Advances in Agricultural Technology & Plant Sciences
ISSN: 2640-6586

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Commentary *Volume 7 Issue 2*

Role of Aquatic Macrophytes in Controlling Fish Diversity of Wetlands

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Received Date: November 15, 2024; **Published Date:** November 26, 2024

Abstract

Floodplain wetlands, a major inland fishery resource of India is not only known for its high production potential, but also for their rich diversity of fishes mostly contributed by small indigenous fishes (SIF). Submerged macrophytes play a definite positive role in favoring this rich fish diversity, in contrary to their counterpart like floating, emergent and rooted-floating varieties of macrophytes. Increased aquaculture activities overwhelmingly support algal trophic chain and put a tremendous pressure on the submerged macrophytes and associated fauna including SIF. It is need of the hour to control this detrimental trend for conserving rich fish diversity of wetlands.

Keywords: Wetland; Submerged Macrophyte; SIF; Fish Diversity

Abbreviation:

SIF: Small Indigenous Fishes

Introduction

Among different types of inland open water resources like rivers, reservoirs, lakes, wetlands, lagoons, canals, etc., wetland being shallow in nature is the one of the most productive waters having maximum potential of fish production [1-3]. The Millennium Ecosystem Assessment [4] estimated that the wetlands cover only 7% of the earth's surface, whereas deliver 45% of the world's natural productivity and ecosystem services of which the benefits are estimated at $20 trillion a year [5]. This high natural productivity is often reflected in high fish productivity from wetlands especially ox-bow shaped floodplain wetlands in northern and northeastern India (locally known as beel, chaur, maun, anoa, pat, etc.) with an area of more than 5.5 lakh ha. Large Asian rivers like Brahmaputra and its associated floodplain wetlands are more diverse than those in other continents like Africa or Latin America [6,7]. Not only quantitative contribution, this fish production from wetlands constitutes a wide diversity of fishes. Being shallow in nature, these wetlands offer a unique aquatic habitat to harbor different varieties of aquatic macrophytes supporting wide diversity of flora and fauna which in turn promotes proliferation of a rich biodiversity of fish species mostly dominated by SIF (small indigenous fish). Many wetlands maintain seasonal or perennial connections with their parent rivers. River connectivity plays a big role in maintaining aquatic biodiversity of floodplain wetlands where aquatic macrophytes especially submerged variety offers breeding and nursery grounds for riverine fishes during monsoon [8]. Thus wetlands can offer high fish production along with huge diversity of fishes especially nutrient-rich SIF.

Presently many wetlands are facing lot of stress factors which are mostly anthropogenic in nature. Deterioration of wetlands comes from the continuous encroachment by different types of human activities leading to over-exploitation. That led to loss of fish diversity as well as other important ecological functions of floodplain wetlands. With loss of diversity, decline of fish productions has been reported from many wetlands. Deka, et al. [9] reported a loss of fish production of 0.21% to 75.51 % (4.94 ± 10.24 %) in 10 years from 54 floodplain wetlands in 13 districts of Assam. As many as twenty-two factors were identified by them for decline of fish catch. Manna, et al. [10] identified nature of riverine connectivity and infestation of different types of aquatic macrophytes as major controlling factors of fish diversity in floodplain wetland of Assam. In this article, discussion will be made on the role of different kinds of aquatic macrophytes influencing ecology of floodplain wetland thereby influencing fish diversity therein.

Aquatic Macrophytes of Wetlands

Being shallow in nature, highly productive ecosystem of floodplain wetlands supports a wide range of aquatic plants which can be defined as plants 'growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content' [11]. Wetland plants are broadly divided under four different categories viz. floating, floating-leaved, submerged and emergent [12]. Emergent plants are rooted in the wetland sediment with basal parts remain within water, but whose leaves, stems and reproductive organs are aerial (e.g. *Phragmites australis*, common reed). Submerged macrophytes may be free-floating like *Ceratophyllum demersum* or rooted like *Hydrilla verticillata*. Submerged macrophytes spend their entire life cycle beneath the water surface. The leaves of floating-leaved plants, also known as floating-attached plants float on the water surface while their root remain anchored with the bottom sediment (e.g. *Nymphaea odorata*, white water lily). In case of free floating plants, the leaves and stems float on the water surface (e.g. *Eichhornia crassipes*). If roots are there, they hang freely in water. In pristine as well as anthropogenically disturbed shallow wetlands, most of the nutrients are recycled within these macrophytes with higher rate of primary production than the plankton.

Role of Submerged Macrophytes in Wetland Biodiversity

Like phytoplankton, wetland plants are the primary producers and forms the base of the food chain of wetland eco-system. Submerged macrophytes contribute maximum in the total primary production of a shallow wetland. Interestingly, very less primary production can directly be transferred to higher trophic level. Only few herbivorous fish (like grass carp), insects, birds can consume them [13]. Instead most of the primary production is transferred to detritus chain. High quality detritus derived from decomposing macrophytes is a good source of food for snails, insect larvae etc. [14]. Vegetation stands usually have a much richer invertebrate community than unvegetated sites, both in terms of species numbers and total biomass. Also, the epiphytes (haptobenthos consisting protozoa, bacteria and algae) grown on surface of the macrophytes are more important as a food source for invertebrates in vegetated areas. That is reflected by their distribution with richer invertebrate community around vegetation [15]. Thus, aquatic macrophytes provide critical habitat structure for other taxonomic groups like epiphytic bacteria, periphyton, invertebrates, fish, amphibians, reptiles, mammals and birds. Diversity of these taxonomic groups depends on the composition of macrophyte community present in a wetland. Aquatic macrophytes decrease phytoplankton density by reducing nutrient availability and also by shading, but increase zooplankton density by protecting them from predation. Macrophyte stands also reported to lower phytoplankton density by allelochemical secretion and also by harbouring attached filter-feeding cladocerans. Thus, aquatic vegetation is identified as the best tool for ecological diagnosis of riverine wetlands [16].

Submerged Macrophyte Control Over Limno-Chemistry: Aquatic macrophytes control limno-chemistry of a wetland in a large way. Submerged macrophytes like *Ceratophyllum* forms a very dense canopy preventing vertical mixing of water column through convection and thus creating strong temperature gradient even in shallow wetland with higher temperature at surface and lower temperature at bottom. Macrophyte increases overall transparency of a wetland by trapping silt as settling material and by preventing wave resuspension. Through photosynthesis, submerged aquatic macrophytes produce oxygen to be utilized by aquatic organisms including themselves. High density of submerged macrophytes produce oxygen in a very high rate to make the wetland ecosystem supersaturated with oxygen. Free carbon-di-oxide concentration in water becomes zero during early hours of the day in a submerged macrophyte-infested wetland. Most of the macrophytes then utilize bicarbonate for photosynthesis for carbon-di-oxide and increases water pH significantly [17]. Very high pH was recorded during early afternoon hours inside submerged macrophyte stands. Such macrophytes stand acts as a sink of phosphorous preventing algal bloom in the nutritionally high wetland ecosystem. Submerged macrophytes can also reduce the nitrogen concentration in the water column. A colonization of 50% of the water area by submerged plants results in a decrease of about 1 mg/l in total nitrogen concentration as reported. Submerged rooted macrophytes are also known to release oxygen in bottom sediment through their roots making the upper sediment surface oxic, which plays a role in reducing methane emission through its conversion by aerobic methanotrophs [18].

Type of Aquatic Macrophytes Vis-À-Vis Fish Diversity: Aquatic macrophytes promotes wetland fish diversity in different ways. Herbivorous fish (like grass carp) directly consume, whereas many SIF consumes epiphytes, or detritus produced of macrophyte origin. Macrophyte associated fauna (mollusk, insects, etc) supports insectivorous fishes. Again, aquatic macrophytes act as substrate for egg deposition of many fishes. Manna, et al. [19] critically analysed the role of different types of aquatic macrophytes in wetlands of Assam, India as given below.

For understanding the role of different types of aquatic macrophytes, total wetland area of a wetland was divided under the four broad heads based on existing macrophyte types viz. submerged macrophyte covered area, floating macrophyte covered area, rooted-floating and emergent macrophytes covered area and area without any types of macrophytes. Similarly, fish catch of the wetlands has been categorised under four broad heads, viz. major and minor carps, air-breathing fishes, carnivorous fishes and Small indigenous fishes (SIF). Major and minor carps group comprised of *Catla catla, Labeo* spp., *Cirrhinus* spp. including exotics like silver, grass and common carps. Air breathing groups consisted of *Clarias batrachus, Heteropneustes fossilis, Anabus testudineus* and *Channa* spp. Carnivorous group included *Wallago attu* and *Notopterus* spp. Rest of the fishes caught from a wetland formed the group SIF which mostly consisted of weed associated species like *Amblypharyngodon mola*, *Chanda* sp., *Colisa* spp., *Danio aequipinnatus, Glossogobius giuris, Macrognathus pancalus, Nandus nandus, Puntius* sp., *Salmostoma bacaila, Tetrodon cutcutia, Xenentodon cancilla*, etc. As maximum numbers of fish species are grouped in the category of SIF, hence yield (kg/ha/y) of these fishes from a wetland has been considered as index of fish biodiversity of a wetland.

To understand the role of different types of aquatic macrophytes, area (%) covered by different types of macrophytes were correlated with yield of SIF. Strong positive correlation was observed between area (%) covered by submerged macrophytes with yield of SIF ($r = 0.526$, $p<0.01$). This reveals the supportive role of submerged macrophyte species for growth of SIF. It is observed that rooted-floating macrophytes do not support fish diversity like their submerged counterpart. In fact, they have negative impact on weed associated fishes. When area under rooted-floating are added with the area under submerged macrophytes, significance of the positive relationship between submerged macrophytes and SIF productivity is lost. On the other hand, productivity of SIF was negatively correlated with area (%) covered with floating macrophytes though not significant. Significant negative correlation ($r = -0.331$, $p<0.02$) was observed when productivity of SIF was correlated with the area covered by floating, rooted-floating and emergent varieties together. So, it can be concluded that rooted-floating macrophytes does not support weed associated fishes like submerged macrophytes.

Parameter	Vs	Parameter	Coefficient (r)
% Area covered with submerged, rooted-floating and emergent macrophytes	Vs	Small indigenous fishes (kg/ha/y)	0.286
% Area covered with only submerged macrophytes	Vs	Small indigenous fishes (kg/ha/y)	0.528*
% Area covered with only floating macrophyte	Vs	Small indigenous fishes (kg/ha/y)	-0.214
% Area covered with floating and rooted-floating macrophyte	Vs	Small indigenous fishes (kg/ha/y)	-0.328**

*Significant at 1% level; **Significant at 2% level

Table 1: Correlation between macrophyte coverage in wetlands and small indigenous fish (SIF) production.

From the study, it can be concluded that floating macrophytes like water hyacinth should be discouraged to conserve fish biodiversity of a floodplain wetland. Rooted-floating and emergent macrophytes also do not support small indigenous fishes. Submerged macrophytes are very much necessary to conserve rich fish biodiversity of floodplain wetlands.

Dense Submerged Macrophytes Versus Fishery: Dense canopy of submerged macrophytes often creates difficulty in fish harvesting from the wetlands through conventional fishing gear like gill net, drag net, etc. Hence, it is sometimes required to do partial cleaning of submerged macrophyte infestation. It is recommended that either we should go for manual clearing or physical clearing by covering an area with black plastic sheets instead of application of weedicides. Biocontrol with herbivorous fishes like grass carp is also encouraged.

Role of Floating Macrophytes (like Water Hyacinth) in Wetlands: Most of the floodplain wetlands in India were observed to be inhabited by floating water hyacinth. Impact of water hyacinth on wetland ecology is tremendous as reported by Rai, et al. [20]. Manna, et al. [21] also observed similar detrimental influence of floating water hyacinth on different water quality parameters as given below.

Impact of Water Hyacinth on Water Quality Parameters: As compared to clear zone, surface water temperature inside floating macrophyte covered zone used to be significantly lower due to shading by dense water hyacinth canopy. During our study, both surface and bottom water inside floating macrophyte zone of contained much less oxygen (0.79-3.67 mg/l) in both the seasons which is not congenial for fish growth. This is due to obstructed equilibration with the atmospheric oxygen caused by dense canopy of water hyacinth. High density of free CO_2 was recorded in floating zone, when there is no free carbon-di-oxide available in clear zone both at surface and bottom. Thus, it is evident from different studies that water hyacinth is not suitable for good fish growth because the area was lacking of sufficient oxygen concentration. Acidic pH inside water hyacinth zone is not been compensated by planktonic photosynthesis happened outside. Available free carbon-di-oxide is the reflection of poor phytoplankton concentration inside water hyacinth zone. So, water hyacinth is not at all congenial for providing both limno-chemical environment and food source.

Floating Macrophyte and Evapo-Transpiration: Floating macropytes transpire at a very high rate and reduce water volume much more quickly. The evapo-transpiration rate of water hyacinth (*Eichhornia crassipes*) is reported to be two to eight times more than the evaporation from a free water surface [22]. So it is obvious that floating water hyacinth should not be encouraged in wetland.

Impact of Floating Macrophytes on Fish and Fisheries: Only few air-breathing fishes can sustain in the hostile environment below the floating water hyacinth mat. Such mat does not allow sunlight to penetrate to bottom water and absorbs plant nutrient very fast due to its prolific growth in congenial environment of shallow wetlands. Degrading water hyacinth releases black colour suspended organic matter which is difficult to be decomposed and thus water becomes less transparent and blackish in colour. Plankton and periphyton growth is hindered in a wetland where maximum area is covered with floating macrophytes especially water hyacinth. Stagnant water hyacinth mat can easily wipe all the submerged macrophyte below it by obstructing sunlight. As expected, very few air-breathing fish species can sustain in a wetland choked with water hyacinth. Stationary mats of water hyacinth shade out bottom growing submerged vegetation, thereby depriving some species of fish and other aquatic invertebrates of food and spawning grounds. Thus, potential impact of water hyacinth mat on fish diversity of wetland is enormous. Such infestations make access to fishing grounds increasingly time consuming or impossible, while physical interference by floating macrophytes with nets makes fishing more difficult or impractical.

Floating Macrophytes and Swampification: Water hyacinth replaces existing aquatic plants, and develops floating mats of interlocked plants, which are colonized by several semi-aquatic plant species. As succession continues, floating mats dominated by large grasses may drift away or be grounded. This process can lead to rapid and profound changes in wetland ecology, e.g. shallow areas of wetland is converted to swamps. Wetlands shrink at a very faster rate caused by death of shoreline mats. Such huge organic load causes rapid reduction of water depth. Many wetlands are at the advanced stage of eutrophication, becoming swamps and are on the verge of extinction due to severe autochthonous deposition caused by death of huge floating macrophyte mats therein.

Management of Water Hyacinth Infestation: As floating macrophyte like water hyacinth mat creates stressed habitat for most of the fishes, those should be discouraged. River connectivity during monsoon gives a good opportunity for many wetland managers to push the floating mat to the main river. Once reach estuary, those macrophytes started dying and decaying due to increased salinity. Need-based manual clearance is recommended instead of chemical control by spraying weedicides.

Role of Riverine Connectivity in Controlling Macrophyte Infestation: Floodplain wetlands are mostly ox-bow shaped cut-off meander of the main river channel and supposed to establish the seasonal connectivity with the parent river during monsoon causing flushing of them by floodwaters. Increased human intervention through embankment, sluice gate, barrages or permanent bunds, etc. at the connecting channel caused adverse impact on overall ecology of many such wetlands with increased organic matter accumulation, aquatic macrophyte infestation etc., [21].

Sometimes, rivers moved further from the wetlands making the low-lying connecting areas suitable for human settlement and intensive agriculture. Being shallow in nature, these wetlands are often infested with submerged macrophytes. Primarily produced autochthonous organic carbon gets deposited at bottom sediment with ageing. Seasonal flushing of wetlands with floodwater through connecting channel creates a natural hydrologic disturbance, which removes that excess organic matter, inhibits competitive exclusion of submerged macrophyte species, and thus maintains diversity [23]. Thick macrophyte infestation in closed wetlands gradually lead to physical change of depth (shallow), followed by biological change with dense growth of emergent form leading to swampification. Seasonal variation in hydrology through turbid floodwater intrusion maintains successional stages of wetland plant communities and thus prevents terrestrialization.

A comparative study was undertaken in a closed wetland (Puthimari) and in an open wetland (Morakolong) in Assam, India to understand impact of river connectivity on different water and sediment parameters as given below [21]. River connectivity significantly increases water depth of floodplain wetlands. Water depth is a known controlling factor for distribution of aquatic vegetation and also benthic periphyton by inhibiting sunlight. It also influences limno-chemical parameters of water mainly that of bottom waters. Flow of the incoming water during monsoon dislodges the loosely bound surface sediment once large-scale mortality of thick infestation of submerged macrophyte occurs due to increased water level with silt turbidity. Bottom erosion by flowing water and subsequent deposition of silt helps in mineralization of bottom organic matter keeping the sediment health of seasonally open wetland in better condition. This also keeps the depth of the water body near constant.

Turbidity caused by monsoon inflow hinders the subsequent regeneration of submerged macrophyte immediately. Those macrophytes only start growing in post-monsoon when most of the silt gets deposited and water level also much reduces. In post-monsoon and winter, specific conductivity values of open wetland increased sharply to exhibit much higher mineralization rate of dead particulate organic matter mainly derived from submerged macrophytes. Closed wetland accumulates much higher organic load, but rate of mineralization is much less as evidenced by narrow range of sp. conductivity variation.

Massive accumulation of humus or organic carbon are generally observed at the bottom of closed wetland which may record soil organic carbon in the range of >5%. Open wetland, on the other hand, recorded much lower values of organic carbon (1-2%). Closed wetland accumulates a major share of primary production by dense submerged infestation of macrophytes and attached periphytons. Sugunan, et al. [24] reported the similar observation of higher organic carbon accumulation in Haripur closed wetland as compared to Haripur open wetland despite their common origin from same river. Establishment of riverine connection in monsoon in open wetland gives entry to the flowing water which cause sufficient churning of loosely bound bottom surface sediment for better mineralization of bottom settled organic matter. This also brings freshness to the sediment and reduces the accumulation of toxic metabolites at bottom. Lack of flooding in closed wetland resulted in organic carbon accumulation thereby accelerating its swampification.

Impact of River Connectivity on Submerged Aquatic Macrophytes: The high degree of river connectivity and thus, flood disturbance strongly influences the vegetation structure in a wetland [25]. As observed, in closed wetland, submerged macrophytes are strongly dominated by tolerant species like *Ceratophyllum* with very small population of other macrophyte (like *Myriophyllum* sp. and *Hydrilla* sp.) [21]. Floating zones were dominated by water hyacinth (*Eichhornia crassipes*). Loss of river connectivity (lack of flood disturbance) played a key role in the species dominance of submerged macrophytes. *Ceratophyllum demersum*, the free-floating submerged one dominated in the secured environment of closed wetland, a clear example of competitive exclusion of submerged macrophyte species. Slight increase in water level with nutrient rich monsoon run-off from catchment helped in flourishing of *Ceratophyllum* sp. in closed Puthimari wetland with formation of dense canopy near surface preventing water circulation. *Potamogeton* sp. dominated in seasonally open wetland during winter. Loss of connectivity from the parent river is one of the main reasons of establishment of dense submerged macrophyte stands in closed wetlands throughout the year.

Algal Eutrophication vs. Macrophyte Infestation

Major nutrient cycling of wetlands occurs through the detrital chain involving aquatic macrophytes. However, certain management intervention sometimes involves large-scale removal of submerged or floating macrophytes. Then huge nutrient load is observed to trigger the phytoplankton density to cause bloom and the wetland becomes eutrophic. In such situation, fish diversity suffered a huge setback where only planktivorous carp fishes dominate.

Conclusion

Submerged macrophytes offer congenial habitat supporting fish diversity in wetlands. Floating macrophyte like water hyacinth is not at all suitable for fishes due to very low DO below the mat. Dense submerged macrophyte zone is also not much congenial for fishes due to high variability of DO and pH within a day. Clear zone is better for planktivorous fishes as it supports more phytoplankton to grow due to more nutrient availability as compared to submerged zone and less shading as compared to floating zone. Most of the wetlands are now stocked with planktivores like Indian major and minor carps, where clear zone can ensure better survival and growth. However, very less area of clear zone is observed in closed wetlands. So, as a management guideline, it is suggested to mark an area inside the wetland and clearing it intermittently to support the stocked fishes. However, how much area should be cleared for sustainable development of fisheries depends upon the target (fish diversity versus fish yield) as large-scale removal of submerged macrophytes will wipe out most of the SIF at the cost of planktivorous IMC. River connectivity brings much-desired flushing to remove sediment organic load as well as control submerged macrophyte infestation. Management measures should be involved with minimum floating macrophyte, moderate submerged macrophyte with seasonal river connectivity which can render wetland fish diversity better sustainability.

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