<0.01 level of significance. Two way ANOVA results for biomass, above ground biomass, leaf canopy height and shoot density for both seagrass species revealed significant variation among the season and no significant interaction fwas ound between sites. We explored the positive correlation between shoot density, above ground biomass and leaf canopy height and they were highly significant although the coefficient corresponded to biomass.

A decrease in leaf growth and shoot density was observed in *C. nodosa* due to adverse effects of salinity and temperature on the meristamatic tissues, inter-ferences with carbon metabolism (Torquemada and Lizaso, 2011). A significant increase in shoot densities and productivity during the December and January respectively can probably be related to clonal recruitment of new seagrass shoots. At the northern range limit of Indian River, temperature should be the major factor controlling seagrass distribution. Interaction of tempe-rature and growth may also contribute to the patchiness of *Syringodium* in the northern Indian River. The flowering was also influenced by temperature in *Halodule, Halophila* and *Syringodium* sp. in the northern Indian River (Pomeroy, 1963; McMillan, 1976). Phospho-rus and nitrogen addition resulted in increased leaf

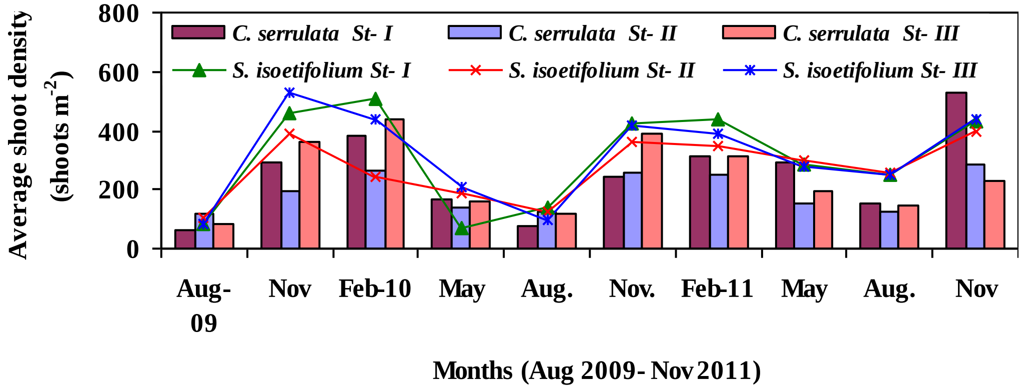

Figure 6. Seasonal changes in average shoot density of *C. serrulata* and *S. Isoetifolium*.

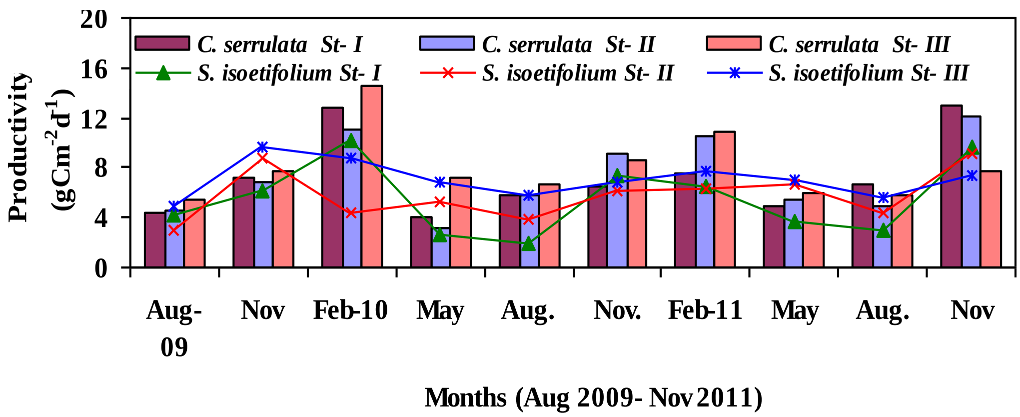

Figure 7. Seasonal changes in the productivity of *C. serrulata* and *S. Isoetifolium.*

phosphorus content, enhanced shoot growth and enhanced rhizome growth. Phosphate concentration did show significant correlations with shoot density. Phosphorous and nitrogen increased shoot density in *C. nodosa* and *S. filiforme* (Williams, 1987; Perez et al., 1991).

Productivity

Productivity of *C. serrulata* varied from 3.071 to 14.586 g $Cm^{-2}d^{-1}$ (Figure 7). Maximum productivity was recorded during the post monsoon season at site III and minimum was observed during the summer season at site II. At site I, *C. serrulata* was influenced by air temperature (r = -0.552), surface temperature (r = -0.507), inorganic phosphate (r = 0.524) at the significant level of 0.05, salinity (r = -0.662), pH (r = -0.613), POC (r = 0.584), all at 0.01 level and total organic nitrogen (r = 0.445) all at p< 0.1 level. Further, at site II, *C. serrulata* productivity was negatively correlated with air temperature (r = -0.562), surface water temperature (r = -0.627), salinity (r = -0.681), nitrite (r = -0.697), at p<0.01, pH (r = -0.726) at 0.001 level and positively correlated with POC (r = 0.785) at P<0.001 level and total organic nitrogen (r = 0.610) at 0.01 level of significance. At site III, the productivity of the species was influenced and positively correlated with POC (r = 0.784) and total organic nitrogen (r = 0.754) at 0.001 level and negatively correlated with nitrate (r = -0.619) all at p<0.01 level. *C. serrulata* productivity was positively correlated with the total biomass and above ground biomass in all the three sites. Productivity showed no significant variation between sites.

S. isoetifolium productivity was recorded maximum (10.224 $gCm^{-2}d^{-1}$) in the post monsoon season at site I and minimum (1.894 $gCm^{-2}d^{-1}$) was recorded in the pre monsoon season at site I (Figure 7). Further, this is evident by the statistical analysis which revealed a significant relationship between various environmental parameters with productivity at all sites. Productivity of *S. isoetifolium* was influenced by air temperature (r = -0.614), surface water temperature (r = -0.615), salinity (r =

-0.684), pH (r = -0.672) all at p< 0.01 level and positively correlated with POC (r = 0.750) at 0.001, inorganic phosphate (r = 0.614) and total organic nitrogen (r = 0.606) all at 0.01 level at site I and also the same trend was retained at site II. At site III, the productivity was highly influenced by salinity, pH, POC, inorganic phosphate and total organic nitrogen.

Inorganic phosphate and total organic nitrogen were considered as most important and limiting factors for the growth, reproduction of seagrasses (Govindasamy et al., 2011). One of the reasons for limitation in seagrass growth during the summer and pre monsoon seasons is self- shading and nutrient limitation (Marta Pérez and Javier Romero, 1992). Carbon is mainly required for the growth of seagrasses. Addition of inorganic phosphate and total organic nitrogen enhanced the total biomass, above ground and productivity of *C. serrualta*. Same results were found in an experiment in *C. nodosa*, *C. roundata* and *S. filiforme* (Williams, 1987; Perez, 1991; Agawin et al., 1996; Udy and Dennison, 1997). This is evident by the statistical analysis which showed significance at 0.001 levels with total biomass, above ground biomass, productivity, leaves canopy height and shoot density with inorganic phosphate and total organic nitrogen in both seagrass species.

Conclusion

The present study concluded that the temperature and salinity are the critical physiological parameters that affect the seagrasses growth, productivity and biomass. Among all other nutrients, inorganic phosphate and total organic nitrogen are the two important factors which enhance the growth, biomass and productivity of both seagrass. Both seagrass species showed marked seasonal variation. The optimum growth was observed in monsoon and post monsoon seasons due to the environmental conditions and nutrient factors. This study is important because seagrasses are excellent indicator of marine ecosystem health and are considered as coastal canaries due to their widespread distribution, ecological role and show measurable and timely response to impacts. But in some stations, seagrass beds get erased to some meters due to fishing activities and human impacts. Near shore areas of Palk Bay are polluted because of increased coastal urban development.

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