Original Research Article

Evaluation of Fisheries Management Techniques in Three Wetlands in Bangladesh

ABSTRACT

Aim: To evaluate the impact of community-based co-management and fisheries management techniques on fisheries production and biodiversity in three large wetlands in Bangladesh.

Study Design: A robust catch assessment approach to measure fisheries production, species composition and biodiversity in large wetlands.

Place and Duration of Study: The study sites are located in three wetlands districts in Bangladesh, namely *Hail-Haor*, *Kangsha-Malijhee* and *Turag-Bangshi* for a period of two years (2010 and 2011) covering MACH and IPAC working area.

Methodology: Species-wise catch and efforts by gear type was monitored through the regular sampling to estimate the annual total catch and fishing effort. Randomly selected samples of the catch by species and effort by gear are recorded for each gear type observed to be operated on the same day. The numbers and weight of all fish species in the catch were recorded. The study also compared results in the last years of MACH initiatives to observe the status of fisheries production (Kg/ha) and biodiversity Index (H').

Results: The study indicated that the 2011 annual fish production (kg/ha) increased by 125 and 271% compared to the baseline survey in 1999 in *Hail-haor* and *Kangsho-Malijhee*, and *Turagh-Bangshi* respectively. The results suggested that *Hail-haor* and *Kangsha-Malijhee* wetlands showed considerably enriched biodiversity over 12 years, whilst, *Turag-Bangshi* showed upwards from 1999 to 2006 and decreased in 2010 and 2011. In 2010, fish production was 393, 322 and 139 kg/ha, and in 2011 fishes production was 370, 556 and 88 kg/ha in *Hail-haor*, *Kangsho-Malijhee* and *Turagh-Bangshi* wetlands, respectively.

Conclusions: The assessment indicated that the overall fish production and biodiversity has been improved due to community-based co-management and this lesson could be replicated widely to sustain wetland resources.

Keywords: Fish production, biodiversity, community-based, impact

1. INTRODUCTION

Bangladesh is the home to numerous rivers, canals, *haors* (deeply flooded low-lying basins), *beels* (deeper depressions in floodplains where in most cases water remains throughout the year), lakes and vast seasonally inundated floodplains [1]. The floodplains of Bangladesh are composed of many types of water bodies, which include some of the world's most important wetlands, harboring hundreds of species of fish, plants and wildlife [2]. The combined deltaic floodplains cover nearly all of the Bangladesh's 147,570 km^2 areas and are formed by a network of the major rivers – the Padma, the Meghna, the Jamuna and the Brahmmaputra. These rivers support rich and diverse fish faunas.

Fish is an essential staple food for the people of Bangladesh, and the fisheries sector plays a vital role in the economy through employment generation, nutrition supply and poverty alleviation [3, 4]. Fish provides 60% of national animal protein consumption [5]. In addition, the fishing provides directly or indirectly employment to nearly 17.1 million people [6]. Further, the fisheries sector contributed 4.4% to the national GDP, 23.4% to the agricultural GDP and 2.0% to foreign exchange earnings through export of fish and fish products in 2012-13 [6]. However, almost two-thirds of the rural households get involved in fishing during the monsoon season. Several studies indicated that about 80% of rural households traditionally catch fish for food or for sale or both [7,8]. Over 70% of households in the floodplains catch fish either for income or food ([9,10]. Floodplains are important sources of fish production. Studies have shown that many miscellaneous small fish species are caught from the seasonal floodplains and lakes by people, which have always be neglected in official statistics, and provide relatively more essential nutrients than the large fish favoured by fish culture programs ([11].

Specifically, floodplains contribute to 20.09% of the total annual fish production, followed by rivers and estuaries (4.72%), *beels* (2.51%), the Sundarban wetlands (0.52%) and Kaptai Lake (0.23%) [5]. The inland open water fisheries of Bangladesh are common property and share two characteristics: it is typically difficult to exclude potential users from gaining access to the resource and each person's use of the resource subtracts from the potential welfare of others. Property rights refer to general recognition that someone can use a resource – "the capacity to call on the collective to stand behind one's claim to a benefit stream" [12]. Seasonally flooded land is mostly privately owned and cultivated, but during the monsoon in moderate-to-deeply flooded lands anyone from the surrounding villages (including the poor) can usually fish, provided this does not damage crops [13]. Over the last two decades, research conducted at different locations around the world has documented many cases of co-management in fisheries [14, 15, 16, 17, 18]. Fisheries experts in Southeast Asia now recognize that without the cooperation of fishers to make laws and regulations work their fishery cannot be managed effectively [19, 20].

Freshwater fishery resources are declining in Bangladesh due to over exploitation, anthropogenic causes and inadequate management. To improve sustainability of these resources in 1998, the Management of Aquatic Ecosystems through Community Husbandry (MACH) initiative was launched in Bangladesh as a response to these socio-natural environmental concerns -, availability of fish, overfishing, fisheries management, impact of fishing on other elements of the environment and conservation. Through the MACH initiative, co-management approaches were accomplished by securing access rights to fisheries in three key wetlands' (*Hail Haor* in the sub-district of Sreemongal and Moulvibazar sadar, the *Kangsha-Malijhee* basin in the sub-district of Sherpur and Jhenaigati and *Turag-Bangshi* in the sub-district Kaliakoir) to design and implement conservation schemes. These study areas are highly prone to flooding, particularly to flash rushes during the wet season (July-August). The MACH initiative -has helped the fishers and resource users to develop resource management organizations (RMOs) to work in a co-management framework with local government and federations of resource users groups (FRUGs) for fisheries resources management [21]. Management committees (RMOs, FRUGs) were formed for each site through the election of members by participants. The RMOs in the wetland site have their own resource management plans and rules. Committees have generally adopted simple conservation-based measures e.g., closed season, closed area, restriction of harmful gears, habitat restoration, reintroduction of indigenous fish species, establishment of small sanctuaries where fishing is not permitted. Members follow a rotational guarding system to prevent poaching of fish from the sanctuaries. The initiative continued until 2005 and co-management organizations worked to secure dry season water, established fish sanctuaries, reduced fishing pressure by exploring alternative income generating activities (AIGAs), promote policy-level coordination, link resource users, and improve local wetland habitats. In 2008, the Integrated Protected Area Co-management (IPAC) initiative began to scale-up natural resource co-management at both at the policy and operational levels. The IPAC initiative was the continuation of the co-management approaches that were developed under the MACH initiative, and operated in some of the same wetlands to meet the needs of co-management arrangements at national, regional, and local levels. Indicators of resource sustainability and recommendation on management interventions are also incorporated. Present study was conducted to establish co-management of three large wetlands, namely *Hail-Haor*, *Kangsha-Malijhee* and *Turag-Bangshi*. The objective of this study is to evaluate the impact of community-based co-management of fisheries production and biodiversity through a robust catch assessment.

2. MATERIALS AND METHODS

2.1 Study Area

The study sites are located in the North-east and North-central regions of Bangladesh (Figure 1). Study sites in the North-east are the intensely flooded areas of Srimongal Upazila of the Moulvibazar district and the Jhinaigati Upazila of the Sherpur district encompassing *Hail Haor* and *Kangsha-Malijhee* wetlands respectively. During the wet season the maximum area of *Hail Haor* is about 13,000 ha, but during the dry season, the area is typically just over 3,000 ha. The *Kangsha-Malijhee* includes the catchments of the upper *Kangsha* and *Malijhee* River system and the wetlands and floodplain have a water area of approximately 8,000 ha during the wet season, which falls to about 900 ha in the dry season [21]. The study sites in the North-central flooded areas of Kaliakoir Upazila (sub-district) of Gajipur district comprised of *Turagh-Bangshi* wetland. The average water area covers about 10,000 ha at full flood, but diminishes to less than 700 ha at the end of the dry season [21]. The study included six sites in the *Hail Haor*, four sites in the *Kangsha-Malijhee* and three sites in the *Turagh-Bangshi* wetlands, and these were also earlier sites of MACH initiative (Table 1).

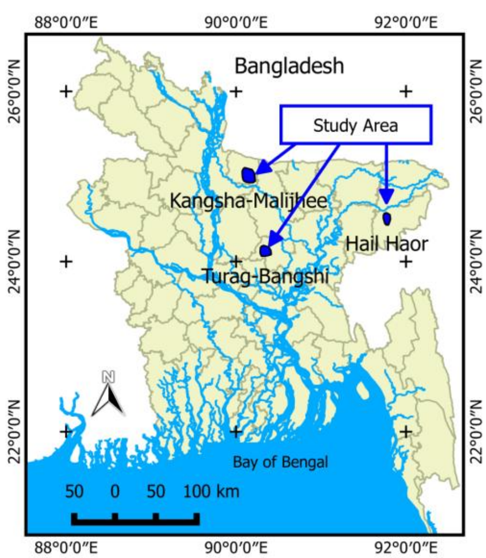

Figure 1 Map of the study area.

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Table 1. Study sites by location, habitat, monitoring area and interventions.

Name of Cluster	Name of wetland	Name of River section/ Beel	Habitat	Monitoring Area (ha)	* Habitat restoration/ re-excavation	*Fish sanctuary	Closed season	Gear restriction
Sylhet Cluster	*Hail haor*	Gopla River Section	River section	41.23	54.1 hectare habitat restoration & sanctuary established	49.6 hectare permanent sanctuary established	Closed season during May-July each year	Small mesh net & mono filament gill nets restricted
		Cheruadubi Beel	Open Beel	30.4				
		Hunamua Beels	Open Beel	8.0				
		Almiberi beel	Open Beel	30.0				
		Balla Beel	Open Beel	159.09				
		Lata River section		7.5				
Central Cluster	*Kangsha-Malijhee*	Kewta Beel	Open Beel	33.04	6.84 hectare habitat restoration & sanctuary established	4.0 hectare permanent sanctuary established		
		Takimari Beel	Open Beel	34.75				
		Malijhee River section	Open Beel	5.0				
		Doli Beel	Open Beel	44.1				
	Turag-Bangshi	Mokash Beel	Open Beel	100	10.92 hectare habitat restoration and sanctuary established	18.0 hectare permanent sanctuary established		
		Mokesh Khal	Canal	2.0				
		Turag River section	River section	14				

* Habitat restoration/re-excavation, and fish sanctuary constructed during MACH project period.

2.2 Data collection

Species-wise catch and efforts by gear type was monitored through the regular sampling to estimate the annual total catch and fishing effort. During the sampling day, a census (complete count) of gears by gear type in operation is undertaken. Randomly selected samples of catch by species and effort by gear are recorded for each gear type observed to be operated on the same day. The numbers and weight of all fish species in the catch were recorded. Fishing activity was observed for four days per month, per site, for 24 months (2010 and 2011). Gear census covered the number and types of gears operating in the study sites. Species-wise catch statistics for each gear type was recorded.

2.3 Data Analysis

The average number of gear units per day was used to estimate total gear-wise fishing effort by month and by year. Mean gear-wise catch rate was used to estimate total catch for that month, as well as for the whole year. Gear-wise, overall species distributions were calculated from annual catch statistics data. Year-wise, as well as overall species distribution, were calculated from catch statistics. Fisheries production was measured by monitoring a sample of individual catch from defined areas that were used to estimate the total catch in each wetland site.

Annual multispecies catch per unit area (CPUA) was employed as a measure of production at each site:

$$CPUA_{s,y} = \frac{\sum_{m=Jan}^{m=Dec} \sum_{g=1}^{n} Catch_{s,y,m,g}}{MaxArea_{s}}$$

Where Catch $_{s.y.m.g}$ is the estimated multispecies catch measured in kg $ha^{-1}y^{-1}$ by site (s), month (m), year (y), and gear type (g).

Fish abundance indicated by multispecies catch per person per day expressed as kg day^{-1} was employed as a measure of resource sustainability:

$$CPD_{s,y} = \frac{Catch_{s,y}}{Annual\ Fishing\ Days_{s,y}}$$

Where Annual Fishing Days $_{s,y}$ is the estimated total number of days spent fishing by the fishers at site *(s)* during *y?*, irrespective of the gear type employed.

The Shannon-Wiener biodiversity Index (H') [22] was used to estimate biodiversity Index (H') and employed for species-wise catch in 2010 and 2011. The index is defined as:

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

Where, s = number of species and p_i = the proportion of individuals from the ith species in the sample.

MACH initiative also collected fish catch monitoring data during 1999 to 2005, using similar methodology from same study sites and estimated annual catch per unit area (CPUA) and biodiversity Index (H') during 1999 to 2005 [21]. The present study also compared results (CPUA) for *Hail Haor*, and similarly compared results (biodiversity Index (H') for *Hail Haor*, *Kangsha-Malijhee* and *Turagh-Bangshi*, in the last years of MACH initiative to observe status of fisheries production (kg/ha) and biodiversity Index (H').

The present study also employed management information of wetlands across a range of locations and habitats. The paper assess literature review of various co-management projects and policies of the government of Bangladesh [10, 13, 23, 24].

3. RESULTS subdivide the results into specific objectives to facilitate understanding

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The estimated fish catch for *Hail Haor*, *Kangsha-Malijhee* and *Turagh-Bangshi* were 107 t, 29 t and 16 t, respectively in 2010 and 102 t, 65 t and 10 t, respectively in 2011 (Figure 2). During 2010, there was substantial variation in catch per unit area (kg/ha) at most sampling sites with overall production of 393 kg/ha in Hail Haor, 322 kg/ha in *Kangsha-Malijhee*, and 331 kg/ha in *Turagh-Bangshi*. However lowest production was found 100 kg/ha in Balla beel in Hail Haor, 123 kg/ha in Mokesh beel in *Kangsha-Malijhee* and 74 kg/ha in *Turagh* river section in Turagh-Bangshi. Two water bodies (*Malijhee beel* and *Mokesh khal*) stand away from this general production trend, and have the highest production of 1,185 and 1,368 kg/ha, respectively.

During 2011, there was considerable variations in fish catch (kg/ha) were also observed at most sampling sites with overall production of 370 kg/ha in *Hail Haor*, 556 kg/ha in *Kangsha-Malijhee* and 88 kg/ha in *Turagh-Bangshi*. However, lowest production was also found 107 kg/ha in Balla beel, 74 kg/ha in Mokesh beel and 80 kg/ha in *Turagh* river section. Correspondingly in the previous year *Malijhee beel* and *Mokesh khal* stood away from this general production value and have the highest production of 1,277 and 1,544 kg/ha, respectively.

Simultaneously fish production (kg/ha) during the MACH intervention of 1999 to 2005 when compared with the current study the fish production (kg/ha) showed increasing trends in *Hail Haor*. Taking account of baseline fish production (kg/ha) during the MACH in 1999 the fish production increased significantly ($p<0.05$) from an annual average of 171 kg/hectare in 1999 to 385kg/hectare by 2011.

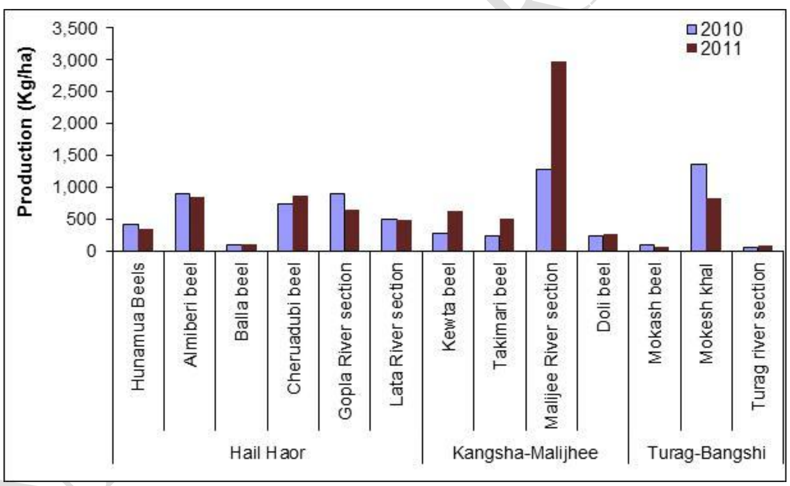

Figure 2. Estimated annual fish production (kg/ha) for *Hail Haor*, *Kangsha-Malijhee* and *Turagh-Bangshi* wetland -sites by year ~~in 2010 and 2011.~~

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An annual variations of average catches (kg) person^{-1} gear^{-1} day^{-1} for different gears in the *Hail Haor*, *Kangsha-Malijhee* and *Turagh-Bangshi* in 2010 and 2011 are presented in Figure 3. Generally, in the *Hail Haor* fish catch person^{-1} day^{-1} was higher compared to the *Kangsha-*

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Malijhee and *Turagh-Bangshi*, possibly due to higher fish abundance and higher numbers of professional fishers.

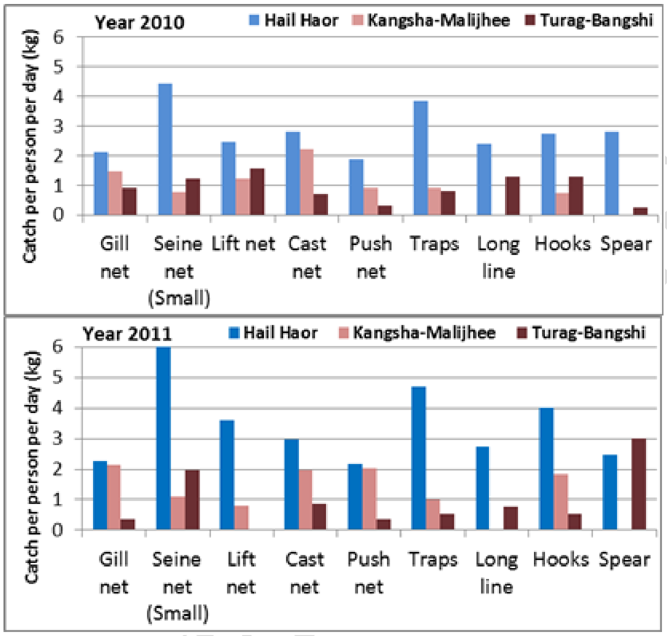

Figure 3. Annual variations of average catch (kg) per person per day by different gears, by year ~~in 2010 and 2011.~~

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In *Hail Haor*, the common species caught by all types of gears were Grass carp (*Ctenopharyngodon idella*-Valenciennes; 7.9%), Rohu labeo (*Labeo rohita*-Ham; 7.6%), Pool barb (*Puntius sophore*-Ham; 6.8%), Bronze feather back (*Notopterus notopterus*-Pallas; 5.8%), and Spotted snakehead (*Channa punctate*-Bloch; 5.3%). Analysis of catch data revealed that twenty main species contributed 77% of the catch by weight in 2011. The annual contribution of the other 65 recorded fish species was 23%. However, the high catches of two exotic species - Common carp (*Cyprinus carpio*-Linnaeus) and Grass carp (*Ctenopharyngodon idella*) are notable, it seemed that Common carps have become naturalized in the *Gopla* River, but the Grass carp is not yet known to breed and reproduce in the wild in Bangladesh [25]. These Grass carps presumably escaped from the rapidly expanding aquaculture enterprises encroaching around the fringes of the *Hail Haor*. These exotic species did not dominate the catch data from MACH period, but floodplain aquaculture areas have expanded rapidly since the start of the MACH initiative in 1998 and co-management institutions have been unable to restrict the trends of expansion.

In the *Kangsha-Malijhee* wetland system the common species caught by all types of gears were Tank goby (*Glossogobius giuris*-Ham), Freshwater shark (*Wallago attu*- Bloch), Spotted snakehead (*Channa punctate*-Bloch), Freshwater garfish (*Xenentodon cancila*-Ham) and Banded gourami (*Colisa fasciatus*-Bloch and Schn), and contributed 13.8%, 11.6%, 10%, 7.9% and 6.6%, respectively. The twenty main fish species contributed to 90% of the total fish catch by weight in 2011. The contribution of the other 42 species was only 10% of the total fish catch by weight.

In the *Turag-Bangshi* wetland system the common species caught by all types of gears were Pool barb (*Puntius sophore*-Ham), Barred spiny eel (*Macrognathus pancalus*-Ham), One-spot barb (*Puntius ticto*-Ham), Indian glassy fish (*Parambassis ranga*-Ham), and Swamp barb (*Puntius chola*-Ham) and contributed 15%, 11.7%, 9.4%, 8.2% and 7.6%, respectively. The twenty main species contributed to 96% of total fish catch by weight in 2011. The contribution of the other 32 species was 4% of the total fish catch by weight. The percentage compositions of the twenty main species in *Hail Haor*, *Kanjsha-Malijhee* and *Turag-Bangshi* wetlands in 2011 were given

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Table 2. Species composition by weight for 20 main species in *Hail haor*, *Kangsha-Malijhee* and *Turag-Bangshi* wetlands in 2011.

IUCN Status Bangladesh	***Hail Haor***		***Kangsha-Malijhee***		***Turag-Bangshi***	
	Name of species	**%**	**Name of species**	**%**	**Name of species**	**%**
Not threatened	*Labeo rohita*	7.58	*Glossogobius giuris*	13.76	*Puntius sophore*	14.99
	Puntius sophore	6.77	*Wallago attu*	11.63	*Macrognathus pancalus*	11.75
	Channa punctatus	5.27	*Channa punctatus*	9.99	*Puntius chola*	7.56
	Colisa fasciatus	4.23	*Xenentodon cancila*	7.88	*Channa punctatus*	5.70
	Wallago attu	3.54	*Colisa fasciatus*	6.57	*Glossogobius giuris*	5.25
	Channa striatus	3.51	*Puntius sophore*	5.88	*Mystus vittatus*	4.87
	Anabas testudineus	2.43	*Macrognathus pancalus*	4.64	*Cirrhinus cirrhosus*	2.69
	Heteropneustes fossilis	2.30	*Heteropneustes fossilis*	3.88	*Gudusias chapra*	2.23
	Clarias batrachus	2.07	*Mystus bleekeri*	3.18	*Channa striatus*	1.92
	Mystus bleekeri	2.00	*Mystus tengara*	2.92	*Tetraodon cutcutia*	0.98
	Xenentodon cancila	1.99	*Lepidocephalus guntea*	2.35	*Heteropneustes fossilis*	0.94
	Mystus tengara	1.76	*Amblypharyngodon mola*	1.33		
	Catla catla	1.52	*Cirrhinus cirrhosus*	1.12		
			Catla catla	1.00		
Vulnerable	*Notopterus notopterus*	5.77	*Nandus nandus*	1.26	*Puntius ticto*	9.39
	Nandus nandus	4.66	*M. aculeatus*	0.97	*Parambassi ranga*	8.15
	M. aculeatus	1.70			*Chanda nama*	4.66
					Cirrhinus reba	0.79
Endangered	*Channa marulius*	4.08	*Ompak pabda*	2.86	*Ompak bimaculatus*	2.59
	Labeo gonius	3.58				
Critically Endangered			*Puntius sarana*	4.58		
Data deficient					*Puntius gelius*	2.57
Exotic species	*Ctenopharyngodon idellus*	7.93	*Ctenopharyngodon idellus*	2.62		
	Cyprinus carpio (communis)	4.26	*Cyprinus carpio (specularis)*	0.98		
Not evaluated					*Macrobrachium birmanicum*	1.50
					Macrobrachium lamarrei	4.69
					Macrobrachium malcolmsonii	2.34

3.4…..

In 2010, a total of 81 fish species were caught in the *Hail Haor*, while 63 fish species were caught in the *Kangsha-Malijhee* and 62 species were caught in *Turagh-Bangshi*. Whilst, in 2011, a total of 85 fish species were caught in the *Hail Haor*, whereas 62 fish species were caught in the *Kangsha-Malijhee* and 52 species were caught in *Turagh-Banglshi*.

In the *Hail Haor*, the number of fish species caught in the monitored sites revealed that the maximum numbers of fish species (64) were found in the *Alniberi-Lalerdoba*, *Balla beel* (59), *Cheruadubi beel* (54), *Gopla* river section (52), *Hunamua beel* (46) and *Lata* river section (41). In the *Kangsha-Malijhee,* the number of species caught in the monitored sites revealed that the greatest numbers of fish species (41) were found in *the Malijhee* river section, followed by *Kewta beel* (35), Doli beel (32) and *Takimari beel* (28). In the *Turagh-Bangshi*, the greatest number of fish species were found in *Mokesh beel* (49), followed by *Mokesh khal* (39) and *Turagh* river section (35).

In 2011, a total of 85, 62 and 52 species of fishes and prawns were recorded in the *Hail Haor*, *Kangsha Malijhee* and *Turagh-Bangshi*, respectively. In the *Hail Haor*, the number of species caught in the monitored sites, revealed that the maximum number of species (62) were found in the *Alniberi-Lalerdoba*, *Balla beel* (57), *Cheruadubi beel* (47), *Gopla* river section (49), *Hunamua beel* (41) and *Lata* river section (34). In the *Kangsha-Malijhee*, the number of species caught in the monitored sites revealed that the maximum number of species (42) were from the *Malijhee* river section, and were followed by *Kewta beel* (34), *Takimari beel* (34) and *Doli beel* (26).

Taking account the results of MACH during 1999 to 2005 the numbers of fish species were found higher in the *Hail Haor* system during 2010-2011, when compared with the MACH impact years. However, numbers of fish species were found lower in the *Kangsha-Malijhee* and the *Turagh-Bangshi* systems during 2010-2011, when compared with the results of MACH initiatives. No significant difference was found between MACH and the present study (ANOVA on number of species, P=0.12). The results from this study clearly show that sustaining fish populations have been established in all three sites and there has been a move away from the traditional top down approach to the promotion of co-management in Bangladesh. Fishes obviously depends on wetland food webs and ecosystem in many different ways. This study shows that the variation of species diversity of six monitored sites appeared to be attributable to varied habitats, and varieties of fish species depending on particular ecological niche of wetland types in the *Hail Haor* ecosystem (Figure 4).

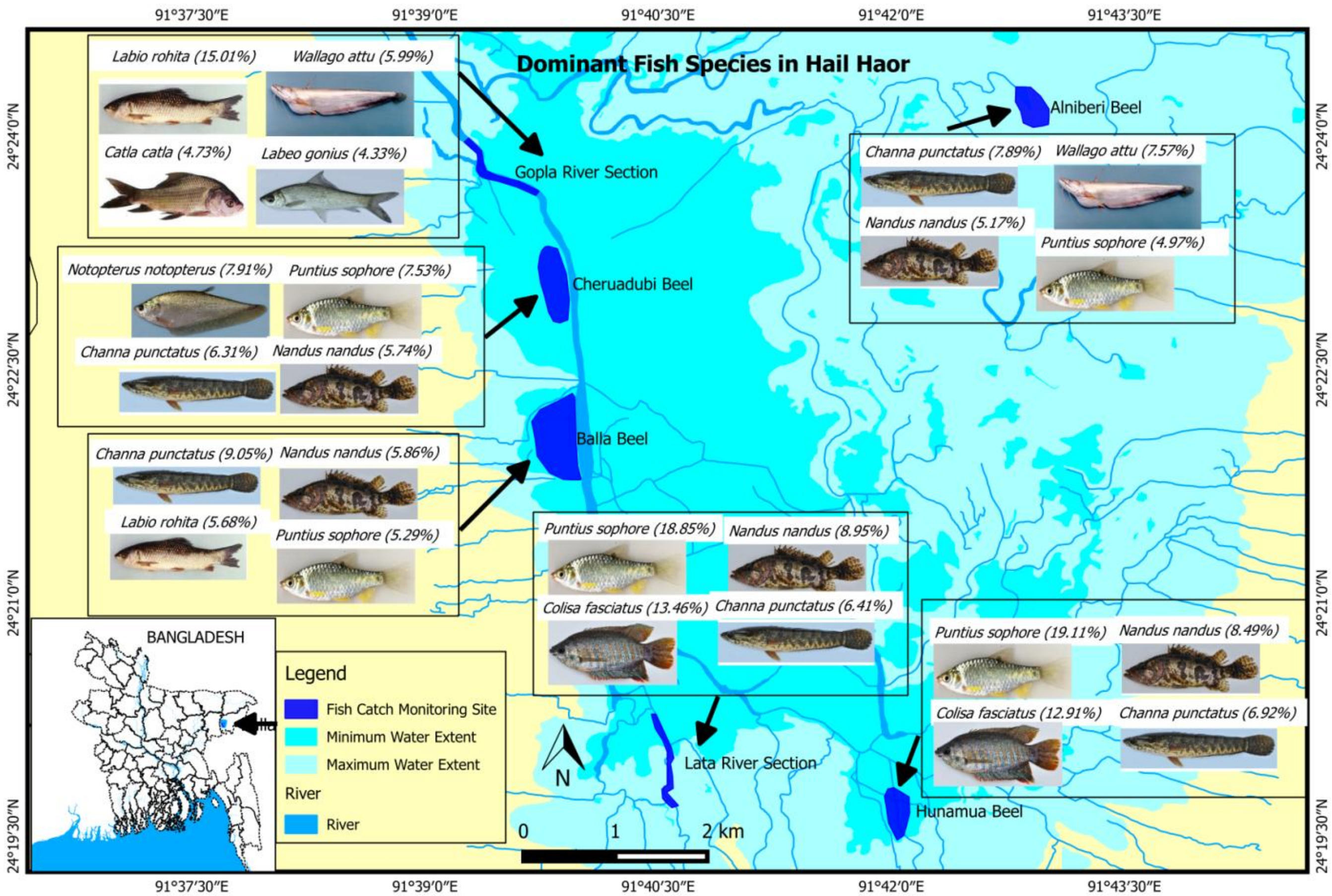

Figure 4. Distribution of four dominant fish species in each of the six monitored sites based on 2011 fish catches in the *Hail Haor*.

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In 2010, the Shannon-Weiner biodiversity index (H') in the Hail Haor ranged from 2.81 to 3.58, whereas in the Kangsha-Malijhee ranged from 2.27 to 2.80 and in the *Turagh-Bangshi* ranged from 2.40 to 2.90. . However in 2011, fish biodiversity ranged from 2.01 to 3.31, 2.13 to 2.66 and 1.60 to 2.56 in the *Hail-Haor* ranged from 2.01 to 3.31, while in the *Kangsha-Malijhee* ranged from 2.13 to 2.66 and in the *Turagh-Bangshi* ranged from 1.60 to 2.56. The comparison of biodiversity index (H') between 2010 and 2011 for 13 sites, based on all species were shown in Figure 5. The index revealed that fish biodiversity has increased in Hail Haor and Kangsha-Malijhee when compared with the MACH years during 1999-2005. However, the fish biodiversity has decreased in the *Turagh-Bangshi* site when compared with the MACH years 1999-2005.

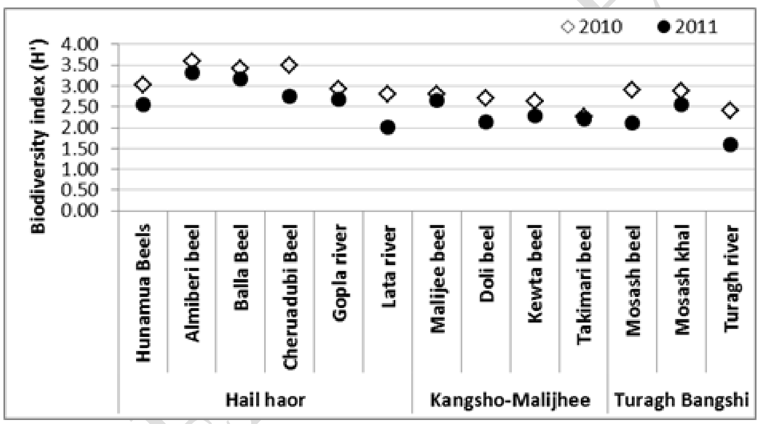

Figure 5. Shannon-Weiner biodiversity index (H) in all monitored wetland sites of Bangladesh in 2010 and 2011.

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The present results on fish production (kg/ha), biodiversity (H') were compared to the MACH intervention results to determine the impacts of management by the co-management organizations. The results suggested that, the *Hail Haor* and the *Kangsha-Malijhee* sites showed considerably improved biological fish diversity (number of species) in 2011 when compared with the baseline and impact period under the MACH initiative in 2005. However, fish biodiversity decreased in the *Turagh-Bangshi* wetlands as compared to the MACH initiatives results. Simultaneously, fish production (kg/ha) increased to 370 kg/ha in the *Hail Haor* (when compared with 322 kg/ha in the last two years of MACH initiative) and to 556 kg/ha in the *Kangsha-Malijhee* (when compared with 307 kg/ha in the last two years of MACH initiative). The results also suggested that, occurrence of exotic fish species in the wild condition of wetlands might be a new challenge in the *Hail Haor*. The present study suggested that harvest of exotic fish species (Grass carp, Common carp, Mirror carp, Bighead carp and Silver carp) from the river within the *Hail Haor* was a considerable component of the open water fish catch. In the *Turagh-Bangshi* system, fish catches decreased to 139 kg/ha in 2010-11 and as low as 88 kg/ha in 2011-12 compared with 278 kg/ha in the last two years of MACH initiative.

3.1 Policy and Management Implications send this paragraph to Discussion

The wetlands are owned by the government of Bangladesh and are termed as *Jalmohals* and access right is subject to obligatory leases as per national policy guidelines [26]. The implementing agencies of the *Jalmohol* Management Policy 2009 is the Ministry of Land (MoL). Besides, the Department of Fisheries, Ministry of Agriculture, Bangladesh Water Development Board, and the Ministry of Environment and Forest were involved in implementing policies and Acts associated with wetland resources [27]. The policy keeps the provision that relevant ministries can have *Jalmohals* (wetlands) in development projects for 6 years with the provision for one term renewal. However, the policy lacks provisions for continuation of access rights of the involved CBOs/RMOs beyond the project and *Jalmohals* would return to MoL, and put on regular leasing systems again [28]. Management system in *Hail-Haor*, *Kangsha-Malijhee* and *Turag-Bangshi* includes resource management organizations (RMOs) as co-management organization. The RMOs were formed by involving all resource users and stakeholders from the adjacent wetland regions. The RMOs work closely with fisheries resources users' groups (FRUGs) and both organizations operate with the support of the Department of Fisheries (DoF). Although several donors supported projects have demonstrated best practices and a number of fish sanctuaries and protected swamp forests have been established in the wetlands, yet the RMOs have no influences over the leased out wetlands (*Jalmohals*). The leasing policy, which has led to severe competition for wetland resources, has reduced the success of co-management.

Wetlands management is not specified separately in water management activities of Bangladesh [29]. Government policy and management activities are associated to more exploitation of wetland resources rather than their development, renewal and sustainable use. Besides, several natural and anthropogenic barriers and constraints have been severely affecting the sustainability of wetland resources [28]. Thus, unsustainable development activities by several relevant government agencies have greatly accelerated the process of degradation of wetlands.

The aims of co-management in the wetland ecosystem is to improve resources management, restoring ecosystems and establishing local fishing rules to sustain harvests of fish. The major interventions with project support taken by local communities are habitat restoration and making fish sanctuaries, re-stocking some lost species, restoring and protecting wetland habitat, introduction of fishing bans in the breeding season and bans on hunting birds.

The key purpose of the fish catch monitoring program was to assess changes in fish catches and fish diversity as indicators of co-management impacts, and to develop evidence-based recommendations for management actions that co-managers could implement to further improve conservation of ecosystems, habitat management, and ensure sustainable use of the fisheries resources of wetlands. The recommendations from several ongoing and completed projects were placed and shared at National Policy Dialogue in order to develop a consensus on the recommendations from which policy can be reformed [28].

Appropriate land and water use policies related to wetlands need to be implemented and awareness of the importance of wetlands at all levels need to be created. All existing fish sanctuaries and swamp forests should continue to be protected by RMOs and FRUGs. The government should enforce rules and limits on fishing by or through leaseholders to allow survival of large fish to reproduce, including closed season and areas. Besides, policy and action plans are urgently needed for the sustainability of wetlands, without which, the future of wetlands in Bangladesh is greatly uncertain.

4. DISCUSSIONsubdivide the discussion in the order of the results

Generally, in the *Malijhee beel* fish catch was found higher due to species richness which coincided with the findings of [30], who obtained higher fish production associated with higher species richness. However, the production per haul in different catchments in the *Chalan beel*, year and months had significant differences due to seasonal variation, water depth and biological condition of fishes [31].

Estimates of the mean CPUA slope coefficient, representing annual rates of change in fish production, were found to vary significantly ($p<0.05$) with habitat type [32]. Besides, study revealed that the fishing capacity was different in some water bodies and the closed season or the sanctuaries were similarly effective so, future research needed to make a harmonized strategy for scientific and sustainable fisheries production [32]. Moreover, study showed that production increased over the duration, due to the community management approach, which encourages participation of fishers, beneficiaries and communities in managing the renewable fishery resources [33].

To address the question: "does community based fisheries management bring sustainable benefits to fishers communities"? Study found that in fish abundance, indicated by annual average daily catch rates by fishers, were increased at 72% of the 64 monitored sites, with an average increase of 17% per year ([34]. Besides, income derived from fishing activities is influenced by several factors, such as catch rates of different species, ownership of gear, family participation in the work process, number of active fishing days and fish price [35]. In Malawi resource user participation in fisheries management or co-management have in some cases promoted sustainable utilization of resources and fishing communities have claimed tangible benefits in their fishing activities [36].

***Fish biodiversity*:** Out of Bangladesh's 260 freshwater species [37]), more than 40% are now threatened with national extinction [38] and may soon follow the path of other wetland fauna and flora. However, study showed that biodiversity index (H') increased in the river Titas (G-G part) from 1997-2002 due to the community management approach [33]. Disconnecting the river channel from its floodplain has obvious negative impacts on biodiversity [39,40]. In addition, study showed that, the *Turagh-Bangshi* site has been seriously affected by industrial pollution during the last decade and species diversity and numbers of fish have dramatically dropped there [41]. The resource users were empowered with a collective effort to build institutions and implement sustainable use practices resulting in wetland resilience of the resources [42].

Pollution from the surrounding industrial establishments has adversely impacted the fishery in the *Turagh-Bangshi* wetland [41]. Here water quality problems that arose with the extensive growth of textile related industries during the MACH period have continued to affect adversely the wetlands' fish biodiversity and catches [43]. Nonetheless integrated and co-management works to negotiate and conserve cleaner and healthy natural fish production systems and adoption of the mandatory effluent treatment plants by the industries are yet to bear fruit.

Inland open water fishery resource system holds multiple stakeholders in its utilization and management, and fishers often report that fish and other aquatic resources have declined hence present analysis provide means to reverse this trend by helping communities to adopt co-management, which is vital to manage fishery resources sustainably. Most recently, the dynamism inherent in the co-management process has been highlighted in relation to knowledge generation, social learning, and adaptation for transformative changes [44]. Attention has been focused on the appropriateness and productiveness of interventions in terms of piloting and nurturing resilience in social-ecological systems [45,46]. Although this paper identifies impacts of co-management on fisheries and biodiversity, concerted effort is required to undertake systematic and comparative analysis of the fisheries co-management process across various contexts and ecosystems.

The study has demonstrated that it is possible to conserve biodiversity, enhance productivity of wetlands in Bangladesh, and thereby enhance livelihoods of poor wetland users. Community-based co-management system should continue in the long term through the resource management organizations and this lesson could be replicated widely to sustain wetland resources. Well-managed capture fisheries in freshwater wetlands are diverse and inherently resilient to environmental variability and drifts including climate changes; hence these need priority conservation initiatives. However, policy, create more sanctuary, coordination between Fisheries Department and Land Ministry and effective action plans are needed for the sustainability of wetlands in Bangladesh.

COMPETING INTERESTS DISCLAIMER:

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Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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