Chapter 1

GENERAL INTRODUCTION

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Aquatic ecosystems claim major share of the photosynthetic biomass production in our planet. The majority of this is represented by algae; both planktonic and benthic (Raven 1991). Algae are a highly diverse group of photoautotrophic non vascular plants with chlorophyll and simple reproductive structures. They are either unicellular or multicellular, found frequently in fresh, brackish to marine habitats. They form a highly diversified group of photosynthetic thallophytes which have a very significant role in the bio-productivity of the marine, estuarine and fresh water ecosystems covering two third of the earth surface. These algae with their photosynthetic pigments, distributed in both pelagic and benthic habitats command unique significance as the primary producers, which initiate the food chain and generate the fishery resources. Algae, the major primary producers in the aquatic environment comprise a large and heterogeneous assemblage of relatively simple plants such as phytoplankton, periphyton (haptobenthos) and herpobenthos. Among these the role of phytoplankton has been discussed extensively with respect to different aquatic environments. Major part of the published data on organic production attributes to this particular group.

The flora on the sub-aquatic surfaces has been subjected to very few systematic studies. Little is known about their geographical distribution and seasonal cycles in relation to flow and water chemistry. The quantitative studies on this flora are scarce presumably due to the difficulties involved in
the separation of algal cells from substrata. The attached algal flora is highly developed in running (lotic) as well as in standing (lentic) waters and form an important community of all water bodies. The flora forms an extremely heterogeneous and complex association due to variability and distribution of natural substrata. The terminology applied to the various algae in individual habitats is almost as varied as the number of investigations (Sladeckova 1962; Wetzel 1964). The assemblage of organisms living on the bottom of fresh water or brackish ponds, lakes, rivers and the sea bed are termed as benthic (from Greek, Beevo=bottom). Microorganisms growing on sticks, aquatic macrophytes and submerged surfaces are designated as periphyton (APHA 1998). Organisms included in this group are the zoogloal and filamentous bacteria, attached protozoa, rotifers, algae and free living microorganisms that swim, creep or lodge among the attached forms. The photosynthetic components include a diverse assemblage of algal forms that colonize nearly every available substrate in aquatic system. A uniform system of terminology is recommended whereby the term periphyton includes all of the plant organisms, excluding rooted macrophytes, growing on submerged materials in water (Wetzel and Westlake 1974). The term periphyton has also been used for the growth on artificial substrata such as glass slides (Sladeckova 1960). In restricted studies of organisms on specific type of material such as rocks, macrophytes,
usage of the general term periphyton is modified by an appropriate adjective such as epilithic, epixylon or epiphytic periphyton.

In general two distinct types of benthic algal associations are logically reasonable. The haptobenthos grow on solid substratum, which is usually either rock or part of an aquatic plant, though sometimes wood, animal surfaces or remains of man made objects, metallic, ceramic, plastic or whatever. The herpobenthos grow in or on mud on which it can easily penetrate. Periphyton refers to the entire complex of attached aquatic biota on submerged substrates, including non-attached organisms and detritus (van Dam et al. 2002). This assemblage comprises bacteria, fungi, protozoa, phyto and zoo plankton, benthic organisms and detritus (Azim and Asaeda 2005). The plant component of the aquatic system can thus be classified into well defined groups such as phytoplankton, periphyton, herpobenthos and macrophytes. The present study is on the periphytic algae in pokkali and prawn fields of North Paravoor and Vypeen Island, Ernakulam, Kerala.

1.1 Scope of the study

The pokkali and prawn fields are highly productive ecosystems than the adjacent water bodies. Primary producers in this environment include phytoplankton, periphyton, herpobenthos as well as macrophytes which are capable of year round photosynthesis. Productivity of an
environment is mainly the sum contribution of various autotrophic flora. Any quantitative estimation excluding any one of these groups would be an under estimation. It has been reported that the periphytic algae attain a high biomass (Moss 1968; Hansson 1988) and may contribute up to 80% of the primary production (Persson et al. 1977).

Considerable amount of work has been done on the productivity in Cochin backwaters (Qasim 1973, 1979; Nair et al. 1975; Gopinathan et al. 1984) but not in Vypeen and Paravoor wetland which is near by to it. But all of them have estimated the productivity based only on the phytoplanktons. Considering the contribution of other autotrophic components of the estuary such as periphyton, sediment flora and macrophytes, the productivity estimated by the authors were essentially underestimations.

Sreekumar (1998) has estimated periphyton primary production rate as 1.4 g C/m²/d., and calculated the production of 92000 tones of carbon per year in Cochin estuary, and this is up to 92% of the planktonic production. It has been documented that the increased surface area for periphyton growth will increase the fish production (Azim et al. 2004). In pokkali fields after the harvest of paddy, a large quantity of paddy stubbles will be left in the aquatic system and this will act as additional substrata for periphyton growth. The disintegrating paddy stalks release
nutrients to the system invigorating photosynthetic activity, periphyton production and live feed generation in addition to transforming itself as detritus (Purushan 2002).

No work has been undertaken so far to identify the periphytic flora and ecology of pokkali and prawn fields of N. Paravoor and Vypeen area. The present work is an attempt to identify the periphytic flora and its ecology to assess their contribution towards the total organic production in the study area.

An understanding of the species diversity and distribution of periphyton would give more information regarding the biodiversity richness of this area. Quantitative estimation of this community would also highlight its contribution to the total organic production.

1.2 Review of Literature

Several studies have described the growth of periphytic algal communities in different aquatic systems, in spite of the difficulty in quantitative assessment of standing crop. The periphyton study is encountered by the lack of suitable natural substrata at the desired sampling site. Furthermore, it is often difficult to get sufficient samples from their irregular surfaces. In order to overcome these problems artificial substrata have been used to provide a uniform surface type, area and orientation. In the majority of periphyton studies artificial substrata like glass plate, plastic, mica plate, bamboo sticks polyvinylchloride,
fibrous scrubber, ceramic tiles etc. have been used by various researchers
(Sreekumar and Joseph 1995a; Sladeckova 1962; Dumont 1969; Rosemarin and Gelin 1978; Loeb, 1981; Khatoon et al. 2007b).

The sampling of periphyton communities on artificial substratum is
well documented and a variety of sampling devices have been employed
(Sladeckova 1962; Austin et al. 1981). The use of artificial substrata however
simplifies the sampling and improves the replicability. A variety of substrata
are in use for the study of effect of periphyton colonization and fish
production (Milstein et al., 2008; Azim et al. 2002 a; Azim et al. 2004).

Epilithic diatoms are the favoured community for biomonitoring
water quality (Kelly et al. 1998). According to Rothfritz et al. (1997),
however epilithic samples contribute only part of the diatom species pool
at any stream site and comprehensive sampling of substrata is required to
assess diatom diversity.

Community structure and seasonal abundance of the periphyton of
different aquatic systems of India have been studied using artificial and
natural substrata, (Jha et al., 1981; Datta et al. 1987; Pal et al. 1988;
Negi 1990; Tiwari (1990); Muthukumar et al. 1991 and Sreekumar and
Joseph 1995a). Garg et al. (2007), of Haryana Agricultural University,
have reported enhanced fish production by the addition of bamboo poles
as additional substrata for periphyton colonization in fish pond. Paul and
Verma (2005) P. G., department of Zoology, Patna University, Patna, India studied the influence of certain abiotic factors on periphyton community in Jharkhand and established the influence of light, water current, richness and nutrients upon the periphyton standing crop.

Gangadhara and Keshavanath (2008) evaluated ten locally available substrates, five biodegradable and five non-degradable, for their potential to harbour periphyton in cement tanks fertilized with poultry manure, and have reported that polyvinyl chloride, glass plate and bamboo had higher periphytic dry matter than ceramic tile.

1.2.1 Factors affecting periphyton growth

The relationship between periphytic algal growth rates in situ to chemical and physical parameters was evaluated in different ecosystems by many workers. Several studies on agricultural streams have found a lack of correlation between periphyton standing crop and increase in either nitrate (NO₃-N) or phosphate (PO₄-P) (Kilkus et al. 1975; Moore 1977). However, Death, et al. (2007) have done studies with nutrient diffusing substrates in tributaries and mainstream of a central North Island river, New Zealand have reported that nitrogen was the limiting nutrient of periphyton growth at most sites of the Rangitikei River. The results obtained by Smith et al. (2006) in the Kettle ponds, also suggest that nitrogen is the primary limiting nutrient to periphyton growth.
Song et al. (2007) have reported that the periphyton biomass was higher following the increase of nitrogen in the condition without macrophyte than with macrophyte. Frost, et al. (2007) have reported that the increased dissolved organic matter concentration caused greater periphyton ash free dry weight, chlorophyll a and total carbon content during their experiment. Increased dissolved organic matter also significantly increased periphyton carbon: phosphorus and nitrogen: phosphorus ratios throughout the experiment. The effects of dissolved organic matter may have resulted from its absorption of ultraviolet radiation, or more likely, its provision of organic carbon and nutrients to microbial communities. The strong effects of dissolved organic matter on periphyton biomass and elemental composition indicated that they potentially play a key role in food web dynamics and ecosystem process in forested streams.

For Georgia costal plain streams, algal periphyton growth appears to be primarily light limited and can be secondarily nutrient limited (most commonly by P or N+P combined) in light gaps or open sea receiving sunlight (Carey et al. 2007). Cattaneo (1987) had observed that high nutrient levels can cause a shift from communities dominated by diatoms to communities dominated by green filaments. Factors limiting periphyton accrual in east-central Illinois agricultural streams were studied by Munn et al. (1989) and reported that variance in the rate of chlorophyll a accrual
on substrata was explained through water temperature and turbidity whereas, stream nitrate and phosphate concentrations accounted for no significant portion of the variance. Atilano et al. (2005) studied the spatial and temporal variation of periphyton in Colombia, and reported that most of the environmental variables do not show a significant difference between the sampling periods, it found that the combination of high light intensity and availability of hard substrates might be influencing the algae and algal density at sampling point.

Hodoki and Yoshikuni (2005a) studied the effects of solar ultra violet (UVR) on the development of a periphyton community in an outdoor artificial stream apparatus. Their results conclude that attached bacteria and algae that colonize substrata first are likely to be sensitive to solar UVR, and the negative effects of UVR are mitigated by the development of a periphyton community.

Dickman et al. (2005) after the studies on benthic diatoms as indicators of stream sediment concentration in Hong Kong, has reported that high concentrations of suspended solids display a higher proportion of motile diatoms than do clear water streams with low concentrations of suspended solids.

Nayar et al. (2004) have studied the impact of petroleum hydrocarbons and their effects on the periphytic biomass in Ponggol
estuary of Singapore and noticed that a reduction of 68% - 93% in periphytic algal biomass (with respect to controls) for various treatments exposed with diesel.

The results of studies by Chen and Kemp (2004) on periphyton communities in experimental marine ecosystems on scaling effects of removal from container walls, illustrated that the periphyton biomass and production were consistently and significantly reduced in containers receiving wall cleaning treatments twice-weekly, than in systems cleaned at weekly intervals.

Kilkus et al. (1975) reported that water temperature was a major driving variable for periphyton in agricultural streams in Iowa. Bushong and Bachmann (1989) also demonstrated that water temperature as an important factor in controlling periphyton growth rates.

Nayar et al. (2005), after correlation studies and principal component analysis reported that the concentration of silicate in water column has significant effect on the settlement of periphytic algae in the tropical estuary in Singapore. Diatoms and Synechococcus in the periphytic algal community were influenced by water temperature, photosynthetically available radiation, pH and dissolved oxygen.

Periphyton accumulation on artificial substrata was fastest near the water surface and decreased rapidly with increasing depth (Eloranta 1982). Hoagland et al. (1982) suggested that vertical gradients exist
within a periphyton community for factors such as light and nutrients. The role of storm events in disrupting periphyton community development has also been discussed (Fisher et al. 1982).

Grazing can substantially reduce periphyton biomass (Dickman 1968; Kehde and Wilhm 1972; Rahman et al. 2007). Grazed communities are often dominated either by prostrate species, which adhere tightly to the substrate or by small under storey species, which can avoid being grazed by virtue of their size (Hunter 1980; Sumner and McIntire 1982; Hunter and Hunter 1983).

Moulton et al. (2004) has reported that baetid ephemeropterans (particularly Americabaetis sp.) were the most important grazers and removers of benthic matter in the studied system. Alvarez et al. (2005) studied the effect of grazing by stream invertebrates on algal biomass and spatial heterogeneity in flow-through microcosms with natural substrates (rocks). They have reported that the mean algal biomass (chlorophyll \(a\)) was reduced in grazer treatments compared to ungrazed controls, but there were no differences among grazer treatments.

The results obtained by White and Lamberti (2005) suggest that benthic grazers can alter epilithon nutrient composition and limitation via nutrient excretion. Consequently, macro invertebrate grazers may serve as “nutrient pumps” that partly regulate the availability of nutrients to algae in stream ecosystems.
Wellnitz et al. (2006) have reported that longer grazing duration reduced periphytic biomass, but also accelerated algal regrowth, and this growth enhancement was more pronounced at slower current velocities.

The studies of the effects of nutrient availability and grazers on periphyton in the littoral zone of Lake Tanganyika, McIntyre et al. (2006), have reported that fish and other large grazers had much stronger effects on periphyton than nutrients. Grazers strongly suppressed periphyton biomass, but had weaker negative effects on area-specific gross primary productivity. The littoral nutrient availability influenced periphyton productivity, but that top-down control predominated.

Hodoki and Yoshikuni (2005b) tested the effect of the density of attached bacteria on the amount of algal immigration in the early development of a periphyton community in an artificial stream by manipulating the density of the attached bacteria and found algal immigration was proportional to the density of attached bacteria on all substrata (glass, PVC and slate), although density differed among substrata.

Kish (2006) evaluated herbicide impact on periphyton community structure with three herbicides, Aatrex, Roundup and Glean and noticed that Roundup and Glean appear to favour eukaryotic periphyton, and Aatrex appears to favour prokaryotic periphyton. Glean may have an additional hormetic effect on eukaryotic periphyton at low concentrations.
1.2.2 Periphyton and biomonitoring

From the early years of the last century, periphytic (benthic) algae have been identified as a valuable option for biomonitoring stream and river ecosystems (Kolkwitz and Marsson 1908 cited by Kitner and Poullickova 2003). More recently, this approach has been applied with success to evaluate a variety of water quality problems. (Kutka and Richards 1996; Mattila and Raisanen 1998; Rott et al. 1998; Hill et al. 2000 b; Winter and Duthie 2000; Munn et al. 2002; Potapova and Charles 2003).

Periphytic communities provide an integrated measurement of water quality as experienced by the aquatic biota and have many biological attributes that make them ideal organisms for biological monitoring (Lavoie et al. 2004). Algae lie at the base of aquatic food webs and therefore occupy a pivotal position at the interface between biological communities and their physico-chemical environment (Lowe and Pan 1996). Furthermore, benthic algae have short life cycles and can therefore be expected to respond quickly to changes in the environment (Mc Cormick and Stevenson 1998).

Effects of chemicals on periphyton structure and function also have been investigated using experimental ecosystems (Grolle and Kuiper 1980; Muller 1980) to which pollutants were added. Species diversity of periphyton as an index of pollution of River Ganga was
reported by Laal et al. (1982). Gaur and Kumar (1985) described algal community structure in effluent holding and treatment ponds of five oil refineries. Singh and Gaur (1989) studied the changes in epilithic algal communities on introduced substrata in a stream polluted with oil refinery effluent at Digboi- Assam, India. The study revealed that the number of algal taxa was less except blue greens. Epilithic biomass (as chlorophyll a) also found to be considerably less at polluted stations.

Epilithic diatoms are the favoured community for monitoring water quality (Kelly et al. 1998) and almost all methods based on diatom indices concentrate on this community (Round 1993). Winter and Duthie (2000) compared the use of epilithic, epiphytic and epipelic diatom communities in stream biomonitoring by investigating species composition and relationship with measured water quality variables in two tributaries of Grand River, Ontario, Canada, have concluded that in sampling, a single substratum should be used as often as possible and a second one only if the first option is not available.

Sterligova et al. (2001) studied the effect of the trout farm on the lake-river ecosystem of the Salmon River Lishma and noticed that at the initial stages of contamination the structure of the community was influenced by the presence of different species and later a marked increase of some species that were previously scarce was observed. With an
increase in the anthropogenic impact the communities become less diverse and structurally simpler. The average specific abundance of families and genera commonly declines (Komulaynen 2002). Substantial changes in periphyton structure were often caused by an enhanced mechanical impact, which retard colonization, rather than any chemical influence. Periphyton structure, which reacts to pollution by mineral-rich and sewage effluents, was shown to reflect clearly the trophic status of the water bodies and their constituents (Komulaynen 2002).

For monitoring the water quality the choice of the substratum makes no difference. Rott et al. (1998) found that the similarity of result obtained from grass and stone samples. Studies by Khatoon et al. (2007a) on periphyton biofilm and subsequent biofouling on different substrates in nutrient enriched brackishwater shrimp ponds, illustrated the invasive nature of attached polychaete hampering the formation of periphyton biofilm on substrates which could have been used for improving water quality. Analysis of concordance showed that diatom community analysis based on generic level alone, or specifically combined with the identification of only the abundant species, could offer a practical and reliable biomonitoring tool for large rivers (Raunio and Soininen 2007).

Bell and Scudder (2007) studied the total mercury and methyl mercury concentrations in periphyton at eight rivers in the United States
and reported that the periphyton may play a key role in mercury accumulation in river ecosystems. Asai and Watanabe (2004) studied the epilithic diatom assemblages over 15 years in Japan and Sumatra and reported that the diatom assemblage index due to organic pollution, the ecological requirements of the most dominant taxa, and the Shannon diversity index are the important factors to assess water quality.

Schmitt-Jansen and Altenburger (2005) studied the effect of herbicide contamination on periphyton and concluded in their results that the herbicide concentrations in river basins, estuaries or coastal zones may change community structure and primary production of microphytobenthos even when the contamination does not exceed levels of acute toxicity.

Dickman et al. (2005) studied role of the benthic diatoms as indicators of stream sediment concentration in Hong Kong, and have reported that diatoms can be used as to assess suspended solid levels in streams. Streams with high concentration suspended solids display a higher proportion of motile diatoms than do clear water streams with low concentrations of suspended solids.

The combination of high temporal stability and high spatial variability, correlating closely with environmental gradients, is the main reason why periphyton observations have become an important constituent in water quality assessment (Lindstrom et al. 2004).
1.2.3 Periphyton and nutrient removal

Wetlands are increasingly recognized as instrumental environments in mitigating nutrient-enriched surface waters, as they are hotspots for denitrification (Howarth et al. 1996; Saunders and Kalff 2001). Traditionally, wetlands research has focused on sediments as the primary site for denitrification (Van Raalte and Patriquin 1979; Payne 1991), identifying maximum denitrification rates in the upper 3-5 cm of wetland sediment (Clement et al. 2002). Other research has shown, however, that denitrification activity is not limited to sediments. Significant denitrification rates have also been measured in periphyton attached to natural and artificial substrata, including benthic polyethylene mesh (Sirivedhin and Gray 2006).

The sensitivity of periphyton to environmental factors and biologically active substances has been well documented, thus making periphyton a favourable bioassay object (Smolar et al. 1998; Genter and Lehman 2000; Kinross et al. 2000).

Periphytic algae can also be successfully used for removal of excessive nutrients, metals and toxic substances, hence improving water quality (Vymazal 1988; Hill et al. 2000a). A recent development using benthic algae technology has proposed by Drenner et al. (1997) and further characterized by Rectenwald and Drenner (2000). In this “ecological water treatment system”, the benthic algae are grown on
vertical plastic screens and are harvested by grazing fish. A conical tank bottom collects fish feces. Experiments on municipal waste water effluent resulted in a 23% reduction in N and an 82% reduction in P (Rectenwald and Drenner 2000).

Wetlands have been used successfully to remove nitrogen and other pollutants from waste water. This removal is based on physical, chemical and biological processes. In most wetlands biological denitrification is the major pathway in nitrogen removal (Nichols 1983; Howard-Williams 1985; Faulkner & Richardson 1989; Verhoeven & Toorn 1990; Johnston 1991; Gumbricht 1993; Vymazal et al. 1998). During this microbial process oxidized forms of nitrogen, mainly nitrate and nitrite, are reduced to gaseous compounds nitrous oxide and dinitrogen (Tiedje 1988). These gases are released to the atmosphere, thus resulting in a removal of nitrogen from the wetland.

The denitrification rate in periphyton on plant shoots (expressed per shoot area) was always considerably higher than in the sediment and varied with the chlorophyll-\(a\) content of the periphyton in the course of the year. The algae in the periphyton provided attachment surfaces and probably also organic compounds to the denitrifying bacteria (Toet et al. 2003).

The studies of Ishida et al. (2008) demonstrated that the use of benthic mesh in restored aquatic systems, such as riparian areas,
constructed wetlands and ponds, holds promise as a feasible way to boost nitrate removal by the cultivation of periphyton communities that promote bacterial consortia of consistently high denitrifying capacity.

Ogura *et al.* (2009) have reported that the periphyton plays an important role in decreasing NH$_4^+$-N concentration in the discharge from waste water treatment plants in the Kurose River in Hiroshima Prefecture, Japan. Studies by McCormick *et al.* (2006) suggested that periphyton can be an important short-term sink for phosphorus in treatment wetlands and that retention is strongly affected by the taxonomic composition of the periphyton assemblage.

The study conducted by Desrosiers *et al.* (2006) on the role of mercury accumulation by periphyton have confirmed that periphyton can accumulate large amount of mercury and accumulation is strongly influenced by watershed characteristics and periphyton biomass.

Jobgen *et al.* (2004) have shown that the exposure of artificial substrata in the pelagial Lake of ‘Fuhlinger See’ lead to periphyton growth, and accumulation of phosphorus. Total phosphorus concentration on the polypropylene fleece was up to 240-fold higher compared to the concentration of total phosphorus in an equal volume of epilimnion. Their results further showed that approximately 100 mg of total phosphorus can be eliminated per m$^2$ polypropylene fleece from the lake.
1.2.4 Periphyton and fish production

The effect of periphyton growth in ponds and fish production has been well documented. Ninety two percent of world aquaculture production comes from resource-poor countries in Asia. For sustainable aquaculture development, two key issues must be addressed: the sustainable use of resources and the development of the world’s poor (Brundtland 1987; NACA/FAO 2002). Because majority of the farmers in Asia are poor, many cannot even provide supplemental feed to their ponds. Feed-driven systems are, however, inefficient, only 15-30% nutrients are trapped into harvestable products, the reminder being lost to the environments (Acosta-Nasser et al. 1994; Gross et al. 2000).

In search of low cost aquaculture technologies, a range of substrate-based aquaculture systems have been developed which provide shelter and increase periphyton production as food for both fish and shell fish and thereby increasing aquaculture production (van Dam et al. 2002). Trials have demonstrated that fish production from ponds having periphyton substrates is higher than from substrate-free controls (Hem and Avit 1994; Wahab et al. 1999; Keshavanath et al. 2001a; Azim et al. 2002 a, b) and the technology seems promising. Azim et al. (2004) while studying the effect of periphyton substrate density on production in fresh water polyculture in Bangladesh, have noticed that the fish production increased linearly with increasing substrate density.
Laboratory studies by Dempster et al. (1993) have demonstrated that ingestion rates by tilapias are up to 25 times greater when algae are presented as periphyton than when given as phytoplankton. There is thus growing interest in the potential of artificial substrates for periphyton production in ponds, both to reduce costs and increase nutrient utilization (Beveridge et al. 1998).

Aquaculture based on periphyton was originally derived from traditional fishing methods known in Africa as Acadja (Welcomme 1972) and in Asia as Kathas and Samarahs (van Dam et al. 2002). Enhancement of pond fish production through provision of substrate for periphyton growth has been demonstrated with Indian carp species (Shankar et al. 1998; Ramesh et al. 1999; Keshavanath et al. 2001a). Periphyton substrates tend to entrap suspended organic material, which is likely to be more abundant when fish are fed due to uneaten feed and fish feces (Keshavanath et al. 2001a).

Gut contents of 34 common fish species were investigated in the Varzea Lago Camaleao by Soares et al. (1986). Periphyton was recorded in the guts of 20 species. Seven species revealed a periphyton gut content higher than 50%. Asaduzzaman et al. (2009a) studied the effect of periphyton substrate and tilapia in fresh water pond and noticed that the substrate contributed 44% and 19% higher net yield of prawn and tilapia,
respectively whereas tilapia addition decreased the net yield of prawn by 14%. The economic analysis showed that the addition of tilapia and periphyton substrates jointly improved the benefit-cost ratio. Asaduzzaman et al. (2009b) in another paper has reported that the polyculture of prawn and tilapia in C/N ratio controlled periphyton based system is promising options for ecological and sustainable aquaculture.

Milstein et al. (2008) introduced plastic substrates equivalent to 50% of the pond surface into the water column to induce periphyton growth to improve the natural food production for tilapia. Their results indicated that improved nitrification and development of a large autotrophic periphyton biomass that competed with phytoplankton in the ponds, and only a 10% and 15% reduction in the tilapia daily and specific growth rates respectively, but with a 40% feed saving. These results point towards the periphyton-based aquaculture as an appropriate technology for the reduction in production costs, allowing economically viable organic tilapia production.

Studies with the periphyton coated substrate to improve the water quality, survival and growth of Penaeus monodon post larvae in a shrimp hatchery, Malaysia, showed that the protein, lipid and carbohydrate levels in post larvae reared in tanks with mixed diatoms coated substrate were higher than post larvae grown in control tanks. This study illustrated the
beneficial effects of periphyton coated substrate in improving water quality, growth and survival of shrimp larvae grown in shrimp hatchery system without water exchange (Khatoon et al. 2007b). The study conducted by Garg et al. (2007), suggested that the provision of additional substrate for the enhancement of periphyton production has a greater importance in growth enhancement of Nile tilapia and pearl spot when stocked at the densities used in their study (10000 fish/ha).

Domingos and Vinatea (2008) studied the effect of different quantities of artificial substrates for periphyton growth on shrimp culture and their result suggested that the effect of artificial substrates on *Litopenaeus vannamei* production in semi-intensive systems can be achieved with a substrate area even less than 15% of the bottom.

Jana et al. (2005) have assessed the potential of artificial substrates for periphyton to enhance fish production in inland saline ground water ponds, and reported that periphyton-supported aquaculture system can be used successfully for the culture of herbivorous brackish water fish species like *Mugil cephalus* in inland saline ground waters and thus could contribute to the development of a sound and sustainable aquaculture technology.

Lin et al. (2005) in the study of relative importance of phytoplankton and periphyton on oyster-culture have reported that the modifying effects
of tidal flushing as well as substratum are on the relative importance of periphyton biomass on oyster-culture pens in response to nutrient enrichment in coastal lagoons.

### 1.2.5 Periphyton and Primary Production

Members of periphyton communities are the dominant primary producers in many lotic environments (Wetzel 1964). In some ecosystems, periphytic algae are responsible for about 90% of total production of organic matter (Wetzel 1990). The rate of primary productivity of periphytic algae depends on the available substratum area, physical and chemical water conditions and the morphometry of the aquatic system (Wetzel 1983). Krock (1972) developed a test system making use of attached microbial communities established on artificial substratum in the San Francisco Bay. The communities were incubated in light/dark bottles and effects on photosynthesis and respiration of various added toxicants and stimulants were recorded. Orhon (1975) in a similar study sampled attached microbial communities in a pollution gradient at Golden Horn estuary and measured the effects on photosynthesis and respiration.

Estimation of primary production with respect to periphyton was done in different ecosystems. In southern England streams, Marker (1976) reported primary production at the rate of 83.62 mg C/m²/h. Wiley et al. (1987) has also reported very high production in prairie river systems.
and sub-arctic streams respectively. Periphyton production in irrigation tanks with permanent turbid waters was studied by Krishna Rao (1990). A periphyton production of 2.8 t C/ha based on preliminary studies in the Central Amazon floodplain was reported by Bayley (1989). He estimated this to be 1.5% of the total amount of carbon assimilated in floodplain.

Putz (1997) has studied the periphyton production in Varzea floodplains and the periphyton production was found to be from 170 to 380 g C/m² at Varzea sites and from 80 to 110 g C/m² at Igapo sites.

Rajesh et al. (2001) studied the primary production of benthic microalgae in the tropical semi-enclosed brackish water pond, in southwest coast of India and estimated the annual benthic production as 33.59 g C/ m² and it was three fold greater than that of the productivity of water column.

Grippo et al. (2009) examined the origin of biomass of sediment associated algae on Ship Shoal, north-central Gulf of Mexico, a submerged sandbank with depth and sediment characteristics favourable to benthic primary production and reported that the benthic primary product may contribute to the Ship Shoal food web and it may be an important ecosystem component on the other large shoals found on Louisiana’s inner shelf.

Periphytic metabolism was studied by Uehlinger and Brock (2005) with unglazed tiles, in USA and reported that colder temperatures
appeared to reduce respiration more than primary production and significantly increased production/respiration. Neither gross primary production nor respiration was correlated with autumn nutrient concentrations.

1.2.6 Periphyton and fouling (Biofilm)

The term fouling is commonly employed to distinguish the assemblage of animals and plants which grow on the artificial or man made structure, such as wood, steel, aluminum, fiberglass etc. when exposed to sea water. Though algae constitute important members of marine fouling community only very little work has been done on the specific role of diatoms in fouling. Hendey (1951), Round (1971), Munteanu and Maly (1981) and Huang and Boney (1983) have studied various aspect of fouling by diatoms. Slime films on paints, are dominated by diatoms intermixed with bacteria, blue-green algae and dinoflagellates. All these have the ability to produce mucilage resulting in a semi rigid jelly like matrix in which the component organisms are embedded.

The diatom *Achnanthes* is frequently the dominant member of the slime occurring on antifouling surface which prevents attachment of larger algae such as *Enteromorpha* (Callow *et al.* 1976). Hardy (1981) has reported the possibility of corrosion caused by various extra cellular products which come in contact with surfaces of structures.
While describing the composition of primary film in the tropical marine waters of Madras, Daniel (1955) identified spores belonging to 14 different algal species as components of primary film in addition to diatoms. Kelkar (1989) studied the fouling diatoms from Bombay offshore and Marmagoa. Microorganisms attach on all submerged surfaces in aquatic environments which leads to the formation of “biofilm” (Characklis & Cooksey 1983).

Biofilms cause damage to all water distribution systems including the cooling system of chemical, fertilizer and power plants. In cooling systems, biofilms reduce the thermal efficiency and increase the pressure drop in heat exchangers (Bott 1990). Microalgae are one of the major components in the biofilms and problems due to algae in many industrial cooling systems have been reported (Ludyansky 1991; Callow 1993). In cooling water systems, materials such as titanium, stainless steel, aluminum brass, admiralty brass are used as condenser tube materials. These materials are highly affected by biofilm formation which leads to their corrosion. The cooling systems of Fast Breeder Test Reactor at Kalpakkam, India faced many operational problems due to fouling and corrosion in the system. Preliminary studies showed that fouling and corrosion of construction material of the Fast Breeder Test Reactor were mainly due to microorganisms present in the cooling water (Rao et al. 1993).
Laboratory studies on adhesion of microalgae to hard substrates, Sekar et al. (2004), have reported that the attachment was higher on rough surfaces when compared to smooth surfaces and the presence of organic film increased the attachment significantly when compared to control.

A consortium of algae, bacteria and micro-fauna, embedded in a polysaccharide matrix is called biofilm. Biofilms are ubiquitous and form the base of local food chains, governing the assimilation, retention and transformation of dissolved and particulate materials in an ecosystem. (Pusch et al. 1998).

Periphytic algae are an important component in biofilms and are the dominant primary producers (Kairesalo 1980; Robert et al. 1995). In addition periphytic algae supply organic carbon to the planktonic system during re-suspension in the water column (Delgado et al. 1991; de Jonge and van Beusekom 1992).

Nayar et al. (2005) studied the settlement of marine periphytic algae at Ponggol Marina estuary, Singapore with three settlement parameters viz. periphytic algal production, chlorophyll a and cell counts, have reported that there is significant difference between the days of settlement, but no significant differences observed for different depths. Biofilms dominated by pennate diatoms are important in various fields as diverse as ship biofouling to marine littoral sediment stabilization. The architecture
of a biofilm depends on the fact that much of its mass consists of extracellular polymers. Although most illuminated biofilms in nature are dominated by autotrophs, they also contain heterotrophic bacteria (Cooksey et al. 2005).

Many oxygenic phototrophic microorganisms have the capacity to accumulate metals in one way or another and there is considerable potential for the application of algal biofilms in the detoxication of waste water polluted with heavy metals (Bender et al. 1994; Mehta and Gaur 2005).

Effluent discharges of intensive fish production system may cause significant nutrient pollution. Fish farmers have a stake in regulating nutrient pollution, because poor water quality can reduce aquaculture productivity. On a small scale, phototrophic biofilm based systems can be used to reduce ammonia and nitrate concentrations in aquaculture effluents (Bender and Phillips 2004).

In fish aquaculture, commercial feeds consisting mostly of fishmeal and oil may account for more than 50% of the total production costs (Elsayed and Teshima 1991). Only about 15-30% of the nutrient input in feed driven pond system is converted into harvestable products (Gross et al. 2000). Therefore, there is a growing interest for substitution of commercial feeds with alternative protein sources. The cost saving and reduction of
ecological impact by using phototrophic biofilms for fish feed production and the possible simultaneous effluent treatment may be significant (Elsayed and Teshima 1991).

The present work is the result of a study of periphytic algae in pokkali and prawn fields of North Paravoor and Vypeen Island with special reference to the ecology and physiology.