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Review Paper

Potentiality of Periphyton-based Aquaculture Technology in Rice-fish Environment

S. K. Saikia[1] and D. N. Das[2]

[1]Department of Zoology, Visva Bharati University, Santiniketan, West Bengal 731235, India

[2]Department of Zoology, Rajiv Gandhi University, Rono Hills, Itanagar, Arunachal Pradesh 791 112, India

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Abstract

Periphyton is being used traditionally as rich aquatic feed for fishes throughout the countries like Cambodia, West Africa, Srilanka, India and Bangladesh. In waterlogged rice environment, it can be judiciously utilized as feed source introducing periphytophagous fish. Studies supported rice straw as suitable substrate for periphyton growth. The study of gut content of Common carp (*Cyprinus carpio* L.) from a periphyton-based rice-fish culture system in Apatani Plateau of Arunachal Pradesh, India showed maximum of 60 genera of microflora and fauna with periphytic in nature. The farmers from this rice-fish culture practice are gaining an average fish production of 500kg ha^{-1} 180 day^{-1} without employing any supplementary feed. Better selection and determination of appropriate stocking density of periphytophagous fish in waterlogged rice-fields might extend the rice-fish culture towards a sustainable and self-substrating periphyton based aquaculture (SSPBA) practice.

Keywords: Periphyton; Sustainable agriculture; Rice-fish; Self-substrating; Common carp; Apatani plateau.

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1. Introduction

Periphyton or '*aufwuchs*', comprising the organisms living on submerged surfaces, includes both the attached forms and the organisms associated therewith. The group consists of algae, zoological and filamentous bacteria, attached protozoan, bryozoan, rotifers and also the free-swimming microorganisms. Young [1] described it as an assemblage of organisms growing upon the free surfaces of submerged objects of water and covering them with a slimy coating. Hunt [2] defined it as an assemblage of algae and minute animals covering submerged objects with a slimy coating. Thus, not only the minute sessile organisms living within a slimy matrix on submerged objects but also the

[1] *Corresponding author*: sksaikai@yahoo.com

free living organisms associated with this matrix have been greatly treated as periphyton. It can comprise a major proportion of benthic algal production in shallow aquatic ecosystem [3, 4]. Though, there is a common assumption that the phytoplankton community is the most important in terms of energy fixation and fueling the food web, however, research has shown that macrophytes and periphyton are significant and often the dominant contributor to primary production [5]. Moreover, detailed nutrient budgets have demonstrated that epiphyte (or periphyton) consumes a significant fraction of nutrients such as available carbon, nitrogen and phosphorus during their growth [6] and aid in macrophytes decomposition [7]. The associated Cyanophyceae group is well known for its contribution to the soil fertility [8]. They could mediate cycling of nutrients such as phosphorus from the nutrient rich sediment through macrophytes, to the relatively nutrient-poor water [9]. Moreover, the added nutrients, in return, increase the periphytic density [10, 11].

2. Periphyton as Food Source

The emergence of periphyton as an important group of organismal assemblages led to establishment of a functional relationship among periphyton and other ecosystem components in aquatic habitats. Periphyton may contribute substantially to primary productivity especially in shallow freshwater ecosystems [12, 13] and thus provide an important energy input to both detritus and grazing food chains of the ecosystem [14, 15].

Periphyton has significant role of providing food for fish and other fauna in natural and controlled environment [16]. Jones *et al.* [17] reported of a wide range of fish and benthic invertebrates including snails, chironomids, mayflies, oligochaetes and several groups of crustaceans that include periphyton in their diet. The foraging habits of some of epifaunal organisms (snails and chironomids) indicate macrophytes along with periphyton being more preferred over macrophytes without periphyton [18-20]. Denny *et al.* [21] proposed the food chain with epiphyton → commercial fish in a reservoir in Tanzania. Grazing of periphyton by wild fish has also been reported [22, 23]. More recently Pandit *et al.* [24] constructed a typical food web of Dal Lake in Kashmir Himalaya, India delineating the trophic relations of periphyton. He described the immediate consumers of periphytic algae in the complex food web as Protozoa, Rotifer, Cladocera, Ostracoda, Nematoda, Gastropoda (Mollusca), Chironomidae, Rhagonoidae, Zygoptera (Nymph), *Barbus conchonius*, *Hydraenidae, Hydrophylus* sp. *Scizothorax* spp. (Snow trout) and *Cyprinus carpio* (Common carp), which in turn are consumed by consumers of successive trophic level. Studies using stable isotopes have provided evidence of periphytic algae as feed that contributed significantly to fish production in lakes throughout the world [25].

van Dam *et al.* [26] estimated the range of Protein/Metabolizable Energy (P/ME) ratios of periphyton which varies from 10 to 40 kJ g^{-1} and overall assimilation efficiency of fish growing on periphyton was 20–50%. Periphyton as food is considered to be of higher quality, as it produces significantly higher growth rates [27, 28]. All these show periphyton as important food for epifaunal organisms. The periphyton communities thus play significant role in shaping the ecosystem by determining the primary production of the ecosystem contributing mainly to the aquatic food chain.

3. Periphyton Based Aquaculture (PBA) - A Global Perspective

Aquaculture is not always a truly sustainable practice, so far the supply of external feeds, chemicals and energy inputs are concerned [29]. Therefore, the trophic status of periphyton led researchers to realize it as a future potential of sustainable system hiding under the water. Horn [30] reported that the herbivorous fish in nature feeds largely on benthic, epilithic or epiphytic algae rather than on phytoplankton. Dempster *et al.* [31] also obtained same result when experimented on *Oreochromis niloticus* in a glass fibre tank. The possibility of consuming periphyton by fish is more due to several reasons. Wetzel [32] reported that the production of periphytic algae per unit water surface area is higher than phytoplankton. Westlake *et al.* [33] explained that the periphytic algae are generally more stable than phytoplankton and the risk of collapse is much lower. Horne and Golderman [34] stated that 'it is mechanically more efficient to scrap or graze a two dimensional layer of periphyton than a filter algae from three dimensional planktonic environment.' Dempster *et al*. [31] also showed that biomass ingestion rates of filter feeding fish on planktonic cyanobacteria were significantly lower than those grazed on periphyton.

In recent years, extensive researches are going on the traditional periphyton based aquaculture practices as fisheries enhancement technique throughout the world (Table 1).

Table 1 Traditional periphyton based aquaculture practices of the world.

Periphyton based aquaculture system	Nature of aquatic system	Country
Acadja [35]	Pond	West Africa
Athkotu [36]	Pond	Sri Lanka
Katha [37]	Pond	Bangladesh
Samarahs [38]	Pond	Cambodia
Phum[39]	Pond	India
Aji gnui assonii [40]	Rice field	India

All these traditional systems advocated the installation of natural substrates to the system for periphyton growth on which fish thrives. The first of its kind was reported by Welcomme [35] on *Acadja* fisheries of West Africa. The '*Acadjas*' describes a group of installations of dense masses of branches that are artificially planted in the muddy bottom in shallow (1.5cm in depth) waters in coastal lagoons of West Africa to attract fish. The harvest from '*Acadjas*' is known to vary from 4 to 20 ton of fish $ha^{-1}yr^{-1}$ [41].

Experiments in Sri Lanka on substrate based fishery using different mangroves and non-mangrove tree species gave yield about 2.3-12.9t ha^{-1} y^{-1} [42]. The '*Samarahs*' are made up of the tree branches and bamboo shoots accompanied with floating aquatic weeds like *Eichornia crassipes*. The fish are harvested 60 days after installation of substrates. Fish yields from '*Samarahs*' were around 4 ton $ha^{-1}yr^{-1}season^{-1}$. The farmers in Cambodia also use paddy straw and palm leaves to clear turbidity in water that also results in increased production by acting as a substrate for periphyton growth [38]. '*Katha*' is the traditional method of fishing in rivers where substrates like *Colocasia esculenta* and branches of bamboo (Kanchi), mango etc. are used as a medium for algal attachment. The '*katha*' fishery showed about 33% increment in fish production [43].

Shresta and Knud-Hansen [44] demonstrated increased attachment of microbial biomass without increased net yield of tilapia when plastic baffles and bamboo poles were used. Increased production was also observed when 'chatai' (a kind of worn bamboo matting) was hung in ponds in Bangladesh. Norberg [45] recorded increased growth and production of caged tilapia when *O.niloticus* and *O.rendelli* were subjected to periphyton growing nets. Tidwell *et al.* [46] observed increased production of *Macrobrachium rosenbergii* using artificial substrates. *Aquamat,* a commercial substrate for periphyton is reported to reduce operational cost of fish culture by 50% [47].

Recently, a group of aquaculturists from Wageningen University showed major developments in periphyton based pond aquaculture research [48]. Using different substrates, Keshavanath *et al.* [49] observed the highest fish yield without feed supplement as 491kg $ha^{-1}90d^{-1}$ with bamboo substrate. Azim *et al*. [50] studied growth and production of Indian major carps, rohu (*Labeo rohita* H. and *Labeo gonius* L.) using bamboo substrate in ponds and recorded a 77% higher production of rohu with bamboo substrates than the ponds without substrates. Azim *et al*. [51] examined potentiality of fish productin in periphyton based polyculture environment with three Indian major carps, catla *Catla catla*, rohu *Labeo rohita* and kalbaush *L. calbasu*, using bamboo as natural substrate and compared it with periphyton free system. Their report showed the fish production from the periphyton-based system 2.8 times higher than that of the periphyton free environment.

4. Periphyton in Waterlogged Rice Fields

In perspective of periphyton as feed source for aquaculture, waterlogged rice fields have yet to draw attention from global fisheries community. The term 'waterlogged rice fields' is synonymous to a "temporary aquatic environment" [52] or "a special type of wetland" that can be considered "a successor of shallow marshes or swamps" [53, 54]. These are characterized by the presence of a temporary and seasonal standing water body and scientists have viewed these as agronomically managed marshes [55]. Therefore, waterlogged rice fields, being temporary aquatic phase followed by a generally predictable dry phase [56], can be scientifically defined as an agronomically managed temporary wetland ecosystem [57].

Fish culture in waterlogged rice fields have been known to be practiced in Asia for 5000-6000 years. The earliest record of rice fish culture was originated from China 2000 years ago [58]. It is thought to have been practiced in Thailand more than 200 years ago [59]. In Japan and Indonesia, rice-fish culture was developed in the mid-1800s [60, 61]. An early review on rice-fish culture showed that by the mid-1900s it was practiced in 28 countries on six continents, namely, Africa, Asia, Australia, Europe, North America and South America [62]. Countries with a recorded history of rice-fish culture are India, Indonesia, Malayasia, Thailand, Japan, Madagascar, Italy and Russia [63].

The presence and abundance of food organisms are very important factors in rice-fish culture. It harbours lots of phytoplankton and filamentous higher algae in its aquatic phase [64]. All these aquatic fauna and flora play important role on the overall ecology of rice field. Roger and Kulasooriya [65], Pantastico and Suayan [66] and Weeraranta and Fernando [67] worked out some of the roles of algae and macrophytes in wet rice agro ecosystem which are often refereed to as photosynthetic aquatic biomass (PAB). The algae alone in a rice field have been reported to develop a biomass of several tonnes fresh weight per hectare [52]. Cattling *et al.* [68] reported 119 species of algae from deepwater rice fields of Bangladesh. In India, Das *et al*. [69] worked on rice stem periphyton and reported 61 genera of periphytic organisms along with their vertical distribution into water column of deep water rice fields in West Bengal. Reports are also available on periphytic detrital aggregate as food for Nile tilapia and Common carp in rice fields of north east Thailand [70]. Fish feeding on periphyton on rice plants could be so vigorous that the rice plants were observed to be shaking [71, 72]. Saikia and Das [40] reported a traditional rice-fish culture system in Apatani plateau of northeastern India with fish production of 500kg ha^{-1}180 $days^{-1}$ which was later recognized as periphyton based rice-fish system [73]. Saikia [74] recorded 97 periphytic genera from local cultivars of waterlogged rice fields in Apatani Plateau. Das *et al.* [73] reported 38 periphytic genera from the stem of this rice-fish culture system of which 28 were found grazed by Common carp stocked in those fields. Awasthi *et al.* [75] also mentioned a total 99 members of Chlorophyta during flood phase from the same rice field of which 56 were common in fish gut stocked in the field. Saikia and Das [76] reported 60 genera of microflora and fauna of periphytic nature from the guts of Common carp (*C. carpio* L) collected from rain-fed rice-fields of Apatani Plateau. An economical analysis of these rice-fish culture practice accounted 65.78% profit per cropping season without any supplementary feed [77] Therefore, full exploitation of such environment by stocking a proper combination of fish species may extend the fish production over 500 kg ha^{-1} [78].

5. Rice Fish System in Apatani Plateau: A Model of PBA Technology

Saikia and Das [40] reported of a traditional periphyton based organic rice-fish practice in north eastern India, locally known as '*aji gnui assonii*' where Common carp (*C.carpio*, L) utilizes the aquatic biota as the source of natural food. The farmers, known as 'Apatani', stock all the strains of Common carp (*C. carpio speularis, C. carpio communis* and *C. carpio nudus*). The fact is that the farmers never utilize any supplementary food to feed the stocked fish. The fish Common carp is totally dependent on the natural food of aquatic phase in the field. Farmers basically follow the traditional agronomic practices initializing rice plantation in March and continuing up to the end of April. After 10 days of transplantation of seedling the fry (3-5 cm) of Common carp are stocked into the field water. The final harvest of fish attains up to 30 cm and the total production ranges between 300-500 kg ha^{-1} $season^{-1}$ in addition to total production of 3.0-4.0 ton ha^{-1} $season^{-1}$ of rice [40].

6. Sustainable Organic Farming by Apatanis: How?

The monocropped field followed by fallow period helped the Apatani farmers to maintain normal soil health of their rice fields. The practices of intensive recycling of organic wastes, retting of rice stubble in the field directly assure them a bumper harvest in a season. Fish being an additional component in the system provided sustainability in production as well as judicious management of minor pest and weed pressure in their fields. Their rice-fish system proves the efficacy of increased production without extra input cost enhancing natural association (periphyton) of fish under rice canopy and conserved biological diversity. It is a model system for rest of world in irrigated and lowland rice ecosystem towards sustainable organic farming of two crops at a time in unit area exploiting periphytic resources. This would in one way increase the popularity of rice-fish farming and thus would lead to better management and wise use of unexploited resources from vast inland waters lying under rice canopy.

7. Self-substrating to Rice-Fish Culture

The utilization of readily stocked rice stem as substrate for association of periphyton bears significant attention in terms of sustainable rice-fish culture technology. Periphyton shows an interdependent link to all resources and the factors functioning and governing the rice field ecosystem (Fig. 1) [74]. It maximizes the availability of natural resources easily to accessible state. In addition, the loss of energy in the food chain during its transfer from primary producers to fish is reduced to 50% in rice-fish system [74]. Such role of periphyton imparts extra dimension to rice field as productive ecosystem. Huda *et al*. [79] in their study in rice-fields of Bangladesh reported the periphyton based aquaculture as economically viable technology for increasing fish production with cheaper local resources.

Duffer and Dorris [80] suggested that the substrate type rather than light intensity or nutrient was the effective agent in periphyton based system. When compared to artificial substrates, studies revealed that periphyton develops better on natural substrate due to its differences in the hydrophilic characteristics [81]. Keshavanath *et al.* [82] suggested

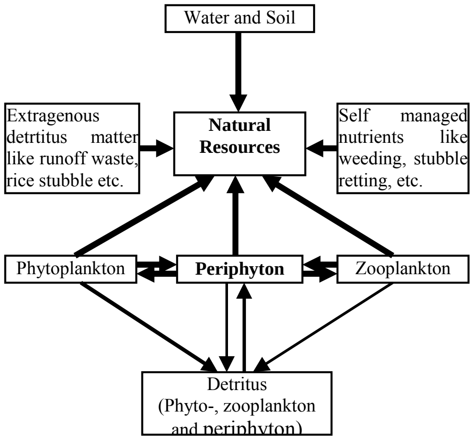

Fig 1. Interdependent link among organic resources functioning in rice fish culture system.

bamboo as the suitable substrate for periphyton colonization in pond. Aquatic macrophyte shows differences in the development of epiphytes, which may be due to ages of plant or plant parts, exposure surfaces or plant texture [83]. Horne and Golderman [34] also suggested that seasonal changes of epiphyton in natural system are affected by seasonal changes in the vegetation upon which it grows. If such considerations are hypothesized, the rice vegetation is rapidly changing system [64] and therefore the rice stem greatly influences succession pattern of periphyton on it. Most of the attached forms including diatom were secured to living substrate by jelly-like secretions, while others were attached to gelatinous stalks [84]. However, the submerged part of the rice stem favours maximum adherence of algal communities [73] when compared to pond where bamboo, jute sticks and hizol were applied as natural substrate for periphyton growth [83]. Moreover, rice field does not require the input of any artificial substrate of natural origin. The extragenous biodegradable substances may have negative impact in imbalancing the nutrient level in the soil phase of the system. Moreover it is expensive for marginal poor farmers. Rai *et al*. [85] reported higher amount of periphytic bacteria on rice straw (41 320 million cfu m^{-2}) when compared to the kanchi (a kind of bamboo met) subtrate (11 780 million cfu m^{-2}). The stocked fishes (rohu, catla and common carp) in his experiment attained 38% and 47% higher combined total weight in substrate-based environment than to substrate free control. The gross margin analysis showed that rice straw resulted in more profit than kanchi substrate type. Therefore, Rai *et al*. [85] advocated the use of rice straw as the potential and low input substrate to be used to increase fish production in rural aquaculture. In Apatani Plateau, it was calculated out that the rice stems provide an additional surface area of more than $1000m^2$ for the local cultivar '*amo*' with stem diameter of 1.0-1.3cm submerged into 20-30cm water in the field. Therefore, rice-fish culture can be regarded as a 'self substrating periphyton based aquaculture' (SSPBA) technology with rice stem as self managed substrate. Periphyton could be an extra trophic level in addition to planktonic resources added to the SSPBA system that retains nutrients and metabolic energy in it. This can be converted to fish biomass by introducing herbivorous or omnivo-periphytovorous fish to the rice-fish environment. Simultaneously, replacement of supplementary animal protein by plant (i.e. periphyton) protein could be done for fish culture on which the recent research is being concentrated [86]. The importance of supplementary feed for fish also, becomes marginal in periphyton rich system [87].

The feeding ecology of common carp (*C. carpio* L) in rice field showed maximum inclination towards periphyton adopting a periphytophagus nature [76]. In addition to Common carp, a judicious combination of fish of both filter feeding and grazing nature may enhance the fish productivity in rice field. For instance, Nile tilapia (*Oreochromis niloticus* L), a micro-herbivorous column feeder coupled with Common carp (*C. carpio* L) in rice-field may increase the productivity rate [88]. All these studies have oriented SSPBA as emerging technology of aquaculture with efficacy of two dimensional and sustainable harvesting of periphyton by fish stocked accelerating maximum energy conversion in the form of fish biomass.

8. Conclusion

To meet the food requirements of the fast-growing human population of the world, a 65% production increase from rice field would have to be met within the next 30 years without much expansion of the actual cultivated area [89]. Such demands should not be achieved at the expense of food security of future generations and necessary approach must be initiated to fulfill the concept of sustainability [90, 89] in wet rice environment. The co-existence of rice and fish in the same cultivated area with optimum exploration of aquatic biota through SSPBA technology could be an alternative.

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