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Epiphytic algal biomass associated with pneumatophores of various avicennia species: An overview

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Abstract
Mangrove swamps are coastal wetlands found in tropical and subtropical regions. They have different types of special root systems and adaptations to cope with the extreme saline environment. Epiphytic algae associated with the mangroves are significant in increasing the productivity of the ecosystem as well as nutrient cycling. The presence of algae doubles the carbon sequestration power of mangrove forests. Among the mangroves, some species like *Avicennia* are wide in occurrence and their pneumatophores contains abundant algal microflora. Few studies on mangrove epiphytic algae are available. However the previous studies reported a number of mangrove associated algae belonging to different groups. Recently developed technologies provides a lots of opportunities to utilize and reveal the role of these epiphytic algal forms for a better environment in future. Hence the present paper makes an attempt to review the studies regarding epiphytic algal forms, their distribution, biomass and seasonal occurrence associated with pneumatophores of *Avicennia* species.

Keywords: *avicennia*, pneumatophores, epiphytic algae

Introduction
Mangrove forest grow at the interface between land and sea and are among the world's most productive ecosystems confined to tropical and subtropical latitudes [5]. Mangroves have different types of special root systems which supports diverse group of microorganisms. Epiphytic algae plays an important role in increasing the productivity in mangrove ecosystems. The presence of epiphytic algae on pneumatophores, prop roots, knee roots and buttress roots of mangroves have been already reported [10, 9, 8, 21]. In mangrove ecosystem there are some species like *Avicennia marina* are widely distributed all over the world. According to [6], compared to the hard substrates and soft mud, the aerial roots provide the most favourable habitat for the algae and it encompass about 50% of the total algal species. Mangrove associated microalgae studies are very significant. Usually this type of studies were performed in small areas only.
The elaborate in depth studies are required to assess the role of these algae in mangrove rich wetlands. It provides a basic data for the economic valuation of the mangrove ecosystem.

Materials and methods
This paper was carried out a review work on the epiphytic algal forms associated with pneumatophores of *Avicennia* species and is based on published reports from various databases such as Google scholar, Research Gate, Pubmed, Academia, Embase etc. This paper was thoroughly reviewed and presented here in brief form. Reviewed papers from 1960 to 2020.

Results and Discussion
Various studies have been carried out worldwide on the algae associated with mangroves. Some of the important studies on the epiphytic algae associated with the pneumatophores of *Avicennia* species are summarized below. A number of attempts have been made to document the mangrove associated macro algae along the coasts of Different tropical and subtropical countries such as India [13], Brazil [16, 1], Australia [3, 7,], Pakistan [17, 18], Egypt [4], South Africa [15], China [27], and America [26]. Studies on the epiphytic algal distribution, biomass and
Seasonal occurrence will help to estimate the productivity of the mangrove ecosystems. Epiphytic algae contributes annual litter production in St Lucia estuary [24].
The distribution of epiphytic algae on the pneumatophores of *Avicennia marina* was reported from the mangrove vegetation of Kosi system with a salinity difference. The study reported about 36 algal species as epiphytes and the identified algae belonging to Rhodophytes (11), Cyanophytes (17), Chlorophytes (7) and only one Phaeophyte [25]. Mangrove associated cyanobacterial species were reported from the Pichavaram, Tamilnadu [14] in which *Avicennia marina* supports the maximum species of cyanobacteria as compared to other mangroves. The identified cyanobacteria belongs to the family such as Chroococcaceae, Oscillatoriaceae, Nostocaceae and

Rivulariaceae. The study also reported that, a total five species of cyanobacteria were epiphytic on *Avicennia marina* in which the dominant species are *Lyngbya major*, *Oscillatoria agardhii* and *Phormidium tenue.* Study on Kadalundi mangrove vegetation, Kozhikode [22] identified a total of 16 algal species belonging to three classes. From the Indian Sundarbans a dense algal association was reported by [21] in which an overall of 32 algal species were identified which includes both epiphytic and epixylic algae. The study has also pointed out that, at the area exposed to daily tidal cycle, filamentous microalgae *Rhizoclonium* which covers the pneumatophores and tree bark whereas the aerial portion of mangrove was occupied by the *Trentepohlia* genus. [9], carried out work on 19 mangrove associated southern African estuaries (from Kosi Bay to River Nahoon) and a total of 12 algal taxa of class Rhodophyceae were reported (including an unidentified Rhodophye). The studies estimated that, among various substrata the *Avicennia marina* pneumatophores supports more number of algae and a general key to the identified Rhodophytes were also given by the study. [19] Investigated on the mangrove habitat of Karachi, Pakistan and reported abundant growth of *Vaucheria karachiensis* as epiphyte on the pneumatophores of *Avicennia marina*. [20] Studied on the pneumatophores of *Avicennia marina* (Forssk.) Vierh.

Along the coast of Balochistan and reported 21 species of algae growing as epiphytes, which belonging to Chlorophyta, Cyanophyta and Rhodophyta.

Apart from the identification of epiphytic algae, some other works focuses on the estimation of biomass & seasonal variation in the occurrence and distribution (zonation) of these algae. The epiphytic algae on the pneumatophores of *Avicennia marina* in Karachi, Pakistan described by [18, 19]. From the mangrove ecosystem of Korangi Creek about 25 Km from Karachi, about 12 epiphytic algal species were reported from the pneumatophores of *Avicennia marina* (Forssk.) Vierh. In which the identified algae belonging to the algal groups such as Chlorophyta, Phaeophyta, Rhodophyta, and Cyanophyta (Cyanobacteria). Out of these 12 species, 9 were new reports from the mangrove area of Pakistan and the Chlorophyta were the most common group and the *Enteromorpha torta* (Mert.) Reinbold were the most common species from this study area [18]. The study also describes that, some algal species shows distinct vertical zonation on the pneumatophores. *Cladophora* species & *Rhizoclonium kerneri* observed on the upper part, *Hincksia terminalis* & *Lyngbya majuscula* occupies along the middle & *Boodleopsis pusilla* at the basal portion of the pneumatophores [18]. [1] Reported the patterns of vertical distribution of macroalgae on the pneumatophores of *Avicennia germinans* during the wet and dry season in mangrove ecosystem of Brazil. The observation shows that *Bostrychia moritziana, Bostrychia radicans* and *Caloglossa leprieurii* occurs on the basal and median portion of the pneumatophore, whereas the distribution of *Bostrychia calliptera* & *Catenella caespitosa* throughout the whole surface during the dry season. The *Bostrychia calliptera* & *Catenella caespitosa* were reported as dominant during the rainy season only and which occupies in the basal and median portions. Based on the survey on three selected mangrove sites from the Clyde River, Australia, six species of macroalgae were reported from the pneumatophores in which five species of algae belonging to the Division Rhodophyta and the remaining one species of algae to the Chlorophyta [11]. The study also revealed that there is a significant intertidal and vertical zonation of several algal species. Macroalgal frequency and biomass in each intertidal zone and vertical segment of pneumatophore also observed. *Catenella nipae* exhibited the highest frequency and abundance among all other species whereas *Caloglossa leprieurii* was the least frequent & abundant. [17] reported fourteen algal species from pneumatophores of *Avicennia marina* in the Indus Delta region, Karachi, which belonging to Chlorophyta, Phaeophyta, Xanthophyta and Cyanobacteria. The study also highlighted that eventhough 14 species were reported, *Vaucheria karachiensis* was the most abundant algae which covers the pneumatophore. The study also estimated the biomass of epiphytic algae on the pneumatophores during the northeast monsoon season in which the biomass were observed along the entire length of the pneumatophores except for the tip. From the mangroves of the Ajuruteua peninsula, Braganca, Para, Brazil, the distribution of macroalgae species on the pneumatophores of *Avicennia germinans* were reported [1] and the algal species belonging to the division Rhodophyta. An overall 5 species of macroalgae were reported by this study. The study also describes the vertical distribution of algae on pneumatophores in which the algae occurs most frequently in the 5-10 cm segment above ground level, whereas above 20 cm, it appears as declining. Spatial and temporal variation of epiphytic macroalgae on pneumatophores of *Avicennia marina* (Forssk.) Vierh. In the Paramatta River, Australia was studied by [12]. [2]

Studied and revealed the seasonal variation in the occurrence and biomass production of macroalgae associated with pneumatophores of *Avicennia marina* (Forssk.) Vierh. From the Miri estuary, Sarawak, Malaysia. The study reported about 11 species of mangrove macroalgae from six genera belonging to Rhodophyta, Chlorophyta and Phaeophyta and the sampling studies were conducted during the 4 seasons (southwest monsoon, northeast monsoon & two intermonsoons) of Malaysia. Maximum frequency of occurrence showed by *Caloglossa ogasawaraensis* and the maximum biomass were observed for the algal species *Bostrychia kelanensis* [2]. Recently [23] estimated the epiphytic algal biomass on pneumatophores of *Avicennia officinalis* from Valapattanam and Kunjimangalam wetlands of Kannur District. By comparing the two selected sites it is reported that the industrialisation and increased pollution in the Valapattanam locality effected the epiphytism on pneumatophores and also identified algae as the indicator of pollution. The algae reported from these sites belonging to Chlorophyceae, Bacillariophyceae and Cyanophyceae.

Mangrove soil is rather anaerobic and thus the plants have specific adaptations to cope with these conditions. Aerial roots are the peculiar feature of mangroves which helps in the gas exchange in oxygen poor soils. There are different types of special roots in mangroves such as pneumatophores, knee root, buttress root, prop root and stilt root etc. My work focuses on the algae associated with all different types of special roots and also to analyse the host specificity of epiphytic algal forms.

Conclusion

A large number of micro and macro algae occur in association with mangroves. Epiphytic algal forms are significant associated with special root system of mangroves. Mangrove associated algae studies have been conducted in different tropical and subtropical coasts which

includes those of India, Brazil, Pakistan, Australia, South Africa, Egypt, China & America etc. More number of studies focuses on the pneumatophores of *Avicennia* species. Certain studies are related to the identification of mangrove algae only whereas some other studies associated with the estimation of epiphytic algal biomass, seasonal variation in the occurrence and distribution of algae. Cyanophyta, Rhodophyta, Chrysophyta & Chlorophyta are the most abundant groups in mangrove ecosystem and the pneumatophore of *Avicennia* supports the richest algal flora. Eventhough the epiphytic algae plays very important role in increasing the productivity of mangrove ecosystem, the study related to this field is performed in small areas only. In present scenario of global warming & climate change biological carbon sequestration technology is very relevant. Mangroves are natural carbon sinks, they absorb carbon as much and stored in its biomass & soil. Presence of algae enhances the carbon sequestration process in the mangrove wetlands. Thus in depth mangrove algae related studies by using recent technologies are required to analyse their role in carbon sequestration.

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