Community-based fisheries management approach adopted in Bangladesh

ABSTRACT

Aims: To promote the sustainable use of inland fisheries resources by empowering communities to manage their own resources.

Study Design: An investigation in the impact of the nationwide Community Based Fisheries Management (CBFM) Project to determine whether or not the Project was successful with respect to the management of floodplain-river fishery resources in Bangladesh.

Place and Duration of Study: The study comprised community managed fisheries (sites) located in five different inland water habitat types in Bangladesh for the period 1997-2005.

Methodology: The assessment employed species-wise catch and gear-wise effort data sampled bi-monthly under the Project's catch assessment survey (CAS). Using quantitative indicators of fish production, abundance and biodiversity, the performance of community managed fisheries at up to 86 sites across the country representing a variety of different aquatic habitat was compared with that of fisheries managed under the existing government-driven regime using contingency table analysis and ANOVA.

Results: Production was found to have increased significantly through time at CBFM sites but not significantly more than at the control sites. However, annual changes in fish abundance were significantly higher at CBFM compared to control sites corresponding to either sustain or significant increases in fish abundance depending upon the choice of the abundance index. In contrast, fish abundance at control sites, indicated by catch rate estimates, and was found to have decreased significantly through time. Changes in biodiversity were also found to be both positive at CBFM sites and significantly greater than control sites. Changes in fish abundance and fishing intensity explained much (60%) of the variation in fish production. Less (up to a maximum of 24%) of the total variation in the fish abundance and biodiversity indicators could be explained by the type of management although the presence or absence of closed seasons was significant in both cases. Fish sanctuaries had no detectable effects on management performance although they may have been too small to produce any detectable effects. The CBFM appeared to have little effect in controlling fishing effort and gear type use.

Conclusion: Community-based fisheries management appears to perform significantly better than the existing management regime in Bangladesh. Existing information sharing networks could support experimentation and learning under future initiatives.

Keywords: Community-based management; co-management; floodplain; biodiversity, abundance, adaptive management.

1. INTRODUCTION

The fisheries sector of Bangladesh contributed 3.61% to national GDP, 24.41% to agricultural GDP in 2015-2016 (DoF 2017). The floodplain-river fisheries of Bangladesh support the livelihoods of millions of poor people but landings and species diversity are believed to be declining as a result of high rates of exploitation and habitat degradation (Halls and Mustafa 2017). The significant decline in fish production over the last 20 years can also be attributed to the current access right system and abundance of proper contributed to overfishing, deforestation of swamp forest and restricted migration of fish during spawning season (Mustafa et al 2017). Inland fisheries under competitive leasing have intermediary managers in the form of "leaseholders" local elites who include fisher leaders, money lenders, landowners, politicians and professional *jalmohal* managers (Thompson 2004). Until recently, the government's practice of short term leasing of small waterbodies or *jalmohals*, alongside a combination of ineffectively implemented technical management interventions (gear bans, minimum landing sizes) set out in fisheries legislation had in the past, provided little incentive for leaseholders to harvest aquatic resources in a sustainable manner and often acted as an obstacle to access by poorer members of the community (Craig *et al.* 2004). In 1995 Government declared "free access to open waterbodies” in order to remove difficulties faced by fisher groups. However, this declaration made open water fisheries management more difficult, as local muscle men took advantage of the open access by excluding poor people from the resources thus, unlimited access for fishing was established (Firoz et al 2016).

The Community Based Fisheries Management (CBFM) Project, funded by the Ford Foundation (1994-1999) and the UK Government’s Department for International Development (2002-2006), aimed to promote the sustainable use of, and equitable distribution of benefits from, inland fisheries resources by empowering communities to manage their own resources. The project was implemented by the WorldFish and the Government of Bangladesh’s Department of Fisheries (DoF) with the support of 11 Non-Governmental Organizations (NGOs). By 2005 the Project had facilitated the establishment of 120 community-based organizations (CBOs) located in regions throughout Bangladesh representing more than 23,000 poor fishing households (Figure 1). Each CBO was responsible for the management of a defined area of fish habitat which included a variety of different depressions or *beels* on the floodplain forming perennial or seasonal lakes, categorized as closed beel, floodplain beel, haor beel or open beel, as well as sections of river channel. The CBOs were encouraged to implement several management interventions, typically in combination, to help manage their fishery resources in a sustainable manner. The main management interventions were stocking with fingerlings, a ban on destructive fishing practices (gear bans), a closed season during spawning between May and July, and harvest reserves of varying size. With support from the WorldFish and facilitating NGOs, the CBOs were also encouraged to monitor and help evaluate the outcome of their management interventions.

Following the completion of the Project in May 2006, this paper reports the outcome of a quantitative assessment designed to determine whether or not the Project was successful with respect to the management of floodplain-river fishery resources in Bangladesh. It also aims to report effective management interventions and important lessons that might help inform the design of future co- or community-based fisheries management initiatives and programmes both in Bangladesh and elsewhere.

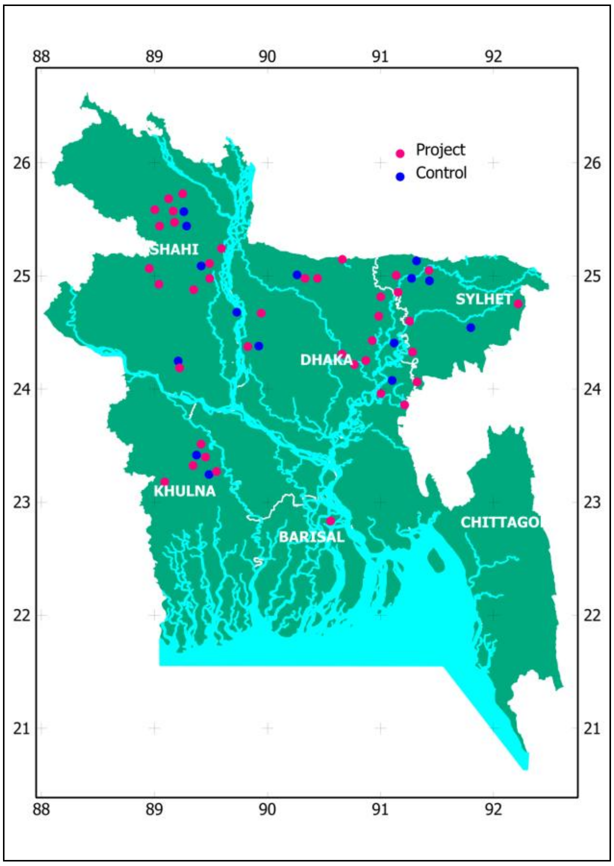

Figure 1 Location of monitored CBFM and control sites in Bangladesh

2. MATERIALS AND METHODS

2.1. Data

The assessment employed species-wise catch and gear-wise effort data sampled bi-monthly under the Project's catch assessment survey (CAS) between 1997 and 2005 from a maximum of 107 of the total 120 project sites (13 sites were not monitored) divided unequally between those under CBFM and unmanaged control sites (Table 1). Monitoring of control sites did not begin until 2002 and the majority of sites were located in the North and Northwest of the country (Figure 1). Because the catch assessment survey (CAS) performance indicators and explanatory variables were calculated for the split year June-May to maximise the number of study observations.

Table 1 Number of monitored CBFM and control sites by habitat type and year. CB- Closed beel; FPB- Floodplain beel; HB- haor beel; OB-Open beel; R – River section.

	CBFM sites					Control sites					Total sites
Split year	CB	FPB	HB	OB	R	CB	FPB	HB	OB	R	
1997-1998	2	2		2	10						16
1998-1999	5	2		2	10						19
1999-2000	4	2		2	9						17
2000-2001	2	2		2	8						14
2001-2002	2	2		2	7						13
2002-2003	9	23	6	20	16	1	4	4	4	6	93
2003-2004	12	24	6	27	19	1	4	4	4	6	107
2004-2005	12	23	6	22	20	2	4	4	4	6	103
2005-2006	11	22	7	27	19	2	4	4	4	6	106

Performance Indicators & Explanatory Variables

Management performance was quantified using indicators of production and resource sustainability. Where appropriate, differences in scale among sites were accounted for by standardizing the indicator by the mean maximum (flooded) area of the site ($MaxArea_s$) observed during the project duration.

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

$$CPUA_{s,y} = \frac{\sum_{m=June}^{m=May} \sum_{g=1}^{n} Catch_{s,y,m,g}}{MaxArea_s} \qquad \text{Equation 1}$$

Where $Catch_{s,y,m,g}$ is the estimated multispecies catch landed by gear type g, during month m and year y at site s measured in kg ha^{-1} y^{-1}.

Production resulting from stocking activities was excluded from this performance indicator although the presence or absence of stocking (STOCKED) was employed as an explanatory variable (see below). The bio-economic performance of different stocking strategies pursued under the CBFM project is examined in detail by Halls *et al.* (2007).

Fish abundance indicated by multispecies catch per fisher per day or 'catch per day' (CPD) expressed as kg day^{-1} was employed as a measure of resource sustainability:

$$CPD_{s,y} = \frac{Catch_{s,y}}{Annual\ FishingDays_{s,y}} \qquad \text{Equation 2}$$

Where $Annual\ FishingDays_{s,y}$ is the estimated total number of days spent fishing by the fishers at site *s* during year *y*, irrespective of the gear type employed.

One of the fundamental assumptions of the catch per fisher per day (CPD) indicator of fish abundance is that the effective fishing power of fishers and their gear (the *fishing unit*) remains constant with time. This assumption was examined by testing for significant changes in a fishing power index (FPI) for net fishers (Equation 3) through time. The FPI was estimated only for August and September to minimise any seasonal (hydrological) effects on the indicator. Gillnet fishing activity is greatest during this period corresponding to floodplain inundation, but gillnet efficiency is unlikely to change significantly.

$$FPI_{i,s,y} = \frac{NetArea_{i,s,y} * Hours_{i,s,y}}{NF_{i,s,y}} \qquad \text{Equation 3}$$

Where $NetArea_{i,s,y}$ is the area of *i*th net sampled at site *s*, in year *y*, $Hours_{i,s,y}$ is the fishing hours and $NF_{i,s,y}$ is the number of fishers operating the *i*th net.

Because of the fundamental importance of sustaining or improving fish abundance as a management objective, an alternative indicator of fish abundance that accounts for any changes in fishing power was also employed based upon observations of gillnet catch per unit effort (GNCPUE) estimates made between August and September (Equation 4):

$$GNCPUE_{i,s,y} = \frac{Catch_{8-9,i,s,y}}{NetArea_{8-9,i,s,y} . Hours_{8-9,i,s,y}} .1000 \qquad \text{Equation 4}$$

Where $GNCPUE_{i,s,y}$ is the catch rate of the *i*th gillnet sampled at site *s* between August (month 8) and September (month 9) of year *y*. The ratio was multiplied by 1000 because units (kg m^{-2} hr^{-1}) were typically very small.

Two measures of fishing effort were employed as additional (indirect) indicators of the sustainability of the fisheries. The first; annual days fished per unit area (DPUA), provided an overall measure of fishing effort (Equation 5).

$$DPUA_{s,y} = \frac{Annual\ \ Fishing\,Days_{s,y}}{MaxArea_{s}} \qquad \text{Equation 5}$$

The second; destructive fishing effort ratio (DFER), provided an estimate of the total annual fishing effort measured in hours with (predefined) destructive gear type (*dg* =1 to *n*) as a proportion of the total annual fishing effort with any type of gear, *g* (Equation 6).

$$DFER_{s,y} = \frac{\sum_{dg=1}^{n} \sum_{m=June}^{m=May} Fishing\ hours_{s,y,m,dg}}{\sum_{g=1}^{n} \sum_{m=June}^{m=May} Fishing\ hours_{s,y,m,g}} \qquad \text{Equation 6}$$

The predefined destructive gear types included monofilament gillnets, small-mesh or fine-mesh seine nets, small mesh set bag net, fencing and dewatering.

Biodiversity, estimated using the Shannon-Weiner biodiversity Index (H') (Shannon, 1948) provided a further indicator of the sustainability of the fisheries from a conservation perspective (Equation 7).

$$H' = -\sum_{j} p_j (\ln p_j) \qquad \text{Equation 7}$$

Where p_j is the proportion of the total biomass arising from the jth species. Here p_j was indicated by the average gillnet catch rate for species j between August and September at site s, during year y (Equation 8):

$$\overline{GNCPUE}_{j,s,y} = \frac{\sum_{i}^{n} GNCPUE_{j,i,s,y}}{n} \qquad \text{Equation 8}$$

Where,

$$GNCPUE_{j,i,s,y} = \frac{Catch_{8-9,j,i,s,y}}{NetArea_{8-9,i,s,y} . Hours_{8-9,i,s,y}} .1000 \qquad \text{Equation 9}$$

2.2 Explanatory Variables

Thirteen explanatory variables hypothesised to affect management performance were identified describing natural variation among sites, management interventions, management support, rule enforcement capacity, and institutional arrangements (Table 2).

2.3 Transformations and Missing Data

Estimates of CPUA, CPD, GNCPUE, and DPUA were loge transformed and estimates of DFER square-root transformed to meet the normality assumptions of the statistical tests employed (see below).

For a variety of different logistical reasons, the CAS was not undertaken every month of the year at some sites. These site-year combinations were not included in the analysis of annual performance indicators (CPUA, CPD, DPUA, and DFER) that were calculated by summing estimates over each calendar month.

Data relating to *katha* (brushpile) fishing activities were missing for a large proportion of site, month and year combinations. Catch and effort data for this gear type was therefore omitted from the estimation of the performance indicators and explanatory variables.

2.4 Analytical Procedure

The impact of fisheries projects or programmes is typically quantified by testing for significant temporal changes in mean estimates of performance indicators at project sites compared to control sites. This type of approach was made difficult here because monitoring of control sites did not begin until six years after the start of the CBFM Project in 2002 effectively creating 'missing cells' in the sampling design. Excluding those CBFM sites that were monitored during these first six years (and beyond) would significantly reduce the dataset and could potentially exclude important historical trends. Including the missing cells is possible by employing a 'Type IV sum of squares' model, however, the interpretation of the results of such models is notoriously difficult and often unreliable (see http://www.statsoft.com/textbook/stglm.html for further details).

To address this issue, the trend (average annual change) in each performance indicator was first estimated for each site using the general linear model (GLM) with SPSS v 11.5 where the performance indicator formed the dependent variable and time (year) was treated as the covariate. The slope coefficient (*b*) of the linear (regression) model provided an estimate of the magnitude of the performance indicator trend and whether it was upward (positive slope value) or downward (negative slope value). Only sites with at least three years of observations were included.

The majority of sites were monitored for three or four years following the start of the second phase of the Project (CBFM2) in 2002. Detecting significant ($p<0.05$) trends within such short time series is difficult because there are few degrees of freedom.

Table 2 Details of hypothesized explanatory variables for each dependent variable.

				Dependent variables					
Explanatory variable category	**Explanatory variable**	**Description**	**Units/coding**	**CPUA**	**CPD**	**GNCPUE**	**DPUA**	**DFER**	**H'**
Natural variation	REGION	Geographic location of site	East (E); North (N); Northwest (NW); Southwest (SW)	√	√	√	√	√	√
	HABITAT	Habitat type	Closed beel (CB); Floodplain beel (FPB); Haor beel (Haor b); Open beel (OB); River (R).	√	√	√	√	√	√
Management interventions	STOCKED	Water body stocked?	Yes (Y); No (N)	√	√	√	√	√	√
	CLOSED	Closed season/gearbans?*	Yes (Y); No (N)	√	√	√	√	√	√
	RESERVE	Harvest reserves present?	Yes (Y); No (N)	√	√	√	√	√	√
	RESPROP	Reserve area : maximum site area	Ratio	√	√	√	√	√	√
Response to management	CPD	See Equation2	kg day^{-1}	√					√
	GNCPUE	See Equation4	kg m^{-2} hr^{-1}	√					√
	DPUA	See Equation5	days ha^{-1}	√	√	√			√
	DFER	See Equation6	Ratio	√	√	√			√
Management support	NGO	NGO name	Banchte Shekha; BRAC; Caritas; CNRS; CRED; ERA; Proshika; SUJON	√	√	√	√	√	√
Rule enforcement capacity	MAXAREA	Average maximum flooded area of site	hectares	√	√	√	√	√	√
Institutional arrangements	JALMOHOL	Resource ownership regime	*Jalmohol* (1); *Jalmohol* but no fee(2); Private ownership (3)	√	√	√	√	√	√

*Gearbans and closed seasons were applied together at almost all CBFM sites and therefore their individual effects could not be tested.

Therefore, 2 x 2 contingency tables were first used to test the null hypothesis that the frequency of observed upward and downward trends in the performance indicators were independent of the management regime (CBFM or control) i.e. the CBFM has no effect on management performance.

To help interpret the results of these tests, further chi-square tests were performed on both CBFM and control sites independently to test whether the relative frequency of upward and downward trends in each performance indicator would be expected by chance. For this purpose, it was hypothesised that the expected frequencies of upward and downward trends would be equal if the CBFM (or control) had no effect. Both sets of tests were repeated for only those trends that were found to be significant.

As a means of providing an overall indicator of management performance an average 'Site score' ($\overline{Score_s}$) was also estimated for each site, *s* (Equation 10) using score values assigned for either upward or downward trends in each of performance indicator, *i* according to Table 3 giving a maximum and minimum attainable site score range of 1 to -1, respectively.

$$\overline{Score_s} = \frac{\sum_{i}^{n} Score_{i,s}}{n_s} \qquad \text{Equation 10}$$

Where n_s is the number of indicators scored at site *s.*

Table 3 Score assigned to observed trends in each performance indicator

	Score$_i$	
Indicator	**Upward Trend**	**Downward Trend**
CPUA	+1	-1
CPD	+1	-1
GNCPUE	+1	-1
DPUA	-1	+1
DFER	-1	+1
H'	+1	-1

Significant differences in mean site score $\overline{Score_s}$ between CBFM and control sites were tested for using GLM. The effects of fixed factors: geographic location (REGION); habitat type (HABITAT); NGO; resource ownership regime (JALMAHOL) and the covariate: waterbody sizes (MAXAREA) on mean site scores were also tested.

In addition, significant differences in the mean slope coefficient (*b*) value of each performance indicator for CBFM and control sites was tested for using ANOVA (GLM) after accounting for region and habitat type. Significant differences in mean slope coefficient values were interpreted as a 'management effect' rather than an environmental effect during the six-year period prior to the start of monitoring at control sites. No significant (p>0.05) trends in river hydrology, indicated by annual estimates of maximum water height in the main river channels (Padma, Meghna and Brahmaputra), were detected during the Project period, or before or after the monitoring of control sites suggesting that this is not an unreasonable assumption. Two-tailed Student *t*-tests where used to determine if the mean slope coefficient estimates for each performance indicator were significantly different from zero for both CBFM and control sites. For $\log_e$ transformed indicators (CPUA; CPD; GNCPUE and DPUA) the mean slope coefficient estimates were used to provide estimates of percentage annual change in each indicator after back-transforming the mean slope estimate. The square-root transformed DFER indicator was excluded from the analysis because, unlike the indicators estimated using log-transformed variables, the (back-transformed) regression model slope coefficients estimated using square-root transformed data cannot be interpreted meaningfully.

Changes in fishing power through time were examined by plotting $\log_e$ transformed estimates of mean FPI against year. Student's *t*-test was then used to test whether the mean FPI slope coefficient was significantly different from zero for each habitat category.

Finally, the GLM was used to identify explanatory variables that were significant in determining site slope coefficient estimates for each performance indicator using data combined from both CBFM and control sites. Hypothesised explanatory variables were: Site slope coefficient estimates for CPD (cpdb), GNCPUE (cpueb), DPUA (dpuab), and DFER (dferb); habitat type (HABITAT); geographic location (REGION); NGO; presence/absence of harvest reserves and closed seasons (RESERVE and CLOSED respectively); resource ownership regime (JALMOHOL); relative reserve size (RESPROP) and water body size (MAXAREA).

3. RESULTS

For each habitat type, the average fishing power index (FPI) slope coefficient was positive (upward through time) but not significantly different from zero at the 5% level, indicating (on average) no significant change in fishing power with time for any habitat type. Catch per day (CPD) was therefore likely to have provided an unbiased indicator of fish abundance.

3.1 Trends in performance indicators

Considering all trends, irrespective of their individual statistical significance, the presence or absence of the CBFM had a significant effect on the relative frequency of upward and downward trends in CPUA, CPD, GNCPUE and H' (Table 4). Trends in DFER and DPUA were found to be independent of management type. These conclusions remained unchanged for those indicators exhibiting significant trends that could be tested.

H_0: The trend (upward or downward) in the performance indicator is independent of the management regime (CBFM or control).
H_A: The trend (upward or downward) in the performance indicator depends upon the management regime (CBFM or control)

The relative frequencies of the upward and downward trends indicated that the CBFM activities have significantly ($p<0.01$) benefited production (CPUA), fish abundance (CPD) and biodiversity (H') at the majority (70-80%) of CBFM sites (Table 5). If only significant CBFM site trends are considered, the probability that this is a false conclusion was less than 13%. Considering only the significant trends, the proportion of upward trends increased to approximately 90% for the three indicators.

Table 4 Estimates of *p* for the chi-square analysis to test the effect of the CBFM on management performance indicators. NA - Estimate not available.

Indicator	*p* (All trends)	*p* (Significant trends only)
CPUA	<0.01	NA[1]
CPD	0.01	NA[2]
GNCPUE	0.02	0.01
DFER	0.09	0.10
DPUA	0.82	0.35
H'	0.02	NA[1]

NA[1] Estimate is biased because 75% of expected frequencies were less than 5 (Zar, 1984).
NA[2] No significant trends for control sites.

Nearly 60% of CBFM sites exhibited downward trends in fish abundance during August and September, indicated by effort standardized gillnet catch rates during the period (GNCPUE). However, these frequencies could be expected by chance. Fishing intensity (DPUA) and destructive fishing practices (DFER) both declined at more CBFM sites than they increased at but these frequencies could also be expected by chance (Table 5). At control sites, downward trends in CPUA, CPD and H' were more frequent than upward trends but the relative frequencies could also be expected by chance (Table 5). The number of downward trends in GNCPUE would not, however be expected by chance for all, and only significant, trends, indicating significant declines in the abundance of fish during August and September at control sites.

Table 5. Summary of the trends in the performance indicators.

		CPUA trend	CPD Trend	GNCPUE Trend	DFER Trend	DPUA Trend	H' Trend
		ALL SITES (CBFM AND CONTROL)					
All trends	Frequency Upward	55	52	32	40	38	54
	Frequency Downward	25	28	54	40	42	31
	% Upward	69	65	37	50	48	64
	Chi-square (p)	<0.01	<0.01	0.02	1.00	0.65	0.01
Significant Trends Only	Frequency Upward	11	11	17	4	4	8
	Frequency Downward	2	1	34	4	3	2
	% Upward	85	92	33	50	57	80
	Chi-square (p)	0.08	0.04	0.09	1.00	0.79	0.18
		CBFM SITES ONLY					
All trends	Frequency Upward	49	46	30	29	30	48
	Frequency Downward	15	18	40	35	34	21
	% Upward	77	72	43	45	47	70
	Chi-square (p)	<0.01	<0.01	0.23	0.45	0.62	<0.01
Significant Trends Only	Frequency Upward	10	11	17	2	3	7
	Frequency Downward	1	1	23	4	3	1
	% Upward	91	92	43	33	50	88
	Chi-square (p)	0.06	0.04	0.50	0.56	1.00	0.13
		CONTROL SITES ONLY					
All trends	Frequency Upward	6	6	2	11	8	6
	Frequency Downward	10	10	14	5	8	10
	% Upward	38	38	13	69	50	38
	Chi-square (p)	0.32	0.32	<0.01	0.13	1.00	0.32
Significant Trends Only	Frequency Upward	1	NA	0	2	1	1
	Frequency Downward	1	NA	11	0	0	1
	% Upward	50	NA	0	100	100	50
	Chi-square (p)	1.00	NA	0.02	0.32	0.48	1.00

3.2 Site Scores

Mean site score was found to vary significantly among habitat type and between CBFM and control sites. Significant differences in mean site score between CBFM and control sites were detected for closed beel ($p=0.03$, $1-\beta=0.60$, d.f.=9), open beel ($p<0.01$, $1-\beta=0.86$, d.f.=25) and river habitat ($p<0.01$, $1-\beta=0.98$, d.f.=23) (Figure 2). For CBFM sites only, site score varied among habitat type but not significantly ($p=0.64$; $1-\beta=0.2$, d.f.=76). No significant differences in site score were detected among geographic location (REGION) ($p=0.17$, $1-\beta=0.43$, d.f.=77), site size (MAXAREA), ($p=0.35$, $1-\beta=0.15$, d.f.=79), the NGO facilitating the site management ($p=0.18$, $1-\beta=0.56$, d.f.=74) or the resource ownership regime (JALMOHOL) ($p=0.60$, $1-\beta=0.13$, d.f.=74).

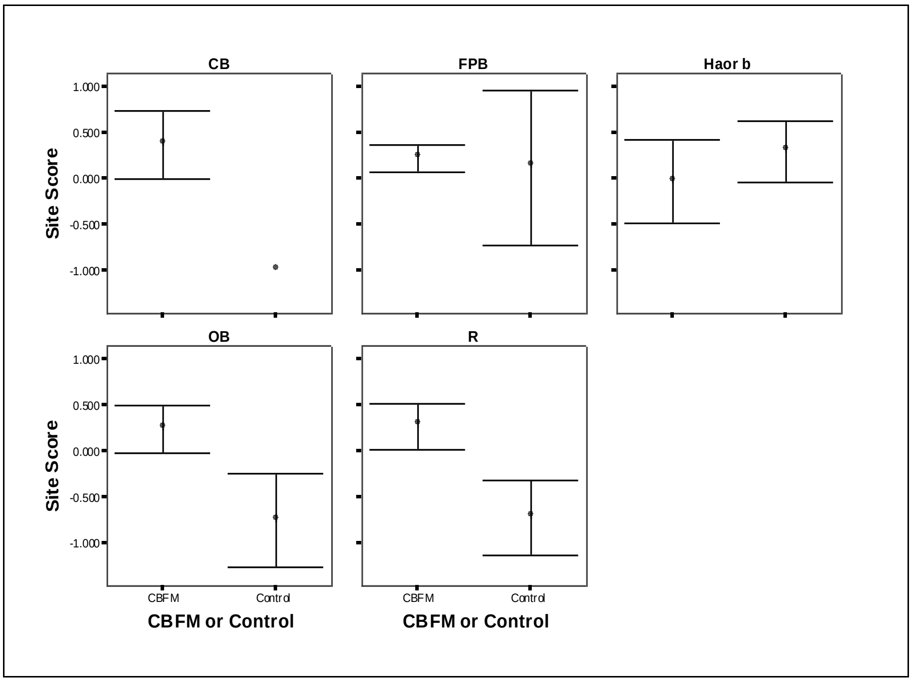

Figure 2 Mean site score with 95% CI for CBFM and control sites by habitat type. CB- Closed beel; FPB- Floodplain beel; Haor b – Hoar beel; OB – Open beel; R – River.

3.3 Mean slope coefficients

Estimates of the mean CPUA slope coefficient (cpuab), representing annual rates of change in fish production, were found to vary significantly ($p<0.05$) with habitat type, but not between CBFM and control sites suggesting that the CBFM has had no significant detectable effect on CPUA (Figure 3). However, estimates of the mean slope coefficient for CBFM sites were greater than zero for all habitat except haor beel, and significantly greater than zero ($p<0.05$) for closed and floodplain beel, and river habitat (Figure 3) indicating increasing production through time in these habitats. Average increases in CPUA ranged from approximately 20% to 30% per year (Table 6). Estimates of the mean slope coefficient for control sites were not significantly different from zero for all habitats tested indicating no significant change in fish production (CPUA) at control sites (Table 7 and Figure 3).

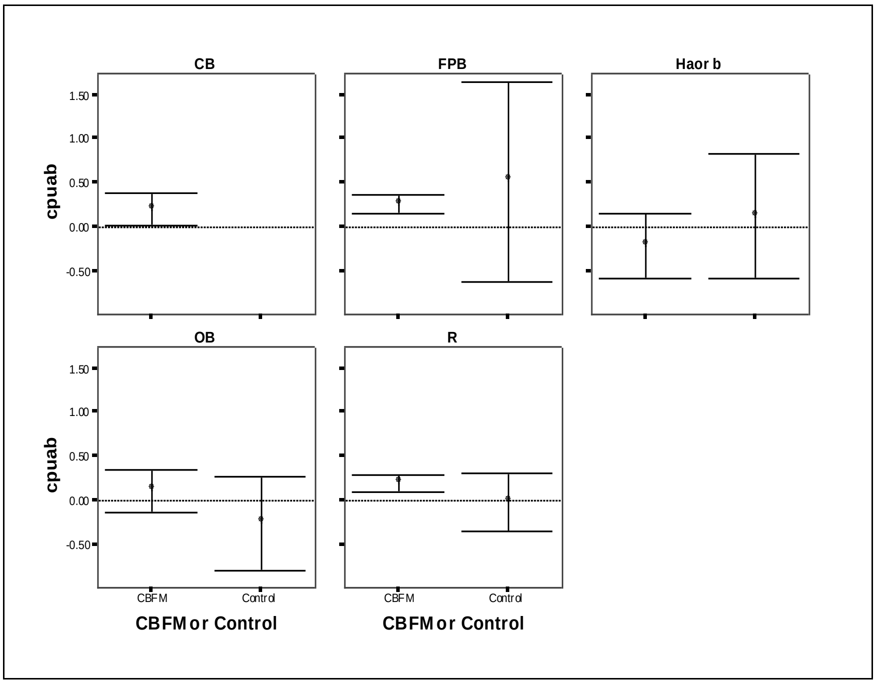

Figure 3 Mean slope coefficient estimates with 95% CI for the fish production indicator CPUA (cpuab) at CBFM and control sites for each habitat. Reference line at zero indicates no change in mean value of indicator.

Variation in fish abundance and fishing intensity, indicated by cpdb and dpuab respectively, best explained the variation in fish production (cpuab) among sites (R^2=0.60; $p<0.01$ d.f.=77). As expected, fish production increases both with increasing fish abundance and fishing effort although these two variables are typically negatively correlated. The 'partial eta-squared' statistic revealed that fish abundance (CPD) explained more of the variation in CPUA than fishing intensity (DPUA) [54% compared to 44% respectively].

Two-way ANOVA tests (GLM) indicated no significant difference ($p<0.05$) in the estimate of the mean CPD slope coefficient among habitat type after accounting for differences between CBFM and control sites. After pooling the data across habitat, the estimate of the mean slope coefficient was significantly ($p=0.03$) greater for CBFM compared to control sites, and significantly ($p<0.01$) greater than zero (Figure 4). The estimate of the mean slope coefficient for CBFM sites translates to an increase in daily catch rates of 16% per annum. Equivalent increases by habitat ranged from 10-20% per annum (Table 6). Rates of change in fish abundance at control sites were not significantly different from zero (Table 7). In order of importance, fishing intensity (dpuab) and the presence/absence of closed seasons (CLOSED) together best explained the variation in daily catch rates (cpdb) (R^2=0.15; $p<0.01$); d.f.=77). Catch rates (cpdb) were found to decline with increasing fishing intensity (dpuab) and in the absence of closed seasons (CLOSED=N). The presence/absence of harvest reserves was found to have no significant ($p>0.05$) effect on catch rates.

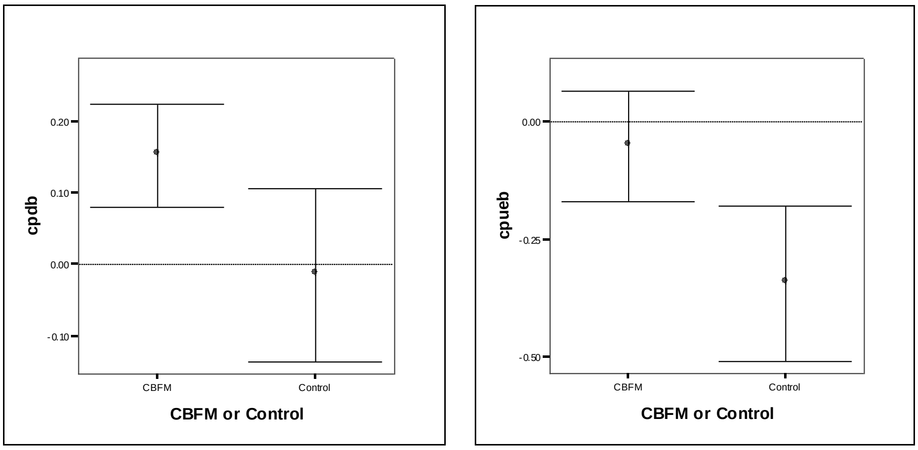

Figure 4 Mean slope coefficient estimates with 95% CI for the fish abundance indicators CPD (left) and GNCPUE (right) at CBFM and control sites for all habitat sites combined. Reference line at zero indicates no change in the value of indicator with time.

Estimates of the mean gillnet catch rate (GNCPUE) slope coefficient (cpueb) were found not to vary significantly across habitat type (Table 6). After pooling the estimates across habitat, the estimate of the mean slope coefficient for CBFM sites was significantly greater ($p<0.05$) than for control sites but not significantly different from zero, indicating no significant decline in mean gillnet catch rates at CBFM sites through time (Figure 4). The estimate of the mean slope coefficient for control sites was however significantly less than zero, equivalent to a decline in catch rates (fish abundance) of approximately 30% per annum (Table 7). The presence/absence of closed seasons (CLOSED) was also found to best explain the variation in gillnet catch rates (cpueb) but only at the α=0.1 level. (R^2=0.04; $p<0.07$; d.f.=83). Gillnet catch rates were also found to decline in the absence of closed seasons.

Estimates of the mean fishing intensity (DPUA) slope coefficient (dpuab) representing annual rates of change in fishing intensity were found to vary significantly ($p<0.05$) between habitat but not between CBFM and control sites (Figure 5). For CBFM sites belonging to floodplain beel habitat, mean fishing intensity increased significantly ($p<0.05$) by approximately 10% per annum, but not significantly more than at control sites (Tables 6 and 7). For haor beel habitat, the mean estimate for CBFM sites was significantly less than zero, equivalent to a decline in fishing intensity of more than 30% per year

(Table 6). This decline was not significantly different from that estimated for control sites. The remaining combinations indicated no significant change in fishing intensity through time. No management interventions were found to have a significant effect on dpuab.

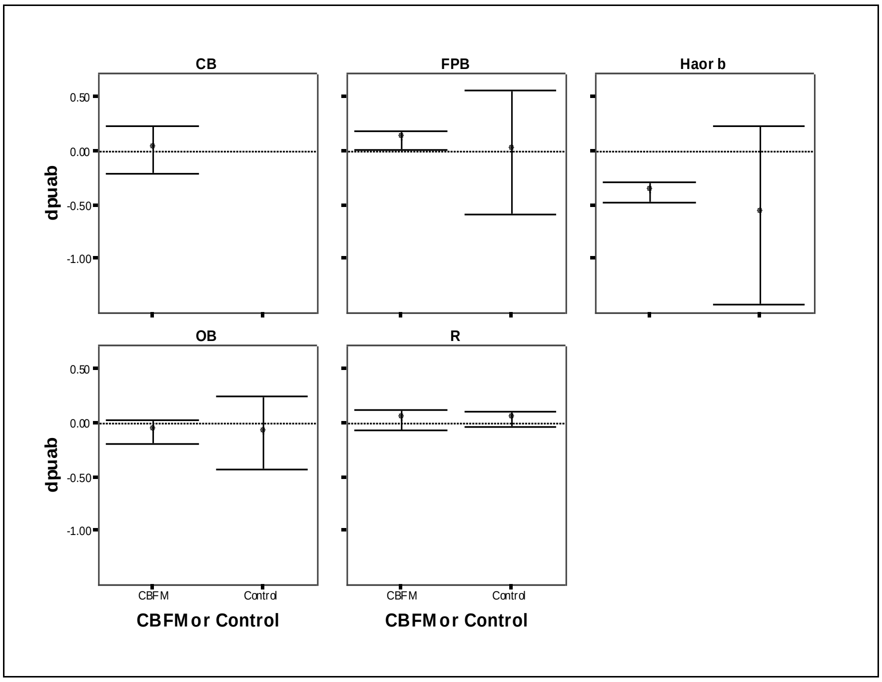

Figure 5 Mean slope coefficient estimates with 95% CI for the fishing effort indicator DPUA (dpuab) at CBFM and control sites for each habitat. Reference line at zero indicates no change in mean value of indicator.

Estimates of the mean biodiversity index (H') slope coefficient (hb) representing annual rates of change in biodiversity were found to vary significantly ($p<0.05$) with habitat and between CBFM and control sites (Figure 6). On average, the value of hb was 0.19 higher at CBFM compared to control sites. Significant increases in biodiversity at CBFM sites through time (mean slope coefficient >0) were found for both closed and floodplain beel habitat equivalent to annual increases in H' of 0.12 and 0.17, respectively. Significant improvements in H' through time were also estimated for control sites in floodplain beel habitat equivalent to 0.21 per annum (Tables 6 and 7). No significant ($p<0.05$) changes in biodiversity were detected at either CBFM or control sites in haor, open beel or river habitat. Estimates for control sites were lower than for CBFM sites for open beel and river habitat but not significantly ($p>0.05$). After accounting for differences among habitat type, the presence/absence of closed seasons (CLOSED) best described variation in biodiversity among sites (R^2=0.24; $p<0.01$; d.f.=75). On average, the presence of closed seasons improved the value of the biodiversity indicator by 0.055 per annum.

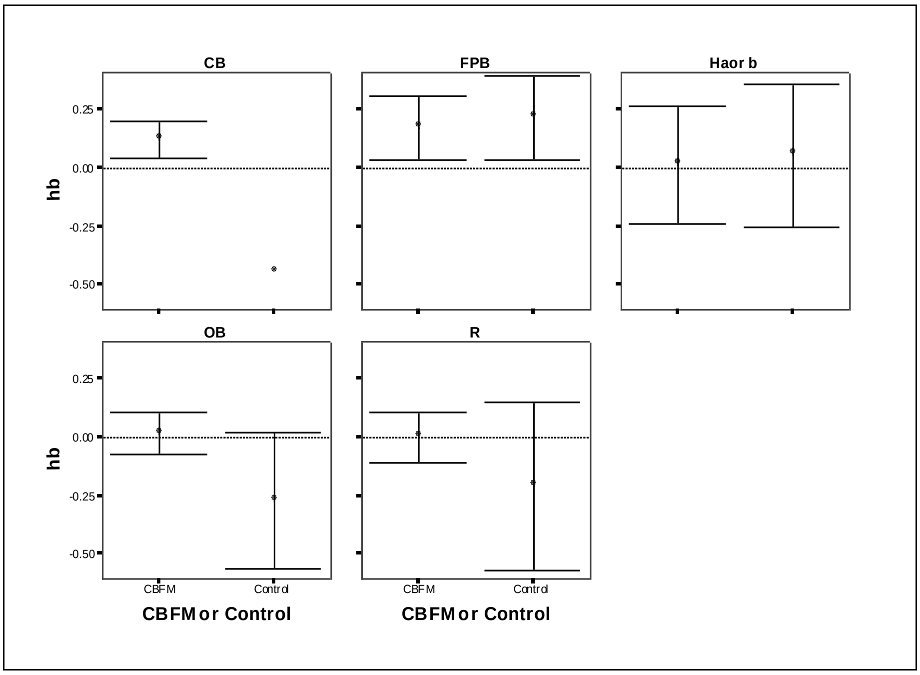

Figure 6 Mean slope coefficient estimates with 95% CI for the fish biodiversity indicator H' (hb) at CBFM and control sites for each habitat. Reference line at zero indicates no change in mean value of indicator.

Table 6 Estimates of the mean slope coefficient (*b*) of regressions of performance indicators with time (year) by habitat for CBFM sites. Bold and underlined slopes are significantly ($p<0.05$) different from zero. Estimates for all habitats are provided in those cases where habitat was found not to be a significant factor in determining mean slope values. Corresponding annual rates of change are provided below.

Habitat	CPUA b	CPD b	CPUE b	DPUA b	H' b
CB	**0.2006**	0.1946	-0.0987	0.0060	**0.1239**
FPB	**0.2579**	**0.1166**	**-0.1869**	**0.0991**	**0.1720**
HAOR	-0.2069	0.0892	**-0.2733**	**-0.3768**	0.0136
OB	0.1101	0.1942	0.1656	-0.0841	0.0161
RIVER	**0.1983**	**0.1753**	-0.1296	0.0230	-0.0025
All habitat	-	**0.1527**	-0.0534	-	-

	% Per annum				Per annum
Habitat	CPUA	CPD	CPUE	DPUA	H'
CB	**22.2**	21.5	-9.4	0.6	**0.12**
FPB	**29.4**	**12.4**	**-17.0**	**10.4**	**0.17**
HAOR	-18.7	9.3	**-23.9**	**-31.4**	0.01
OB	11.6	21.4	18.0	-8.1	0.02
RIVER	**21.9**	**19.2**	-12.2	2.3	-0.003
All habitat	**-**	**16.5**	-5.2	-	-

Table 7 Estimates of the mean slope coefficient (*b*) of regressions of performance indicators with time (year) by habitat for control sites. Bold and underlined slopes are significantly ($p<0.05$) different from zero. Estimates for all habitats are provided in those cases where habitat was found not to be a significant factor in determining mean slope values. Corresponding annual rates of change are provided below.

Habitat	CPUA b	CPD b	CPUE b	DPUA b	H' b
CB	-	-	-0.2242		-0.4491
FPB	0.5158	0.0022	-0.0925	-0.0102	**0.2130**
HAOR	0.1238	0.2713	-0.2931	-0.5917	0.0550
OB	-0.2579	-0.1648	-0.5845	-0.0931	-0.2718
RIVER	-0.0167	**-0.1654**	**-0.3556**	0.0324	-0.2083
All habitat	-	-0.0142	**-0.3435**	-	-

		% Per annum			Per annum
Habitat	**CPUA**	**CPD**	**CPUE**	**DPUA**	**H'**
CB	-	-	-20.1	-	-0.45
FPB	67.5	0.2	-8.8	-1.0	**0.21**
HAOR	13.2	31.2	-25.4	-44.7	0.05
OB	-22.7	-15.2	-44.3	-8.9	-0.27
RIVER	-1.7	**-15.2**	**-29.9**	3.3	-0.21
All habitat	-	-1.4	**-29.1**	-	-

4. DISCUSSION

According to the relative frequency of upward and downward trends in performance indicators at CBFM and control sites, the CBFM Project appears to have benefited fish production (CPUA), abundance (CPD and GNCPUE) and biodiversity (H’) at participating sites, but has had little or no apparent effect on destructive fishing practices (DFER) or fishing intensity (DPUA). No significant ($p<0.05$) overall trends in management performance were detected at control sites except for fish abundance indicated by gillnet catch rates (GNCPUE) which declined at significantly more sites, than it rose.

The analysis of slope coefficients corresponding to these trends generated largely consistent results to those above but indicated that some of the above conclusions were habitat specific. The CBFM was found to have a significant beneficial effect on CPD, GNCPUE and H’, but not CPUA or DPUA after accounting for variation among habitat type and region.

Whilst changes in production at CBFM sites were not significantly different from those observed at control sites, they were significantly greater than zero in three habitats, with annual increases ranging from between 20% and 30% per annum. Improvements in production were found to be dependent upon fish abundance (CPD) and fishing intensity (DPUA).

Mean annual increases in fish abundance, indicated by CPD, were significantly greater at CBFM compared to control sites, particularly in river habitat (20% per annum). Furthermore, the mean change in fish abundance at control sites was not significantly different from zero. Fish abundance increased in response to a decrease in fishing intensity (DPUA) and the use of closed seasons, but these factors explained only 15% of the total variation in fish abundance. Whilst gillnet net catches rates (GNCPUE) indicated no significant change in fish abundance at CBFM sites, a significant ($p<0.05$) decline in mean rates was detected at control sites equivalent to almost -30% per annum.

Which abundance indicator is the more reliable? The GNCPUE takes full account of any changes in the fishing power of the *fishing unit* and is also less susceptible to bias resulting from any changes to relative effort among gear types during each fishing year. However, the fishing power index (FPI) was found not to have increased significantly through time within any habitat suggesting that the CPD indicator is unlikely to be biased from changes in fishing power. Unlike the annual perspective of the CPD indicator, GNCPUE provides an index of fish abundance only during a two month period during the flood season when gillnets tend to target migratory *whitefish* species (Welcomme 1985). GNCPUE may therefore be a poor indicator of the abundance of less migratory *blackfish* species, and thus the entire assemblage. Therefore each indicator has advantages and disadvantages.

Irrespective of the choice of indicator, the results suggest that fish abundance does benefit from CBFM manifest either as increasing, or at least sustained, abundance.

Rates of change in biodiversity were found to vary significantly among habitat and were on average also significantly greater at CBFM compared to control sites. Improvements in biodiversity at CBFM sites through time were significant in closed and floodplain beel habitat. Significant improvements in biodiversity were also detected for control sites belonging to floodplain beel habitat. The presence/absence of a closed season best described the variation in biodiversity among sites.

The slope coefficient analyses also supported the conclusion that the CBFM appears overall to have had little effect on fishing intensity (DPUA) although significant declines (31% per annum) were found at CBFM sites belonging to haor beel habitat and modest (10%) but significant increases were observed in floodplain beel habitat. No significant changes in fishing intensity were detected at control sites.

Variation in the slope coefficient estimates for the individual management performance indicators at CBFM sites was significant within the majority of habitats categories but no discernable patterns were evident among the indicators to suggest that overall CBFM performance varied significantly among habitat, nor site size, geographic region or facilitating NGO.

The mean composite measure of management performance (site score) was found to be greater at CBFM compared to control sites in four of the five habitats and significantly ($p<0.05$) greater in three. The size of the waterbody (MAXAREA), the NGO facilitating management and the ownership regime (JALMOHOL) were also found to have no detectable effects on the site score estimates among CBFM sites.

Whilst co- and community-based management approaches have long been advocated as a means to addresses the failures associated with conventional ‘top-down’ approaches to management (Pomeroy & Williams 1994; Hoggarth *et al*. 1999; Wilson *et al*. 2003), few studies have quantitatively demonstrated their benefits. On the basis of the results presented here, it is concluded that the practices implemented under the Community Based Management (CBFM) Project in Bangladesh have improved, or at least sustained, fish abundance and biodiversity without significant loss to production compared to those at the control sites. In other words, the community-based approach adopted under the Project appears to give rise to better management performance than the existing top-down government-driven regime.

Increases in fish abundance and fishing intensity explained much (60%) of the variation in fish production. Greater uncertainty surrounds which factors were responsible for improvements in the remaining indicators. Closed seasons appear significant but explain less than 15% of the variation in fish abundance (CPD) after accounting for differences in fishing intensity, and only 24% of the variation in biodiversity. Halls *et al.* (2001) predicted that closed seasons during the rising flood period (April-July) would significantly increase floodplain fish production and abundance by improving both recruitment and yield-per-recruit. Whilst the effect of gear bans on the response of performance indicators could not be separated from those arising from closed seasons (because the two interventions were implemented together at almost all CBFM sites) the observed trends in destructive gear use (DFER) indicated that gear bans had been ineffective and therefore were unlikely to have been responsible. Hoggarth & Kirkwood (1996) predicted that gear bans do not increase overall yield, but can be an effective means of redistributing benefits to preferred gear of fisher socio-economic categories.

Reserves have been recommend as potentially effective means of controlling fishing mortality in the floodplain environment (e.g. Hoggarth *et al*. 1999; 2003) but studies robustly demonstrating their efficacy, and recommendations concerning minimum reserve areas, are lacking. Here, reserves were found to have no detectable effect on any of the management performance indicators. Their apparent ineffectiveness here may reflect poor enforcement, inappropriate reserve location or simply that they were too small to produce any detectable effects. Seventy-five percent of the reserves occupied less than 10% of the dry season area of CBFM sites.

Up to 12 CBFM and control sites were also stocked to improve production. Estimates of fish production employed in the CPUA, CPD and GNCPUE indicators excluded landings of stocked fish although the effect of stocking activities on performance indicators was considered.

The CBFM Project has already demonstrated that CBOs are motivated to share and disseminate their knowledge and experiences through meetings, exchange visits and newsletters (Halls *et al* 2005). Consideration might therefore be given to strengthening these types of CBO networks to support experimentation and learning under future initiatives. Halls *et al* (2005) describe guidelines for designing data collection and sharing systems to support this type of adaptive management approach.

5. CONCLUSION

Upcoming initiatives may choose to place greater emphasis on identifying effective habitat-specific management interventions and arrangements with respect to specific management objectives. For example, CBOs might be encouraged to experiment with closures to the fishery of different durations or during different months of the year (seasons), allocate different proportions of their dry season fish habitat as reserves, or control fishing effort at different levels as a means of determining the best strategy to increase fish production, abundance or biodiversity. Future impact studies of this type would benefit from greater consideration to the sampling design to avoid the problems encountered here arising from missing cells and an unbalanced design, and to optimize the use of project resources.

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