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Water productivity for living aquatic resources in floodplains of Northwestern Bangladesh

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PEER REVIEW

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Comments

This manuscript is written well with aiming to measure the productivity of water on the floodplain land in terms of fisheries and living aquatic resources based on two floodplain beels in Bangladesh. Also this study will be useful for further research in Bangladesh and neighboring countries where floods occur every year.

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ABSTRACT

Objective: To measure the productivity of water on the floodplain land in terms of fisheries and living aquatic resources based on two floodplain *beels* in Bangladesh.

Methods: Among two *beels*, *beel* Mail is practicing community based fish culture management, and *beel* Chandpur is open access and improperly managed. The production and market price data of fish, snail, and aquatic plants were collected by direct observation based on 30 samples fishers in the year 2006-2007. This study also collected production related water quality data, such as water temperature, pH and dissolved oxygen.

Results: The water quality data are found within the normal range. Net aggregated water productivity values based on production costs were TK 8016.23 ha^{-1} and TK 3912.9 ha^{-1} and based on all cost TK 7160.97 ha^{-1} and TK 3741.13 ha^{-1} at *beel* Mail and *beel* Chandpur, respectively. The contribution of fish, snails and aquatic resources were 96.50%, 3.10%, and 0.40% of the gross aggregated water produced in *beel* Mail and 87.85%, 8.38%, and 3.77% in the *beel* Chandpur. The water productivity values in *beel* Mail are higher than in *beel* Chandpur due to the intervention of community based fish culture.

Conclusions: The proper management and techniques of harvesting fish through appropriate number of fish fingerlings stocked, good quality of fish fingerlings, size of *beel*, good fencing and well defined embankment, *etc*. can help to improve the productivity of water in the *beel* areas.

KEYWORDS
Bangladesh, Community based- management, Floodplain, Water productivity

1. Introduction

Habitat values in floodplain river systems are tied to the complex and time-varying aquatic-terrestrial interface which includes wetlands and normally lentic water bodies proximal to the main channel. River channels in such systems have multiple, stage-dependent connections to lakes, sloughs, wetlands and depressions. Such off-channel habitats are important for fish populations because of the survival, feeding and reproduction opportunities they provide[1]. Some fish species move into off-channel habitats with rising stage and return to the river as the hydrograph recedes[2]. A floodplain is a low lying flat land which is adjacent to a stream or river that experiences occasional or periodic flooding[3]. Nevertheless, if pits are located on the riverside of the levee, they experience periodic hydrologic connection with the stream, enhancing their habitat value for fish[4,5]. It is a dry area susceptible to being inundated by water from any natural resource. Some

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places, like Bangladesh, farmlands that become flooded (over 1 meter depth) during wet season are known as floodplain. *Beel* is a very common form of floodplain area in the Ganga–Brahmaputra floodplains of states of West Bengal, and Assam in India and in Bangladesh. It is formed by inundation of low lying lands during flooding, where some water gets trapped even after flood waters recede back from the floodplains. It also may be caused by rain water during monsoon season. There are two types of *beels viz.*, the seasonal *beels* which dry–up annually and the perennial *beels* which retain water all the year round. *Beels* may be formed from great river when the mainstream of the river changes the direction leaving a remnant. Again this can be formed as a result of silt deposition in the river bed which makes the river flow with two parallel streams leaving a land in between. The land between a pair of parallel rivers then forms a ditch or depression which is converted to *beel* during flooding[6]. *Beels* are more potential water resources among the vast inland fishery. Soil and water of floodplains (*beels*) are very productive and are inhabited by distinct fauna and flora. It is a very good natural habitat for large and small indigenous fishes of different food habits. Many of fish and prawn species can multiply in number in *beels*. Many other fish and prawn species move into the inundated areas of *beel* from adjacent rivers and canals to feed and grow during monsoon.

Floodplains lands are an important aquatic ecosystem that supports a wide range of biodiversity and provides indispensable benefits to the people. Bangladesh is said to be world's largest floodplain with 80% floodplain land area. The country has a great opportunity to improve its economy by aquaculture. As seasonal flood is part of life here, so flood water can be blessings if managed properly for producing food. The seasonal water bodies which remain inundated for 4–6 months each year remain unutilized in terms of managed aquatic resources. These floodplains are used only for dry season for rice crop cultivation and wild fish catch in monsoon. These waterbodies are assumed to be unsuitable for fish culture as fish can be drained out with flooding and also because of short term existence of water.

Floodplain lands are also important for the diversity of fish species. Moreover, they are important areas in maintaining biological diversity but the fish diversity in Bangladesh is decreasing[7–9]. There are now 13 critically endangered, 28 endangered and 14 vulnerable fish species out of a total of 296 freshwater/brackish fish species existing in Bangladesh. It was reported that in floodplain *beels* of Bangladesh the fish production has dropped down to 50–55%, due to human interventions through construction of flood control embankments, drainage system and sluice gates, conversion of inundated land to crop land–thereby reducing water area and indiscriminate use of pesticides and insecticides, pollution from domestic, industrial and agro–chemical wastes and run–off, *etc*. These also have resulted in extinction of a considerable amount of an aquatic biota in some stretches of the open water system[10].

At the same time, proper utilization of floodplain lands is very important for rural economic and community development. Therefore, assessment of water productivity (WP) of floodplain waterbody is essential to govern for the scopes prevailing in these water bodies to be utilized for better economic purposes and for producing more food from the same water resources. Absence of such information, concerning authority or policy makers and underestimating the contribution of these resources to productive usage, hence fails to take initiative to improve management actions to utilize these resources. For the successful implementation of such approaches, information on values of resources and enhancing these values are needed. This study is an attempt to fill up this knowledge gap through measuring the productivity of water of the floodplain land in terms of fisheries and living aquatic resources based on two *beels* in Bangladesh.

2. Materials and methods

2.1. Study area

The study was conducted on two *beels* which are situated in Mohanpur upazila of Bangladesh. Mohanpur is a sub–district under Rajshahi district. It is situated between 24°28′ and 24°38′ north latitude and between 88°34′ and 88°43′ east latitude having an area of 162.65 km^2.

The *beel* Mail is open *beel* that is shallow depressions where land is converted to agriculture while permanent water is limited to deeper areas during dry season connected nearby a local Shiba River, which further connected to Padma river basin. This floodplain *beel* is mainly privately owned lands with total 100 ha area of which 15 ha government Khas lands having water availability for 5–6 months. Melandi, Goalpara, Dangapara and Moheskundi villagers are the main beneficiaries of this *beel*.

The *beel* Chandpur is mainly private own lands with total 202.43 ha of land of which 9.15 ha of land is government Khas land. The depth of water is 1.5 to 3.5 meters having 5–6 months of water during the wet season. This *beel* is connected with Barnoi River, which further connected to Padma basin. There are 5 villages surrounding the *beel* area namely Batupara, Horiphala, Chandpur, Chuniapara and Nondonhut.

Among the two *beels*, the *beel* Mail is practicing community based fish culture with the help of Department of Fishery (DoF) and Challenge Program for water and food project, South–east Asia, World Fish Center, but *beel* Chandpur is leased from local government that generally managed by group of poor fishers.

2.2. Data collection

Fishes were harvested from October to March in *beel* Mail and February to March in *beel* Chandpur. Data collection was done after fish harvested at landing centre by direct observation. Stocked and non–stocked fishes were separated at landing centre and weighted for selling to the wholesale markets. Price of fishes was estimated with TK kg^{-1} by market survey. Two types of production monitoring gears were used–*ber jal* (seine net) and *Khulsun* (fishing traps). Snail (naturally occurring) and aquatic plants (AP) production data were collected by direct observation in 3 d in a month to calculate the weight of snail and AP collected by sample farmers. Total amount of monthly snail and AP collection were obtained by multiplying the average weight of per day snail collection with the average number of days of snail collection in a month. This study data were collected in the year 2006-2007.

This study also collected water quality parameters that are directly concerned with water habitat and growth. Water quality parameters – water temperature, pH and dissolved oxygen were recorded from three stations of each *beel*. The samples of waters were collected from surface, middle and bottom level of water body once in a month in a sunshine day at 10.00-12.00 am with the help of black color bottle and transported to the laboratory for immediate analysis. Water temperature was recorded with the help of Celsius mercury thermometer. Immediately after collection, DO_2 and pH were determined with the help of hatch kit. Depth of water was measured with the help of measuring meter of bamboo pool and a boat from five fixed stations located at different depths four times in a month. Rainfall data was collected from government office at Upazila (sub-district) level as a secondary source.

2.3. Models and estimations

Under aquatic and terrestrial environment framework, the measurement of productivity means that water in the natural setting is a resource similar to land resource, and can be used as habitat or biophysical medium in the production of values and benefits. WP measures are expressed by the equations given below. The equation 1 measures WP in pure physical terms as

$$WP_P = \frac{Q_p}{A_{wr}} \qquad (1)$$

Where, WP_p=water productivity in terms of fisheries products; Q_p=net production of aquatic/fisheries products as physical units; A_{wr}=surface area of waterbody in hectare.

Here physical productivity is the quantity of net fisheries product that is, Q_p is wild fish (naturally occurring fishes) or culturable fish (fish for culture) or snails or aquatic plants per unit surface area of seasonal floodplain *beels* used for production. But for net production of culturable fish Q_p is gross fish production minus stocked of fish fingerlings per unit surface area of waterbody. The equation 2 measures the WP in value terms as

$$WP_p = \frac{Q_v}{A_{wr}} \qquad (2)$$

Where, WP_p=water productivity in terms of fisheries products; Q_v=value of net productions in monetary terms; A_{wr}=surface area of waterbody in hectare.

Equation 2 is the suitable one for multi-product outputs. The value of output (Q_v) here can be taken as the summation of the values of the different products derived from the multiple uses of the seasonal floodplain *beels*. It is to be noted that in this analytical framework, seasonal floodplain *beels* are treated as land resources, whose productivities are both measured in terms of surface area used for agricultural production.

The following equations were followed by early researchers to measure the WP of living aquatic resources (fish, snails and aquatic plants) in physical terms.

$$WP_1\ (kg/ha) = \frac{Q_{lo}\ (kg) - Q_{li}\ (kg)}{A_{wr}\ (ha)} \qquad (3)$$

$$WP_2\ (kg/ha) = \frac{Q_2\ (kg)}{A_{wr}\ (ha)} \qquad (4)$$

$$WP_3\ (kg/ha) = \frac{Q_3\ (kg)}{A_{wr}\ (ha)} \qquad (5)$$

Where, WP_1 (kg/ha)=water productivity of fish (wild or culturable) in terms of kg; WP_2 (kg/ha)=water productivity of snails in terms of kg; WP_3 (kg/ha)=water productivity of aquatic plants in terms of kg; Q_{plo} (kg)=gross output of fish, usually expressed in kg; Q_{pli} (kg)=gross input of fish fingerlings, usually expressed in kg; Q_2 (kg)=net output of snails, usually expressed in kg; Q_3 (kg)=net output of aquatic plants, usually expressed in kg; A_{wr}=per hectare area of seasonal floodplain *beels*.

The following equations measure the aggregate WP of living aquatic resources (fish, snails and aquatic plants) in physical terms,

$$WP_p\ (kg/ha) = \frac{Q_1\ (kg) + Q_2\ (kg) + Q_3\ (kg) + Q_4\ (kg)}{A_{wr}\ (ha)} \qquad (6)$$

Where, WP_p=per hectare WP by living aquatic resources is terms of kg; Q_1=net output of culturable fish, usually expressed in terms of kg; Q_2=net output of wild fish, usually expressed in terms of kg; Q_3=net output of snails, usually expressed in terms of kg; Q_4=net output of aquatic plants, usually expressed in terms of kg; A_{wr}=per hectare area of seasonal floodplain *beels*.

The following equations measure the WP of living aquatic resources (fish, snails and aquatic plants) in values,

$$WP_p\ (\$\ ha^{-1}) = \frac{Q_{vlo}\ (\$) - Q_{vli}\ (\$)}{A_{wr}\ (ha)} \qquad (7)$$

$$WP_p\ (\$\ ha^{-1}) = \frac{Q_{2v}\ (\$)}{A_{wr}\ (ha)} \qquad (8)$$

$$WP_p\ (\$\ ha^{-1}) = \frac{Q_{3v}\ (\$)}{A_{wr}\ (ha)} \qquad (9)$$

$$WP_p\ (\$\ ha^{-1}) = \frac{Q_{4v}\ (\$)}{A_{wr}\ (ha)} \qquad (10)$$

Where, WP_P ($\$$ ha^{-1})=water productivity by fisheries products per (ha^{-1}) in monetary value; Q_{1v}=Q_{v1o}-Q_{v1i}=net return of cultivable fishes usually expressed in monetary value; Q_{2v} ($\$$)=net return of wild fishes, usually expressed in monetary value; Q_{3v} ($\$$)=net output of snails, usually expressed in monetary value; Q_{4v} ($\$$)=net output of aquatic plants, usually expressed in monetary value; A_{wr}=per hectare area of seasonal floodplain *beels*.

As physical productivity varies among different living aquatic resources, the productivity in terms of monetary value is the only proper measurement to calculate the aggregate WP. The following equations measure the aggregate WP of living aquatic resources (fish, snails and aquatic plants) in values,

$$WP_p\ (\$\ ha^{-1}) = \frac{Q_{v1}\ (\$) + Q_{v2}\ (\$) + Q_{v3}\ (\$) + Q_{v4}\ (\$)}{A_{wr}\ (ha)} \quad (11)$$

Where, WP_p=per hectare WP by living aquatic resources is ($ ha^{-1}); Q_{v1}=net return of culturable fish; Q_{v2}=net return of wild fish; Q_{v3}=net return of snails; Q_{v4}=net return of aquatic plants; A_{wr}=per hectare area of seasonal floodplain *beels*.

That is, productivity is the value of fisheries products per unit surface area of the seasonal floodplain *beels* used for production. It is evident that equation 11 is the suitable one for multi-product outputs. The value of output (Q_v) here can be taken as the summation of the values of the different products derived from the multiple uses of the seasonal floodplain *beels*.

Analyses related to economics have been done based on BD currency (BDT) and US dollar rate was 1 $ USD=69.25 BDT during this study.

3. Results

3.1. Water productivity by fish

Production of wild fish and stocked fish were measured against per hectare waterbody and valued with prevailing market price. Thus WP was calculated in both physical and monetary terms. Production cost of fish culture and interest on operational costs were also considered while measuring net WP by fish. Production monitoring was done at field level during harvesting.

In *beel* Mail 3493 kg (about 34.93 kg/ha) fish fingerlings were stocked. The number of fish fingerlings was 747 kg/ha. The fish species were *Catla catla, Hypophthalmichthys nobilis, Labea rohita, Cirrhinus mrigala and Cyprinus carpio* (Table 1).

Table 1

Stoking ratio of carp fish fingerlings and its prices in *beel* Mail.

Species	Numbers		Weight (kg)		Price	
	Total	Per hectare	Total (kg)	Per hectare	Rate (TK/kg)	Total (TK)
Catla	10018	100	551	5.51	120	66120
Bighead	31980	320	1567	15.67	61.5	96370
Rui	6361	64	528	5.28	110	58080
Mrigal	10889	109	294	2.94	95	27930
Carpio	15361	154	553	5.53	74.4	41170
GT	74609	747	3493	34.93	82.9	289670

(Source: field survey data)

Of *beel* Chandpur, total 1960 kg of carp fish fingerlings (about 9.68 kg/ha) which was average 324.6 numbers per hectare released by some landowners without following any community based fish culture approach. The scientific name of these fish species are *Catla catla, Hypophthalmichthys nobilis, Labea rohita, Cyprinus carpio and Hypophthalmichthyes molitrix* (Table 2).

Table 2

Stoking ratio of carp fish fingerlings and its prices in *beel* Chandpur.

Species	Numbers		Weight (kg)		Price	
	Total	Per hectare	Total (kg)	Per hectare	Rate (TK/kg)	Total (TK)
Catla	9000	44.50	280	1.38	80.00	22400
Bighead	20000	98.80	600	2.96	37.50	22500
Rui	9000	44.50	320	1.58	67.50	21600
Carpio	21000	103.70	600	2.96	62.50	37500
Silver	6700	33.10	160	0.79	37.50	6000
GT	65700	324.60	1960	9.68	57	110000

(Source: field survey data)

In *beel* Mail fish fingerlings of TK 2896 per hectare waterbody were released whereas in *beel* Chandpur only TK 543 per hectare waterbody was spent for fish fingerlings. Other most important production costs of fish culture were harvesting, lease value, fencing costs and netting/labour charges, guard cost and deep tube-well cost of the waterbody. Per hectare production cost of fish culture in *beel* Mail and *beel* Chandpur were TK 7283.17 and TK 1444.58, respectively. And total cost including production cost, other cost and marketing cost were TK 8138.43 and TK 1616.35 (Table 3).

Table 3

Per hectare costs of fish culture in seasonal flooded *beels*.

Items	*Beel* Mail		*Beel* Chandpur	
	Value (TK)	total cost %	Value (TK)	total cost %
Production costs (TK ha^{-1})	7283.17		1444.58	
Lease value	1470.00	18.06	197.60	12.23
Fingerling cost	2896.70	35.59	543.40	33.62
Fencing cost	800.00	9.83	172.90	10.70
Guard cost	100.00	1.23	106.70	6.60
Deep tube-well	0.00	0.00	24.70	1.53
Harvesting/netting charge	2016.00	24.78	399.28	24.70
Others cost (TK ha^{-1})	208.20		35.32	0.00
Interest on operating capital	158.20	1.94	35.32	2.19
Depreciation cost for boats	50.00	0.61	0	0.00
Marketing cost (TK ha^{-1})	647.07		136.45	0.00
Commission and tax	258.07	3.17	108.78	6.73
Transport and refreshment	389.00	4.78	27.67	1.71
Total cost (TK ha^{-1})	8138.43	100.00	1616.35	100.00

(Source: field survey data)

Production of non-stocked fish species from per ha waterbody in *beel* Mail and in *beel* Chandpur were 86.4 kg and 30.78 kg respectively. Gross yields of stoked fishes were 215.5 kg/ha, 33.64 kg/ha in *beel* Mail and *beel* Chandpur. Per hectare net yields of stocked fishes were calculated by the gross yield of harvested carp yields minus weight of fingerlings stocked. Per hectare net yields of stocked fishes were 180.6 kg in *beel* Mail and 24 kg in *beel* Chandpur. Thus per hectare total net production of fishes were 267 kg and 54.8 kg in *beel* Mail and *beel* Chandpur respectively (Table 4).

Table 4

Per hectare yields from fishes in seasonal flooded *beels*.

Particulars	*Beel* Mail		*Beel* Chandpur	
	Unit (kg)	of total (%)	Unit (kg)	of total (%)
Gross yields (kg/ha)				
Stocked fishes	215.50	71.38	33.60	52.17
Non–stocked fishes	86.40	28.62	30.80	47.83
Total	301.90	100.00	64.40	100.00
Net yields (kg/ha)				
Stocked fishes	180.60	67.64	24.00	43.80
Non–stocked fishes	86.40	32.36	30.80	56.20
Total	267.00	100.00	54.80	100.00

(Source: field survey data)

Per hectare gross returns of fishes were valued by multiplying the total amount of gross yields to the prevailing market price. Per hectare net returns of fishes were calculated by deducting the production costs from the gross returns of harvested fish. Per hectare gross returns of fish were TK 10278.8 and TK 2497.78 from the *beel* Mail and *beel* Chandpur respectively. Again for *beel* Mail and *beel* Chandpur per hectare net returns based on production costs were TK 7481.23 and TK 3261.90 and net returns based on all costs were TK 6625.97 and TK 3090.13 (Table 5).

Table 5

Per hectare returns from fishes in seasonal flooded *beels*.

Particulars	*Beel* Mail		*Beel* Chandpur	
	Unit (TK)	of total (%)	Unit (TK)	of total (%)
Gross return (TK/ha)				
Stocked fishes	10278.80	69.62	2497.78	53.07
Non–stocked fishes	4485.60	30.38	2208.70	46.93
Total	14764.40	100.00	4706.48	100.00
Net return (TK/ha)				
Based on production	7481.23	–	3261.90	–
Based on all costs	6625.97	–	3090.13	–

(Source: field survey data)

While WP by living aquatic resources (fishes, snails and APs) are being calculated with kg/ha or TK ha^{-1}, so WP values of per hectare waterbody by fish based on gross fish yield, net fish yield, gross return (based on production costs), and net return [based on all cost (production costs, other costs and marketing costs)] were 301.9 kg, 267 kg, TK 14764.4, TK 7481.23 and TK 6625.97 respectively in *beel* Mail whereas these values were 64.4 kg, 54.8 kg, TK 4706.48, TK 3261.90 and TK 3090.13 in *beel* Chandpur (Tables 4 and 5).

3.2. Water productivity by snail

Productions of snails from per hectare waterbody were 92.8 kg and 85.1 kg in *beel* Mail and *beel* Chandpur respectively. Though snails are not marketed and only used for duck feeding, yields of snails were valued tan alternate feeding price of duck and were found TK 474 and TK 449 for those *beels*.

3.3. Water productivity by AP

Per hectare WP by AP (AP, also called hydrophytic plants or hydrophytes, are plants that have adapted to living in aquatic environments) in terms of kg were estimated 5.73 kg and 19.36 kg in the seasonal floodplain *beel* Mail and *beel* Chandpur respectively. As monetary terms, per hectare WP was estimated TK 61 and TK 202 in *beel* Mail and *beel* Chandpur.

3.4. Aggregated water productivity

According to aquatic and terrestrial environment framework, WP is defined as gross or net production of aquatic resources from unit area of waterbody. Table 6 shows the gross and net WP of different aquatic yields in monetary term from per hectare waterbody of the study *beels* during rainy season.

Table 6

Per hectare aggregated WP from various values of living aquatic resources in *beels*.

Water productivity	*Beel* Mail (TK)	*Beel* Chandpur (TK)
Gross WP (TK/ha)		
Stocked fishes (TK)	10278.78	2497.78
Non–stocked fishes (TK)	4485.60	2208.70
Snails (TK)	474.00	449.00
Aquatic plants (TK)	61.00	202.00
Gross total	15299.40	5357.48
Net WP (TK/ha)		
Based on production costs	8016.23	3912.90
Based on all costs	7160.97	3741.13

(Source: field survey data)

Aggregated WP of the study *beels* were obtained by adding the monetary values of per hectare productions of different living aquatic resources. Per hectare aggregated WP of aquatic values based on gross return were TK 15299.40 and TK 5357.48 for the *beel* Mail and *beel* Chandpur. The contribution of fish, snails and AP were 96.50%, 3.10% and 0.40% to the gross aggregated WP of *beel* Mail and the contributions of fish, snails and AP were 87.85%, 8.38% and 3.77% to the gross aggregated WP in the *beel* Chandpur (Table 6). Whereas net aggregated WP values based on production costs were TK 8016.23 ha^{-1} and TK 3912.90 ha^{-1} at *beel* Mail and *beel* Chandpur. Again these were TK 7160.97 ha^{-1} and TK 3741.13 ha^{-1} based on all costs at the *beel* Mail and *beel* Chandpur.

Therefore, per hectare aggregated WP values were higher in *beel* Mail where community–based forest management was introduced than per hectare aggregated WP values in *beel* Chandpur.

4. Discussions

Information regarding on the water productivity for living aquatic resources in floodplains was very scare in the literature. However, this study first attempted to fill up this knowledge gap through measuring the productivity of water of the floodplain land in terms of fisheries and living aquatic resources based on two *beels* not only in Bangladesh, but also in the worldwide.

Bangladesh is blessed by having the world's largest river delta. The geographic location of the country is in the delta of three river systems, Ganges, Brahmaputra and Meghna. There are so many ponds, *beels*, *haors*, and various water bodies all over the country. The water area is about 4.9 million hectares which is about 34% of the country's total land area. There, about 13 lacks ponds and *dighi* that occupy 3.05 lacks hectare area and 24 000 km long rivers which are of 10.32 lacks hectare[11]. The vast waterbodies of Bangladesh are rich sources of fishes. Inland freshwater provides 260 varieties of fishes and 24 types of shrimps[11]. Thus, fishery is one of the important sub-sectors of Bangladesh economy, which contributes 4.39% to the total GDP and 22.76% to the agricultural GDP in year 2011–2012. Fisheries sector employs about 1.31 million full-time fishermen and 12.5 million part-time fishermen whose number peak is from June to October at flood season[11].

During rainy season (July–September), huge volume of water enters into the country on the way to the Bay of Bengal. At the same time, about 90% of annual rainfall also occurs. This leads to occurrences of flood and submersion of the country's low lands for 4–6 months each year. A number of different habitats occur within the Bangladesh floodplains. These include the river itself, canals and permanent and semi-permanent standing water bodies (*beels* and *haors*). More than half of Bangladesh's 10.2 million hectares of rice land is flooded to the depth of more than 50 cm during the rainy season[12]. According to Master Plan Organization (MPO)[13], the net cultivable area of Bangladesh is 9 562 402 hectares (ha), out of which 6 300 723 ha are floodplains and vulnerable to annual submersion in different depth.

It is observed that the return of *beel* Mail and *beel* Chandpur differs significantly. In *beel* Mail, stocking of per hectare carp fish fingerlings was 34.93 kg and the weight of harvested stocked fishes was 6.17 times than the weight of fish fingerlings released. At *beel* Chandpur, 9.68 kg carp fish fingerlings were stocked in per hectare waterbody and weight of harvested stocked fishes was only 3.5 times than the weight of released fish fingerlings. Another cause of less productivity of fish in *beel* Chandpur was vast water area with ill defined embankment which was difficult to manage and to fence. Therefore, large amount of fishes flew away to the connecting river when flood water increased in height. Again the *beel* was dried up by opening the sluice gate to remove the water for making the *beel* suitable for crop cultivation by the non-participating and owners. This also hampered the optimum growth of the stocked fish in *beel* Chandpur. This improper management was also responsible for lower production of non-stocked fishes in *beel* Chandpur than *beel* Mail. Thus, it reveals that WP by fish in *beel* Chandpur was less from the *beel* Mail due to inappropriate knowledge and training of the fishers about fish culture in these seasonal waterbodies, funding constraint and also due to non supporting attitude of the other beneficiaries of the *beel*. But in *beel* Mail site, waterbody was well managed due to formation of community. Open access was controlled and fish harvesting was done after optimum growth of fishes. Fish culture was possible up to boro season, so the duration of fish culture was longer. Again fishermen got support and training from the concerned authority. So management action for fish culture was better and WP by fish was better in *beel* Mail than *beel* Chandpur.

Again WP by snail in *beel* Mail was also higher due to longer duration of water stay and collection of snail during fish harvesting with net. The average price rate of snails was TK 5.12 kg^{-1} and average production from snail was TK 474.40 ha^{-1} in *beel* Mail whereas in *beel* Chandpur price rate of snails was TK 5.28 kg^{-1} and average production was TK 449.08 ha^{-1}. But the WP by aquatic plants was lower in *beel* Mail than *beel* Chandpur due to restriction of open access to the *beel* during fish culture. The price rate of AP was TK 10.64 kg^{-1} and average production from AP was TK 60.95 ha^{-1} in *beel* Mail whereas in *beel* Chandpur price rate of AP was TK 10.45 kg^{-1} and average production was TK 202.27 ha^{-1}. Snails and AP were collected freely from both the *beels*.

The gross yield of stocked fish from per hectare waterbody was 215.53 kg in *beel* Mail and 33.6 kg in *beel* Chandpur. The WP by cultured fish is similar to the International Fund for Agricultural Development and World Fish Center report[12], where they found yield of stocked fish in seasonal floodplain *beels* of Bangladesh in alternating rice fish culture system ranging from 178 kg/ha–1 559 kg/ha. The production of non-stocked fish, 86.4 kg/ha in *beel* Mail and 30.8 kg/ha in *beel* Chandpur that is also similar with the International Fund for Agricultural Development and World Fish Center report that is 29.54 kg/ha–490.91 kg/ha. Per hectare gross yield was 301.6 kg in *beel* Mail and 64.4 kg in *beel* Chandpur. *Beel* Mail is 4.69 times higher than *beel* Chandpur. The national catch statistics indicate a catch per unit area (CPUA) for Bangladesh floodplains of 60–130 kg/ha per year[14]. Other estimates range from 50 to 400 kg/ha per year[15]. According to Official Development Assistance report, production in range of floodplain was 68–202 kg/ha/year whereas Halls *et al.* reported it was 51–131 kg/ha/year[16,17]. Tapiadon stated that about 43% of approximately 35 million hectares of the floodplains of the region is used for rice culture, with yields averaging from 0.5 to 1.5 ton ha^{-1}/year[14]. The average natural floodplain fish production was estimated between 50 and 100 kg/ha/year. He expected that even if only 10% of the total 35 million hectares of floodplain areas in the region could be developed and utilized for fish culture, this would increase the fish production by at least 5 to 6 million tons per year.

MPO presented near about the same production of floodplain fish that is 50–200 kg/ha/year[18]. They also estimated average production per hectare from deep-water *beels* can be quite high, as 1 819 kg/ha/year. Fishery production in similar tropical regions from rivers has been reported in a range from 100 to 600 kg/ha, whereas floodplain productivity tends to be somewhat higher and in some cases has been reported to be as high as 6 000 kg/ha. Whereas, DoF reported that the fish production from July 2008 to June 2009 in floodplains was on average 310 kg/ha whereas in *beels* it was 693 kg/ha. Haque also stated a production statistics of fishes in different water resources in Bangladesh in which he reported that in *beel* area (11 161 ha), total fish production was 0.53 lakh MT in 1992–1993, *i.e.* 464 kg/ha/year[9]. Whereas in *baor* (ox-bow lake) area (5 488 ha), total fish production in the same year was recorded at only 0.02 lakh MT, *i.e.* 364 kg/ha/year. Flood Action Plan reported that the annual CPUA from rivers inside the Pabna irrigation and rural development project ranged from 191 to 1 631 kg/ha and a total annual number of fish species recorded from low elevation floodplains inside scheme was 30% lower than outside it[19].

In monetary term, per hectare gross return of fishes (stocked and non–stoked fishes) were TK 14 764.4 and TK 4 706.48 for *beel* Mail and *beel* Chandpur, respectively. It is 3.13 times higher in *beel* Mail than *beel* Chandpur. The net return based on production cost is TK 2 995.61 in *beel* Mail and TK 1 053.20 in *beel* Chandpur from stocked fish only. The average rate of price was TK 48.91 and TK 73.08 for *beel* Mail and *beel* Chandpur, respectively. This happened due to high price of fishes in *beel* Chandpur than *beel* Mail. In *beel* Mail, fishes were harvested in October–December when plenty of fishes were available in the market and the price was less. The size of fishes was also small due to early harvest. But in *beel* Chandpur, fish was harvested in March and was getting much more time for growing. On the other hand, this time called dry period and fishes were less in the market and the price was high. Though the market price is low in *beel* Mail, gross return is higher due to more production of stocked fishes (6.41 times more). Therefore, the WP values in *beel* Mail is higher than in *beel* Chandpur. The intervention of community based fish culture is better for more productivity of water.

Bangladesh is placed fourth in inland open water fish production and placed second in fish export around the world. In year 2011–2012, fish production was 32.61 metric ton, out of which 9.57 metric ton was from inland open waterbody. Bangladesh earned TK 47 039 million in the year 2011–2012 by exporting fish and fishery product[11]. Pond fish culture contributes 41% of production with 3.05 million hectares of waterbodies, but floodplain contributes only 21% produced by captureing fisheries with 28.33 million hectares of inland waterbody. Marine waterbodies are contributed by 18% of fish production.

The Bangladesh Aquaculture Development Project Preparation Report (1986), supported Asian Development Bank, stated that by the year 2000, implementation of over 150 flood control projects would be complete and many more would be planned. The report anticipated that by the year 2000, the net negative impact of these projects on the natural fisheries production would be annual declines of 150 000 to 250 000 metric tons. Craig *et al.* also supported that the area under flood control is expected to be 5.74×10^6 ha in 2010 resulting in a loss of 151 300 tons of fishes[15]. He mentioned that flood control, drainage and irrigation schemes obstruct the lateral migrations of rheophilic white fish species and the passive drift of larvae from the main channel to the modified floodplains and cause reductions in CPUA and fish biodiversity.

Ahmad *et al.* estimated that open water fish production declined from 690 000 tons in 1972 to a low of 424 000 tons in 1989[20]. In 1987, the MPO measured a loss of fish production between 30 000 and 45 000 metric tonnes due to a loss of 814 000 ha of floodplains caused by flood control development projects[21]. This report also projected that from 1985 to 2005, another 2 000 000 ha of floodplains would be lost from the open water fisheries production system due to the construction of an increasing number of flood control development projects. This was predicted to cause a further loss of open water capture fisheries production of 73 000 to 108 000 metric tons annually.

Weigelhofer *et al.* indicated that the terrestrialization processes prevail as a result of lowering of the floodplain water level and sediment accumulation[22]. Without any further restoration measures promoting enhanced, surface water exchange, aquatic and semi–aquatic habitats and their rich biodiversity would severely become reduced[23]. Sadeque pointed out that resource use, conflict, improper infrastructure, lack of restocking, indiscriminate pesticide use and over fishing were as the cause of this decline[24]. Ali and Fisher noted that apart from the disruption of the natural cycle of fish migration, reproduction and growth, agricultural expansion and agro–industrial pollution have contributed to this decline estimated to be between 3 and 10 percent per year[25]. Alam and Thomson demonstrated that a host of factors are responsible for the under–utilization of fishing areas, including resources limitation, poor implementation of fisheries laws, the limited spread of fish farming technology, low financial capacities and ineffective production practices[26].

Conflict of interest statement

We declare that we have no conflict of interest.

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Comments

Background

Floodplains lands are an important aquatic ecosystem that supports a wide range of biodiversity and provide indispensable benefits to the people. Habitat values in floodplain river systems are tied to the complex and time–varying aquatic–terrestrial interface which includes wetlands and normally lentic water bodies proximal to the main channel. River channels in such systems have multiple, stage–dependent connections to lakes, sloughs, wetlands and depressions. Such off–channel habitats are important for fish populations because of the survival, feeding and reproduction opportunities they provide.

Research frontiers

Fishes were harvested from October to March in *beel* Mail and February to March in *beel* Chandpur. Data collection was done after fish harvested at landing centre by direct observation. Stocked and non stocked fishes were separated at landing centre and weighted for selling to the wholesale markets. WP measures are expressed by the equations.

Related reports

Few research has been done on this aspects, but not specifically on these two floodplain *Beels* respectively *beel* Mail and *beel* Chandpur.

Innovations and breakthroughs

Information regarding on the WP for living aquatics resources in floodplains very scare in the literature, however, this study was first attempted to fill–up this knowledge gap through measuring the productivity of water of the floodplain land in terms of fisheries and living aquatic resources based on two beels not only in Bangladesh, but also in the worldwide.

Applications

From the literature review, it is found that this study would be an effective tool for managing the aquatic resources friendly biodiversity in the floodplain ecosystems. It will also be used for conservation of various species of fishes.

Peer review

This manuscript is written well with aim to measure the productivity of water on the floodplain land in terms of fisheries and living aquatic resources based on two floodplain *beels* in Bangladesh. Also this study will be useful for further research in Bangladesh and neighboring countries where floods occur every year.

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