Consultancy Report 2006/03

COMMUNITY BASED FISHERIES MANAGEMENT PROJECT (CBFM-2)

Fisheries Impacts of the CBFM-2 Project

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Fisheries Impacts of the CBFM-2 Project

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October 2006

Final Assessment of the Impact of the CBFM Project on Community-Managed Fisheries in Bangladesh

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Citation: Halls, A.S. & Mustafa, M.G (2006). Final Assessment of the Impact of the CBFM Project on Community-Managed Fisheries in Bangladesh. Report to the WorldFish Center, Bangladesh, October 2006, 83pp.

Acknowledgements: Many thanks to Mohammod Ilyas (CNRS), Khalilur Rahman, Ismat Ara, and Susmita Choudhury for all their valuable contributions towards the compilation, analysis and interpretation of the data.

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1 Executive Summary

Following the recommendations of earlier investigations reported by Halls and Mustafa (2006), this study reports a final assessment to address the question: "Does CBFM bring sustainable benefits to fisher communities? Or in other words "Does the CBFM work"? It employs most of the methods described by Halls & Mustafa (2006) supported by additional statistical methods including unit slope tests using and an updated set of data containing additional observations made since the time of last reporting. The same performance indicators and explanatory variables were used for the analysis. Similar to the earlier study, it also aims to identify important explanatory factors to help inform future co- or community-based management initiatives and programmes. It was intended that key findings and conclusions would be incorporated into evolving communications products, working documents and peer-reviewed publications.

This re-assessment of the impact of the CBFM was determined on the basis a maximum of 107 of the total 120 project sites divided unequally between those under CBFM and unmanaged control sites (Table 2). The data set now comprises performance indicator estimates for 488 waterbody-year combinations, compared to 458 estimates used in the Phase II assessment, equivalent to an increase of more than 6% (Section 3.1).

Following the same methodology employed in Phases I and II, significant trends (slopes) in performance indicators through time were tested for using GLM (SPSS v 11.5) where time (year) was treated as a covariate. Only sites with at least three years of observations were included (Section 3.4).

The frequency of upward and downward trends in the performance indicators, irrespective of whether or not they were statistical significant at $\alpha=0.05$, were compared along with those for significant trends. Chi-squared tests were used to determine whether these observed frequencies were significantly different than the expected frequencies. In all cases, it was assumed that the expected frequencies of upward and downward trends would be equal if the CBFM has no effect.

Estimates of slope coefficients representing annual rates of change in each performance indicator at each site were compared among habitat type and between CBFM and Control sites. Two-tailed Student t-tests where used to determine if unit (average) slopes were significantly different from 0.

Binary logistic regression analysis was used to determine which explanatory variables (predictors) were significant in determining the trends in the performance indicators (dependent variables).

A 'site score' comprising the trends of all the performance indicators was calculated for each site and compared between CBFM and control sites. Factors affecting site score were also sought.

The results indicate that the community based fisheries management (CBFM) approach in Bangladesh "works" in respect of improving or sustaining production, fish abundance and biodiversity relative to unmanaged control sites.

Production measured in terms of catch per unit area (CPUA) has, on average, either increased or been sustained at CBFM sites. Whilst production has also been sustained at control sites, no significant increases were detected.

Fish abundance indicated by gillnet catch rates (GNCPUE) was found to have declined by 5% per annum but this decline was judged to be not significant ($p>0.05$). However, there is strong evidence to suggest that fish abundance has declined significantly ($p<0.05$) at control sites, far more than at CBFM sites and particularly within river habitat.

It would therefore appear that CBFM is better than no management in terms of sustaining fish abundance.

Fisher catch per day (CPD) - an alternative indicator of fish abundance was found to have increased significantly ($p<0.05$) across CBFM sites and by as much as 20% per year in CBFM river habitat sites, but has remained unchanged at control sites.

Changes in abundance are unlikely to have resulted from changes in fishing effort (except in floodplain beel habitat) or destructive fishing gear use since changes to these two factors have been largely insignificant.

Biodiversity at CBFM sites increased with time in two habitats, but remained unchanged in the remainder. Biodiversity at control sites remained unchanged in all habitats. Species assemblages are richer and more abundant at CBFM compared to control sites in floodplain beel and river habitat in the north and east regions of the country respectively. Considered together, this evidence suggests that CBFM benefits biodiversity.

The mean site score, encapsulating the trends of all the performance indicators, was also found to be significantly greater at CBFM compared to control sites. Comparisons of mean site scores suggests that the CBFM works best in closed beel and river habitat, although the differences were not significant ($p>0.05$). Furthermore, management performance was found not to vary significantly among region, or with site (waterbody) size, facilitating NGO or ownership regime (see Section 4.6.3).

Unsurprisingly, fish abundance, indicated by catch per day (CPD) and fishing effort measured in terms of fishing days per unit area (DPUA) were found to be the best predictors of trends in fish production (CPUA). The probability of an upward trend in CPUA was 99% when the trend in CPD was upward and the trend in DPUA was downward, although the two factors are not independent (Section 4.6.1). Guidance relating to levels of effort to maximize catch (production) are provided in Section 5.1 and summarized below.

No significant predictors of trends in fish abundance measured in terms of gillnet catch rates (GNCPUE) were identified. Closed seasons and/or gearbans were found to be the only significant predictors of trends in fish abundance measured in terms of catch per day (CPD). Trend in CPD was found to be the only significant ($p<0.05$) factor in predicting trends in biodiversity H' through time although the effect is small.

Whilst a great deal of uncertainty surrounds which CBFM interventions were responsible for the observed improvements in the management performance indicators, the control of fishing effort should be fundamental to any management approach. The data generated by the project provided an opportunity to explore the response of catch to effort based upon among site comparisons. Such models can provide estimates of maximum yields and corresponding levels of effort. Three types of production model were fitted to the data, stratified by habitat. Except for closed beel habitat, there was little evidence of a decline in yields with increasing fishing effort. This may reflect the existence of external sources of recruitment in these habitats. For closed beel habitat, the best fitting (Schaefer) model predicted a maximum yield of 540 kg ha^{-1} yr^{-1} (95% CI [160, 2335]) at 633 fishing days ha^{-1} yr^{-1} (95% CI[272,2085]). For the remaining habitats, an asymptotic model was the best fitting model in all cases. However, this model cannot provide estimates of fishing effort that maximize yield. Therefore, in addition to this asymptotic model, the next best fitting model (the Fox) which predicts a decline in catch with effort, was also fitted, to provide some guidance of levels of effort that maximize yields.

Stocking waterbodies with fingerlings is a common form of fisheries management in Bangladesh. Whilst there were too few control sites to determine if stocking programmes under CBFM were more effective than under non-CBFM, data from stocking events recorded under the Programme were used to develop a simple bio-economic stocking model (see Section 5.2).

The model offers managers guidance on selecting stocking densities depending upon the (available) size of fingerlings to maximize profit (harvest revenues-stocking costs) whilst minimizing risk. The model is an empirical type and therefore the model recommendations may not be applicable beyond the project sites that generated the data to construct the model. As more data becomes available from future stocking events, the model should be updated.

The report recommends that given the fundamental importance of sustaining fish abundance, any future CBFM programmes should focus attention towards monitoring fish abundance in a consistent and precise manner. This might include either employing routinely collected catch statistics from a standard gear or by periodically (annually) undertaking dedicated surveys such as depletion estimates.

Any future CBFM programmes should also consider designing and implementing experiments or adaptive learning programmes to identify effective management interventions (closed seasons, gear bans, mesh regulations etc) and thresholds such as minimum reserve size in relation to explicitly defined management objectives.

The CBFM is a unique study in terms of its duration, coverage, and the quantity of data generated. Consideration should be given to publishing the main findings of this report in mainstream journals to disseminate the findings and encourage lesson learning among stakeholders. Suggested themes/titles are provided in Section 6.5.

2 Introduction

2.1 Background

Fish from Bangladesh's vast inland waters are vital to millions of poor people, but landings and species diversity are believed to be declining. Fishers and experts have identified potential causes for this decline including habitat degradation due to siltation and conversion to agriculture, increasing fishing pressure, destructive fishing practices and an acute shortage of dry season wetland habitat (Hughes *et al*. 1994; Ali 1979).

The practice of short term leasing small waterbodies (*jalmohals*) provides little incentive to lease holders to harvest aquatic resources in a sustainable manner and often acts as an obstacle to access by poorer members of the community (Craig *et al.* 2004).

The first phase of the Community Based Fisheries Management (CBFM) during 1994-1999 was funded by Ford Foundation grants to government and non-government partners. It aimed to promote the sustainable use of, and equitable distributions of benefits from, inland fisheries resources by empowering communities to manage their own resources.

After an interim period of nearly two years with little or no community-based management activity, a second phase of the project (CBFM-2) began in September 2001. This ongoing 5-year follow-on phase, funded by the UK Government's Department for International Development (DFID), is being implemented jointly by the WorldFish Center and the Government of Bangladesh's Department of Fisheries, through a partnership involving 11 Non-Governmental Organizations (NGOs).

The 11 partner NGOs are Banchte Sheka (BS), Bangladesh Environmental Lawyers Association (BELA), Bangladesh Rural Advancement Committee (BRAC), Caritas, Centre for Natural Resource Studies (CNRS), Centre for Rural and Environmental Development (CRED), FemCom, PROSHIKA, Shikkha Shastha Unnayan Karzakram (SHISUK), Grassroots Health and Rural Organization for Nutrition Initiative (GHARONI), and Society Development Committee (SDC). These field-based partner NGOs are responsible for organizing about 23,000 poor fishing households around 120 waterbodies representing a range of different habitat types and located in regions throughout Bangladesh.

The CBFM Output to Purpose Review 2 (OPR2) Report identified a need to further examine the impact of the CBFM activities on fisheries performance at the local level in preparation for the final phase of the Project. The review also emphasised the need to assess the *relative* importance of CBF management activities and environmental factors (particularly hydrology) in determining fisheries performance (CBFM 2, 2004).

A study was therefore commissioned in May 2005 specifically to determine the impact of the CBFM activities on fish production, resource sustainability and fisher well-being, whilst taking account of inter and intra-annual variation in important environmental variables such as hydrology.

The study employed data collected from 78 CBFM and control sites since 1997, representing a range of different habitat type and geographic location. Performance indicators relating to production, resource sustainability (including biodiversity) and fisher well-being were identified in consultation with the WorldFish Center, Bangladesh, together with more than 15 explanatory variables hypothesised to affect management performance.

Impacts of the CBFM were examined in two ways. Firstly, by testing for significant differences in estimates of mean values of performance indicators between CBFM and control sites (controlled comparisons) using general linear models (GLMs). Secondly by testing for significant upward or downward trends in estimates of performance indicators at CBFM sites through time (time series analysis).

Most of the controlled comparisons indicated no significant differences in mean management performance indicators between CBFM and control sites. However, the power of the tests performed i.e. the probability of detecting a true significant difference, was very low (<10%) in almost all cases. The power of the statistical tests was low because of the small number of samples gathered in each month and the very unbalanced sampling design with many missing cells.

It was therefore concluded that there was a very high chance of drawing erroneous conclusions about the apparent non-effectiveness of the CBFM on the basis of these controlled comparisons. In other words, the CBFM may have a positive or negative effect on many or all the performance indicators examined, but these effects remain undetectable at present. These controlled comparisons were therefore unable to answer the question: Does the CBFM work?

For the time series analysis, significant trends in performance indicators through time were explored by testing the significance of the "slope" coefficient of regression models of performance indicators fitted using the GLM routine where time (year) was treated as the independent variable. Only sites with at least four years of observations were examined.

With the exception of those relating to fish consumption, the results of the time series analysis were equally inconclusive. It was recommended that any remaining project resources should be directed at improving the trend (time series) analyses of management indicators at individual CBFM sites (see Halls *et al* 2005 for further details).

Additional data for 2005 became available in April 2006, increasing significantly the number of sites with at least three years of observations. The data set comprised performance indicator estimates for 458 waterbody-year combinations, compared to 288 estimates used in the first assessment, equivalent to an increase of more than 60%.

Following the same methodology employed for the first study, significant trends in performance indicators through time were tested for using the General Linear Model (GLM) where time (year) was treated as a covariate. Frequencies of upward and downward trends were compared using chi-square tests and composite site scores were compared between CBFM and control sites). Binary logistic regression analysis was also used to determine which explanatory variables (predictors) were significant in determining the trends in the performance indicators (dependent variables) - see Halls & Mustafa (2006) for further details).

The report concluded that if trends in the performance indicators are taken at face value i.e. simply whether they are up or down, irrespective of whether the slopes of the trend lines are significantly different from zero, then the results suggested that the CBFM does "work". If only significant trends are considered, then the frequency of upward and downward trends in each indicator could be expected by chance for both CBFM and control sites.

The authors recommended repeating the analysis when additional data was expected to become available in July 2006. They also recommended using checking the validity of indicators of fish abundance and selecting alternative indicators if necessary. Other recommendations included attempting to develop empirical production models for specific habitat, and bio-economic stocking models.

Following the completion of the CBFM2 monitoring programme in May 2006, the dataset was updated for a final time. Following the recommendations of Halls & Mustafa (2006), these data were employed for this final impact assessment study.

2.2 Aims of this study

Building on the earlier assessments and using the augmented data set described above, this final assessment aims to draw conclusions concerning the impact of the CBFM project providing conclusive answers to the question: “Does CBFM bring sustainable benefits to fisher communities? Or in other words “Does the CBFM work”?

Similar to the earlier assessments, it also aims to identify important explanatory factors to help inform future co- or community-based management initiatives and programmes. It was intended that key findings and conclusions would be incorporated into evolving communications products, working documents and peer-reviewed journal publications.

Following the recommendations of Halls & Mustafa (2006), the development of empirical production models for specific habitat, and bio-economic stocking models were also sought to help guide managers towards improved outcomes.

3 Materials and Methods

3.1 Data

This final impact assessment of the CBFM Project was based upon an updated set of data containing additional observations made up until May 2006 and the same performance indicators and explanatory variables employed during the Phase II assessment reported by Halls and Mustafa 2006) (see Tables 1 and 2 in Annex 1).

The data were provided by WorldFish Center in a format requested by the consultant (see dataformat.xls').

Because the monitoring programme ended in May 2006, where appropriate, the performance indicators and explanatory variables were re-estimated for the split year June-May to maximise the number of available estimates. Previously, annual estimates were compiled from monthly samples collected between January and December.

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

3.1.1 Changes in Fishing Power and the Reliability of the CPD Indicator

One of the fundamental assumptions when employing catch per fisher per day (CPD) as an indicator of fish abundance through time is that the effective fishing power of the fisher and his gear (the *fishing unit*) remains constant. This is because CPD is expected to increase with the effective fishing power of the fisher and his gear. Therefore, if fishing power increases, then any observed increase in CPD could be erroneously interpreted as an increase in fish abundance rather than simply an increase in fishing power of the fishing unit.

The daily fishing power of the fishing unit will depend on fishing time and the power of the gear. The power or efficiency of the gear is likely to vary with size, but also seasonally in response to prevailing hydrological conditions. The CPD indicator of fish abundance therefore also assumes that relative fishing effort by gear type during the fishing year remains approximately constant from one year to the next.

A simple indicator of fishing power for net fisherman might be expressed by the following fishing power index (FPI):

$$FPI_{i,s,y} = \frac{NetArea_{i,s,y} * Hours_{i,s,y}}{NF_{i,s,y}}$$

Where $NetArea_{i,s,y}$ is the area of net *i* 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 net.

Estimates of FPI for gillnet fishers were used to test the assumption that fishing power of net fishers has remained constant during the CBFM. The FPI was estimated only for August and September to minimise any seasonal effects on the indicator. Gillnet fishing activity is greatest during this period (floodplain inundation), but gillnet efficiency is unlikely to change significantly.

Previous assessments of changes in fishing power reported by Halls & Mustafa (2006) based upon only the size (and number) of common gears such as gillnets and traps, found that whilst fishing power had increased through time, the changes were not significant at the p=0.05 level. However, this previous assessment employed data only for CNRS monitored sites between 2002-2006. The results presented below include previously unavailable data for WFC monitored sites from 1996-2006 and also include fishing hours in the index.

Unsurprisingly, the effect of fishing power per fisher (FPI) on catch per fisher was found to be significant for all habitat types (Figure 1). Therefore, if trends in fishing power through time are significant, these changes in fishing power must be accounted for when interpreting the results presented in this report.

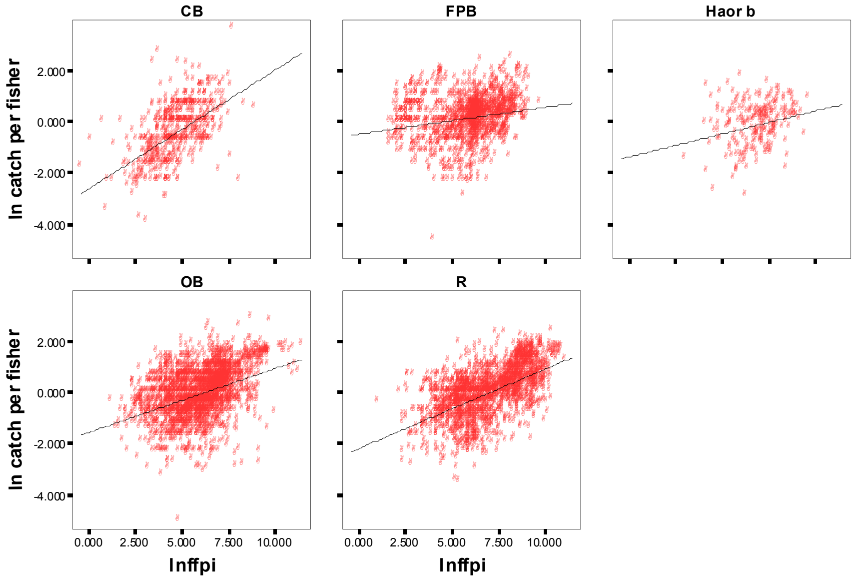

Figure 1 Observed loge transformed gill net catch per fisher during August and September 1996-2006 plotted as a function of loge transformed FPI with fitted regression model for each habitat.

Changes in fishing power through time were examined by plotting loge transformed FPI against year (Figures 2-6). A mean (unit) slope for each habitat category was then estimated. A student t-test was then used to determine if the mean slope for each habitat was significantly different from zero.

For all habitat types, the average FPI slope was positive (upward through time) but not significantly different from zero at the 5% level (Table 1), indicating (on average) no significant change in fishing power with time in any of the habitat types.

Table 1 Estimated mean (unit) slopes (b) of regressions of the fishing power index (fpi) with time (year) by habitat.

Habitat	N	Minimum (b)	Maximum (b)	Mean slope (b)	Std. Error (b)	p
CB	9	-0.235	0.974	0.234	0.118	0.33
FPB	26	-0.265	0.770	0.189	0.053	0.20
Haor beel	11	-0.148	0.876	0.377	0.087	0.30
OB	27	-0.997	1.299	0.049	0.104	0.19
River	17	-0.489	2.068	0.299	0.132	0.24

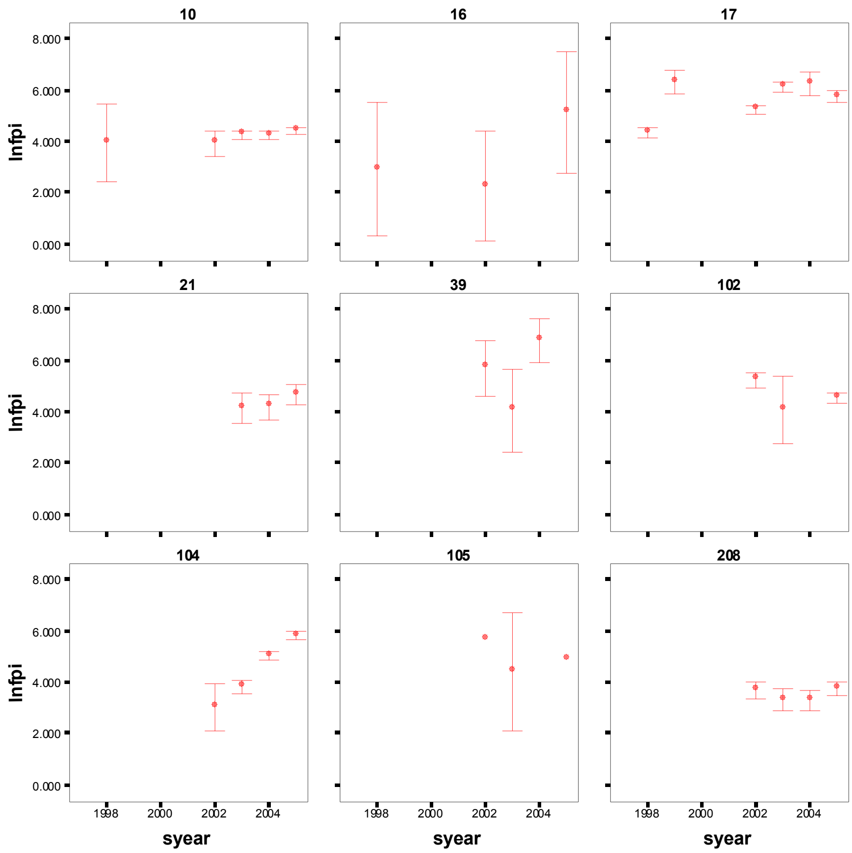

Figure 2 Mean (loge transformed) FPI with 95% confidence intervals plotted as a function of time (project year) for closed beel (CB) sites.

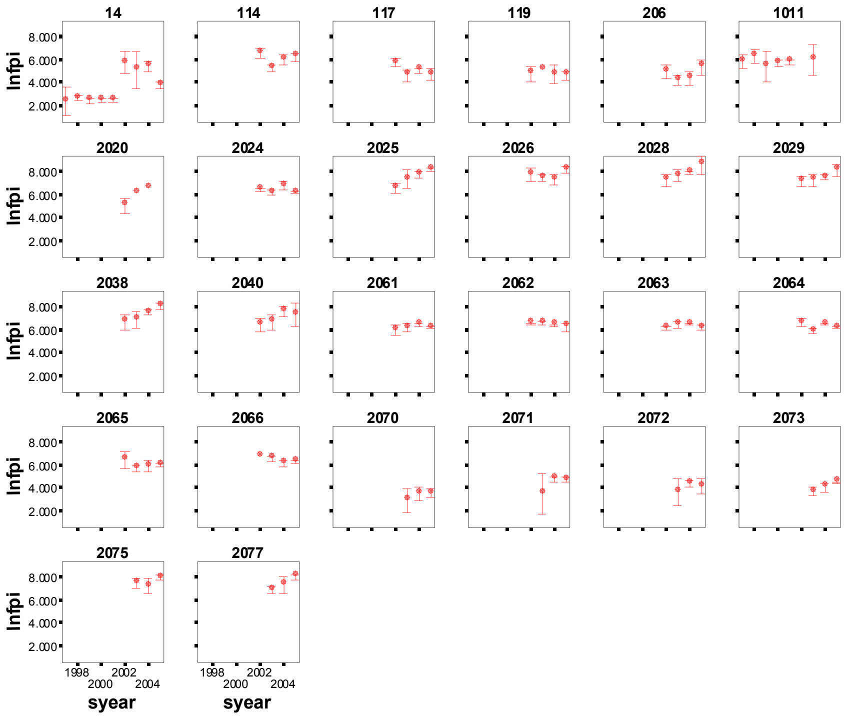

Figure 3 Mean (loge transformed) FPI with 95% confidence intervals plotted as a function of time (project year) for floodplain beel sites.

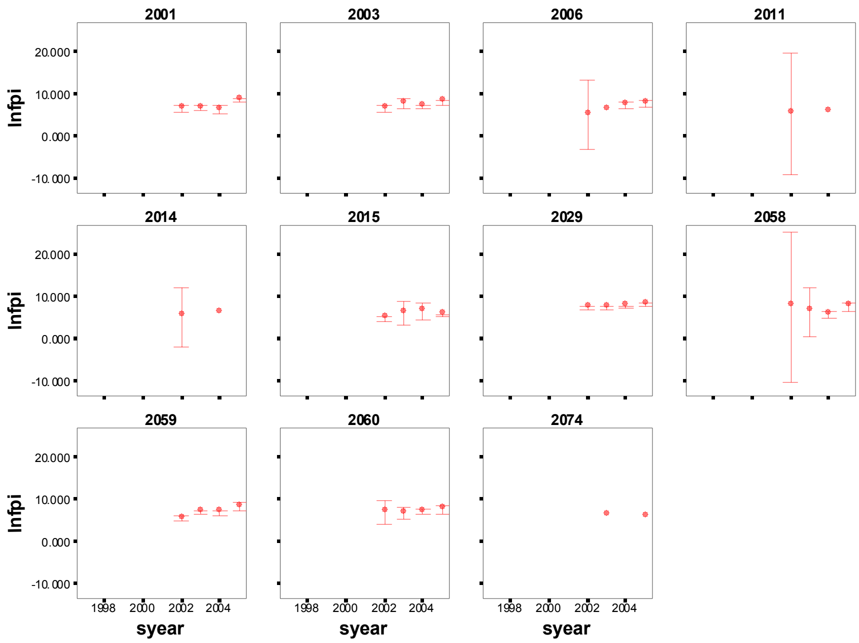

Figure 4 Mean (loge transformed) FPI with 95% confidence intervals plotted as a function of time (project year) for Haor beel sites.

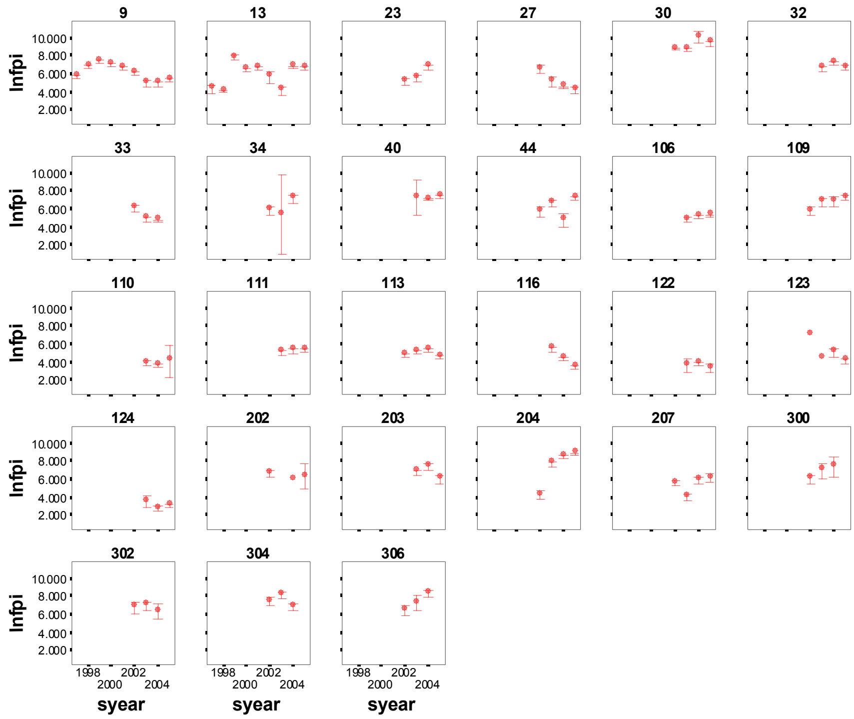

Figure 5 Mean (loge transformed) FPI with 95% confidence intervals plotted as a function of time (project year) for open beel sites.

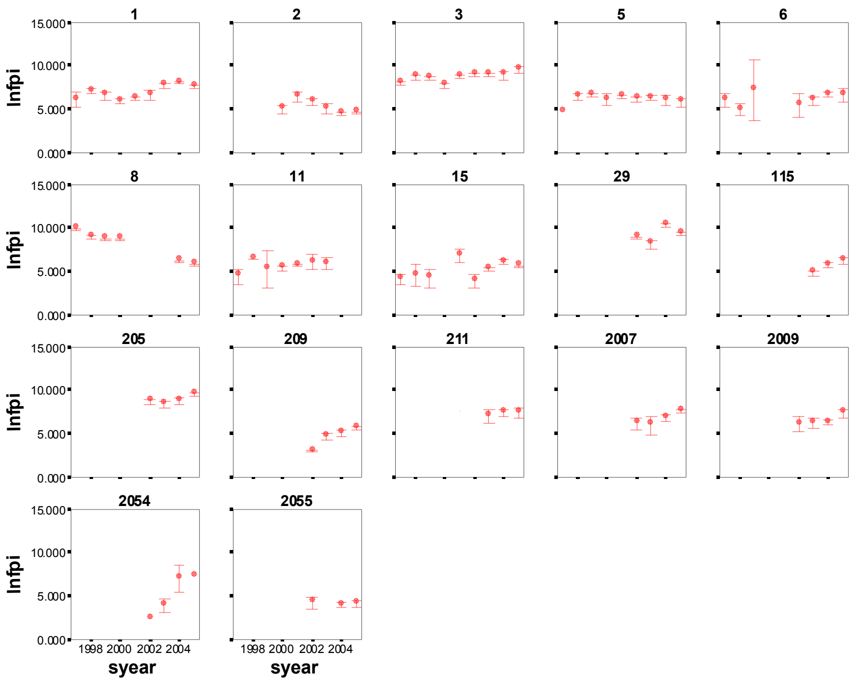

Figure 6 Mean (loge transformed) FPI with 95% confidence intervals plotted as a function of time (project year) for river sites.

3.1.2 An alternative indicator of fish abundance

Because average fishing power was found to have increased through time across all habitat types although not significantly at the 5% level, the following alternative indicator of abundance was also employed for this impact assessment study:

$$GNCPUE_{8-9,i,s,y} = \frac{Catch_{8-9,i,s,y}}{NetArea_{8-9,i,s,y} * Hours_{8-9,i,s,y}}.1000$$

Where $GNCPUE_{8-9,i,s,y}$ is the catch rate for gillnet *i*, sampled at site *s* between August and September of year *y*. The ratio is multiplied by 1000 because estimated values are typically very small.

This indicator provides a potentially more robust and reliable indicator of fish abundance by taking account of any changes to net area, and the soak (fishing) hours of the net. The number of fishers in the team is not included because catches during the soak hours will NOT be dependent upon the number of fishers in the team once the net is set. It is also less susceptible to bias resulting from changes to relative effort among gear types during each fishing year.

However, it does have a number of disadvantages compared to the CPD indicator. In particular, it provides an index of fish abundance only during a 2 month period during the flood season. During this period, gillnets tend to target whitefish species and therefore indices based upon catches from gillnets may be poor indicators of blackfish (and overall fish) abundance.

Because of their relative advantages and disadvantages, both CPD and GNCPUE8-9 were employed as indicators of fish abundance.

3.1.3 Quantifying the bias on CPD

Whilst we can take account of changes to net area and fishing time in gear-based indicators of CPUE during different fishing seasons (see above), these potentially more robust gear based-indicators have the disadvantage that they do not catch the full multi-species assemblage, and their use is often highly seasonal. The question is therefore to what extent might the CPD indicator be biased by the observed (but not significant) changes in fishing power (gillnet area and hours spent fishing by fishers each day)?

To answer this question, it would be necessary to first standardise fishing effort across all (i) gears, (ii) years, (iii) fishing seasons and (iv) habitat types to account for changes in gear efficiency among the four factors. This is notoriously difficult to undertake principally because observations for each gear, year, season and habitat combination are often missing. This often necessitates dropping gears and years of data from the dataset or reducing the number of fishing seasons over which catchability is relatively constant. The net effect may be standardised effort which bears little relationship to fishing mortality (Sparre & Venema, 1985). These are the main reasons why CPD indicators are commonly used instead where the fishing day is employed as the standard unit of effort. Indeed, there are no published reports of attempts to undertake this type of standardisation process for floodplain-river fisheries. In this case, the task is would be made almost impossible by missing gear size data which must be used to estimate fishing effort before it is standardised.

3.1.4 Data Transformations

Following the completion of the data compilation exercise, the supplied data were checked for errors where possible and transformed where necessary to meet the normality assumptions of the GLM approach as described by Halls *et al* (2005).

3.2 Data Coverage

3.2.1 Location

Details of the geographic location of sites monitored under the CBFM Project have already been described and illustrated by Halls *et al* (2005).

3.2.2 Numbers and categories of sites

This re-assessment of the impact of the CBFM was determined on the basis a maximum of 107 of the total 120 project sites divided unequally between those under CBFM and unmanaged control sites (Table 2). The data set now comprises performance indicator estimates for 488 waterbody-year combinations, compared to 458 estimates used in the Phase II assessment, equivalent to an increase of more than 6%.

Monitoring of control sites did not begin during 2002. Most sites are located in the North and Northwest of the country (Table 3).

Table 2 Number of monitored CBFM and control sites

Year	Split year	CBFM	Control	Total
1997	1997-1998	16		16
1998	1998-1999	19		19
1999	1999-2000	17		17
2000	2000-2001	14		14
2001	2001-2002	13		13
2002	2002-2003	74	19	93
2003	2003-2004	88	19	107
2004	2004-2005	83	20	103
2005	2005-2006	86	20	106

Table 3 Number of monitored sites by region and year

Year	Split year	E	N	NW	SW
1997	1997-1998	3	9	2	2
1998	1998-1999	3	9	4	3
1999	1999-2000	3	8	4	2
2000	2000-2001	3	5	4	2
2001	2001-2002	3	5	4	1
2002	2002-2003	29	32	16	16
2003	2003-2004	31	38	20	18
2004	2004-2005	24	42	18	19
2005	2005-2006	25	41	21	19

Monitored CBFM and control sites represent a range of different habitat type. Open *beels* (OB), which are floodplain depressions connected to river systems, are the most common habitat type. Closed *beels* (CB) have no or limited connections to river systems (Table 4).

Table 4 Number of monitored sites by habitat type and year

		CBFM					Control				
Year	Split year	CB	FPB	Haor b	OB	R	CB	FPB	Haor b	OB	R
1997	1997-1998	2	2		2	10					
1998	1998-1999	5	2		2	10					
1999	1999-2000	4	2		2	9					
2000	2000-2001	2	2		2	8					
2001	2001-2002	2	2		2	7					
2002	2002-2003	9	23	6	20	16	1	4	4	4	6
2003	2003-2004	12	24	6	27	19	1	4	4	4	6
2004	2004-2005	12	23	6	22	20	2	4	4	4	6
2005	2005-2006	11	22	7	27	19	2	4	4	4	6

3.2.3 Management

The CBFM sites are managed either through stocking programmes, closed seasons, gear bans, or harvest reserves (sanctuaries) or a combination of these. Monitored control sites are typically not managed in any way (Table 5). In those (two) sites that are, stocking is the only form of management activity (Table 6).

Table 5 Presence of management activities at monitored CBFM and Control sites

		CBFM		Control	
Year	Split year	Not Managed	Managed	Not Managed	Managed
1997	1997-1998	13	3		
1998	1998-1999	8	11		
1999	1999-2000	1	16		
2000	2000-2001		14		
2001	2001-2002		13		
2002	2002-2003	5	69	18	1
2003	2003-2004		88	18	1
2004	2004-2005		83	18	2
2005	2005-2006		86	18	2

Table 6 Monitored CBFM and control sites with stocking programmes

		CBFM		Control	
Year	Split year	Not Stocked	Stocked	Not Stocked	Stocked
1997	1997-1998	15	1		
1998	1998-1999	15	4		
1999	1999-2000	13	4		
2000	2000-2001	12	2		
2001	2001-2002	11	2		
2002	2002-2003	67	7	18	1
2003	2003-2004	78	10	18	1
2004	2004-2005	73	10	18	2
2005	2005-2006	77	9	18	2

Following the start of monitoring activities in 1997, most CBFM sites have been managed with a combination of closed seasons and gear bans (Table 7). In 2003 and 2004, all CBFM sites were managed with at least gear bans and closed seasons. Harvest reserves (sanctuaries) have become increasingly important between 2002 and 2005.

Table 7 Management interventions employed at monitored CBFM sites

Year	Split year	Closed Season	Gear Bans	Reserve
1997	1997-1998	2	1	1
1998	1998-1999	2	10	1
1999	1999-2000	2	16	1
2000	2000-2001	2	14	1
2001	2001-2002	3	13	2
2002	2002-2003	70	73	12
2003	2003-2004	91	91	36
2004	2004-2005	86	86	54
2005	2005-2006	86	89	57

3.3 Monitoring Programmes

These have already been described in detail by Halls *et al* (2005).
Also see Section 3.1 of Halls and Mustafa (2006).

3.4 Analytical Procedure

As explained in Halls et al (2005), the examination of changes through time provides a means of assessing the effect of CBFM activities on management performance indicators. For example, sustained or increasing values of indicators of fish abundance (CPUE) through time would suggest that the CBFM activities are sustainable or beneficial. Declines in CPUE through time would indicate that the CBFM activities are not sustainable or are significantly depleting stocks.

Following the same methodology employed in Phases I and II, significant trends (slopes) in performance indicators through time were tested for using GLM (SPSS v 11.5) where time (year) was treated as a covariate. Only sites with at least three years of observations were included.

In some years at some sites, the CAS was not undertaken during some months for a variety of different reasons. 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.

Monitoring for the majority of sites began in 2002 corresponding to the start of the CBFM2 project. For these sites, performance indicators were available only for three or four years. Detecting significant ($p<0.05$) trends within such short time series is difficult because there is only one degree of freedom. Therefore additional analyses were employed as follows:

(i) The frequency of upward and downward trends in the performance indicators, irrespective of whether or not they were statistical significant at $\alpha=0.05$, were compared along with those for significant trends. Chi-squared tests were used to determine whether these observed frequencies were significantly different than the expected frequencies. In all cases, it was assumed that the expected frequencies of upward and downward trends would be equal if the CBFM has no effect.

(ii) Estimates of the slope coefficients for each performance indicator were compared among habitat type and between CBFM and control sites using ANOVA (GLM). Two-tailed Student t-tests where used to determine if unit slopes were significantly different from 0 (zero). For $\log_e$ transformed indicators (CPD; CPUA; CPUE; DPUA) the unit slope estimates were used to provide estimates of percentage annual change in the indicator (after back-transforming the unit slope estimate). For the untransformed H', the predicted annual change in value of H' is given. 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 slopes (coefficients) estimated using square-root transformed data cannot be interpreted meaningfully. This is important when comparing slopes or estimating average slopes. This problem arises because the estimation of the slope value is not independent of the intercept value. Because intercept values (baselines) vary, differences in slope value cannot be attributed to the CBFM effect.

(iii) Binary logistic regression analysis was used to determine which explanatory variables (predictors) were significant in determining the trends in the performance indicators (dependent variables). The dependent (dichotomous) variable was the trend in the indicator i.e. up or down. Explanatory variables were:

- GNCPUE trend
- DPUA trend (up/down)
- DFER trend (up/down)
- Reserve present (Y/N)
- Relative reserve size (loge reserve area/max area)
- Waterbody type
- Region
- Water body size
- NGO

(iv) An average 'Site score' ($Score_s$) was calculated for each site, *s* using the following score values assigned for either upward or downward trends in each of performance indicator, *i*:

	$Score_i$	
Indicator, *i*	**Upward Trend**	**Downward Trend**
CPUA	+1	-1
CPD	+1	-1
$GNCPUE_{8\text{-}9}$	+1	-1
DFER	-1	+1
DPUA	-1	+1
H'	+1	-1

$$\overline{Score_s} = \frac{\sum_i^n Score_{i,s}}{n_s}$$

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

Significant differences in mean site score $\overline{Score_s}$ between CBFM and control sites were tested for using GLM. The effect of fixed factors: NGO, waterbody type, geographical region and the covariate: waterbody size (area) on mean site scores were also examined using GLM.

3.4.1 Multivariate Comparisons of Species Assemblages

The impact of the CBFM on species assemblages was examined by comparing indices of species abundance data (small meshed seine net catch per unit effort during September 2003) between CBFM and control sites. Because of the unbalanced nature of the design, only data recorded for open beel (OB) habitat in the N and NW regions of the country could be used. Similarities in the species assemblages at CBFM and control sites were summarised in two-dimensional space using non-parametric multidimensional scaling (MDS) ordinations following a strategy proposed by Clarke (1993). The approach aims to construct a map or ordination of sites (samples) such that their placement reflects the rank similarity of their species assemblages. Sites positioned in close proximity to each other in the ordination have very similar species assemblages, whilst sites that are far apart share few common species, or have the same species but at very different levels of abundance. A "stress" measure indicates how well the ordination satisfies the (dis)similarities between sites. Stress values <0.2 indicate acceptable fits to the data. The null hypothesis [H_0: There are no differences in species assemblages between CBFM and control sites] was tested using a non-parametric permutation (analysis of similarity or ANOSIM) test based upon the difference in the average rank similarity within and between the CBFM and control site groups (*r* statistic). The significance level of the test is calculated by referring the observed value of the *r* statistic to its permutation distribution generated from randomly sampled sets of permutations of site labels.

The species most responsible for the site groupings were then determined by computing the average contribution of each species to the overall average dissimilarity between all pairs of intergroup sites.

The MDS and ANSOSIM analyses were performed with the PRIMER (**P**lymouth **R**outines **I**n **M**ultivariate **E**cological **R**esearch) software (Clarke and Warwick, 1994) on fourth-root transformed data and employing the Bray-Curtis (Bray & Curtis, 1957) similarity coefficient as the measure of similarity between pairs of sites.

4 Results

4.1 Production CPUA

4.1.1 Time Series Analysis of CBFM sites

Annual production (CPUA) estimates for three or more years were available for 80 sites. At 55 sites, the trend in $\log_e$ transformed CPUA was upward. Eleven of these upward trends were significant ($p<0.05$) (Figure 7 and Table 8). The remaining 25 sites exhibited downward trends in CPUA, only two being significant ($p<0.05$).

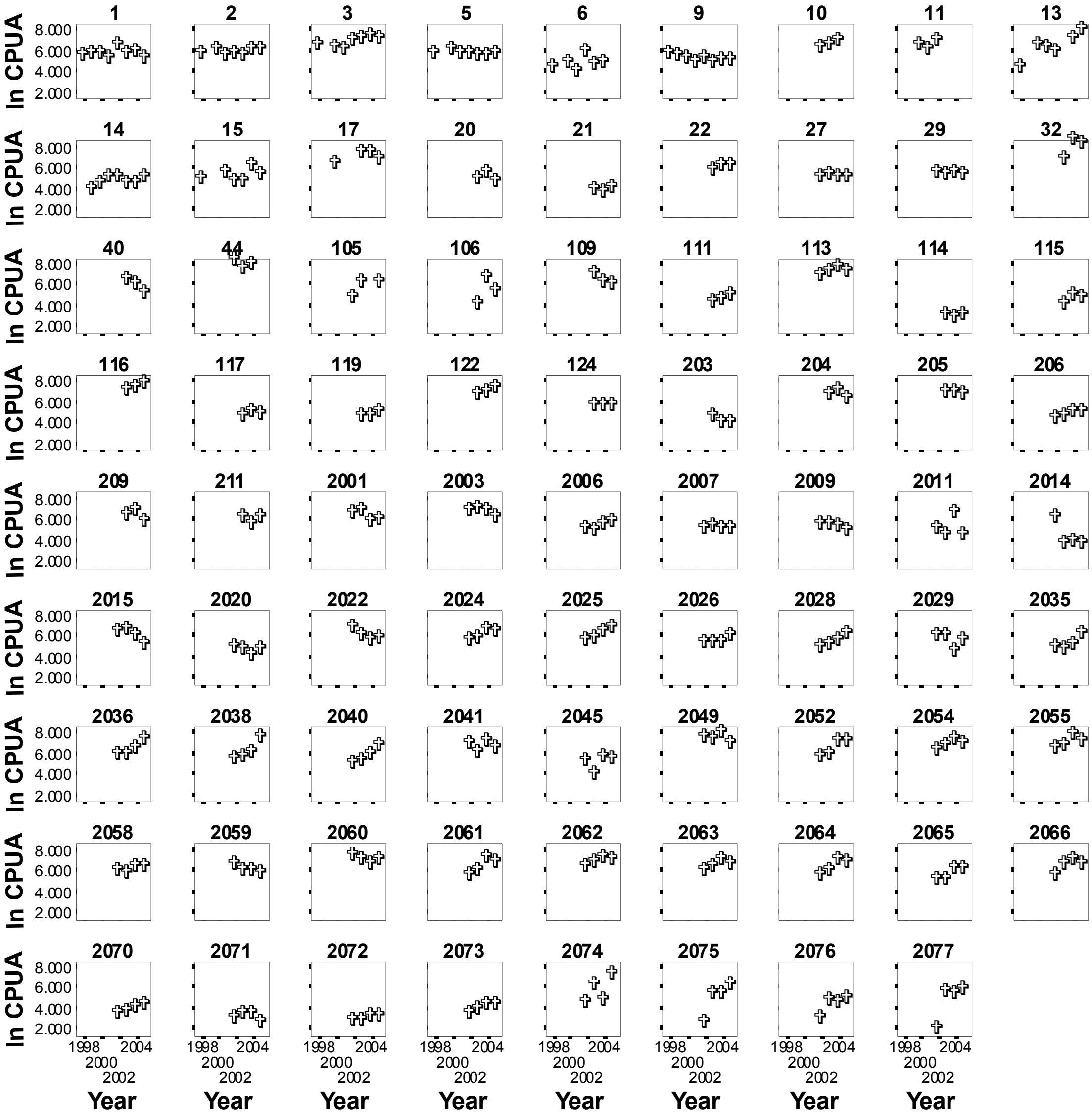

Figure 7 Estimates of loge transformed annual fish production (catch) per unit area (lnCPUA) plotted as a function of time (Year) for sites with at least three years of observations.

Table 8 Results of regression models to test for significant changes in loge transformed CPUA with time. * significant at 5% level. ** significant at 1% level. † at α = 0.05.

Site code	N	Slope (b)	p	CPUA Trend	Significance	Interpretation†	Power
1	9	0.022	0.68	Up		No change	0.07
2	8	0.071	0.14	Up		No change	0.29
3	8	0.185	<0.01	Up	**	Up	0.92
5	8	0.036	0.48	Up		No change	0.10
6	7	0.130	0.23	Up		No change	0.20
9	9	-0.079	0.03	Down	*	Down	0.63
10	3	0.380	0.03	Up	*	Up	0.91
11	3	0.271	0.63	Up		No change	0.06
13	7	0.385	<0.01	Up	**	Up	0.98
14	7	0.096	0.32	Up		No change	0.15
15	7	0.148	0.11	Up		No change	0.35
17	4	0.136	0.44	Up		No change	0.09
20	3	-0.030	0.96	Down		No change	0.05
21	3	0.075	0.71	Up		No change	0.06
22	3	0.236	0.28	Up		No change	0.13
27	4	0.023	0.78	Up		No change	0.05
29	4	-0.029	0.71	Down		No change	0.06
32	3	0.662	0.53	Up		No change	0.07
40	3	-0.614	0.08	Down		No change	0.45
44	3	-0.167	0.72	Down		No change	0.06
105	3	0.406	0.48	Up		No change	0.08
106	3	0.624	0.69	Up		No change	0.06
109	3	-0.527	0.22	Down		No change	0.17
111	3	0.307	0.03	Up	*	Up	0.94
113	4	0.210	0.32	Up		No change	0.13
114	3	0.029	0.89	Up		No change	0.05
115	3	0.334	0.45	Up		No change	0.08
116	3	0.287	0.25	Up		No change	0.15
117	3	0.100	0.67	Up		No change	0.06
119	3	0.221	0.33	Up		No change	0.11
122	3	0.327	0.11	Up		No change	0.33
124	3	-0.007	0.67	Down		No change	0.06
203	3	-0.300	0.47	Down		No change	0.08
204	3	-0.216	0.70	Down		No change	0.06
205	3	-0.092	0.54	Down		No change	0.07
206	4	0.241	0.05	Up	*	Up	0.62
209	3	-0.319	0.55	Down		No change	0.07
211	3	-0.003	>0.99	Down		No change	0.05
2001	4	-0.262	0.22	Down		No change	0.18
2003	4	-0.179	0.24	Down		No change	0.17
2006	4	0.273	0.09	Up		No change	0.41
2007	4	-0.078	0.19	Down		No change	0.21
2009	4	-0.180	0.14	Down		No change	0.29
2011	4	0.062	0.92	Up		No change	0.05
2014	4	-0.721	0.24	Down		No change	0.17
2015	4	-0.414	0.09	Down		No change	0.39
2020	4	-0.111	0.63	Down		No change	0.06
2022	4	-0.359	0.19	Down		No change	0.21
2024	4	0.297	0.15	Up		No change	0.26

2025	4	0.445	<0.01	Up	**	Up	1.00
2026	4	0.181	0.33	Up		No change	0.12
2028	4	0.401	0.04	Up	*	Up	0.74
2029	4	-0.225	0.54	Down		No change	0.07
2035	4	0.444	0.15	Up		No change	0.26
2036	4	0.547	0.05	Up	*	Up	0.58
2038	4	0.676	0.09	Up		No change	0.40
2040	4	0.593	0.04	Up	*	Up	0.66
2041	4	0.004	0.99	Up		No change	0.05
2045	4	0.220	0.61	Up		No change	0.07
2049	4	-0.113	0.70	Down		No change	0.06
2052	4	0.557	0.06	Up		No change	0.56
2054	4	0.232	0.35	Up		No change	0.12
2055	4	0.313	0.29	Up		No change	0.14
2058	4	0.200	0.19	Up		No change	1.98
2059	4	-0.294	0.05	Down	*	Down	0.63
2060	4	-0.123	0.50	Down		No change	0.08
2061	4	0.515	0.14	Up		No change	0.29
2062	4	0.246	0.11	Up		No change	0.34
2063	4	0.287	0.18	Up		No change	0.22
2064	4	0.483	0.07	Up		No change	0.50
2065	4	0.437	0.10	Up		No change	0.36
2066	4	0.359	0.23	Up		No change	0.18
2070	4	0.313	0.03	Up	*	Up	0.85
2071	4	-0.149	0.47	Down		No change	0.09
2072	4	0.187	0.12	Up		No change	0.33
2073	4	0.293	0.04	Up	*	Up	0.73
2074	4	0.712	0.32	Up		No change	0.13
2075	4	1.067	0.11	Up		No change	0.34
2076	4	0.571	0.18	Up		No change	0.23
2077	4	1.114	0.18	Up		No change	0.22

4.2 Sustainability - Fish abundance indices

4.2.1 Catch per fisher per day (CPD) (trend) analysis

Trends in fish abundance indicated by CPD were upward at 52 sites. Eleven of these upward trends were significant ($p<0.05$) (Figure 8 and Table 9). The remaining 28 sites exhibited downward trends in CPD, but only one was significant ($p<0.05$).

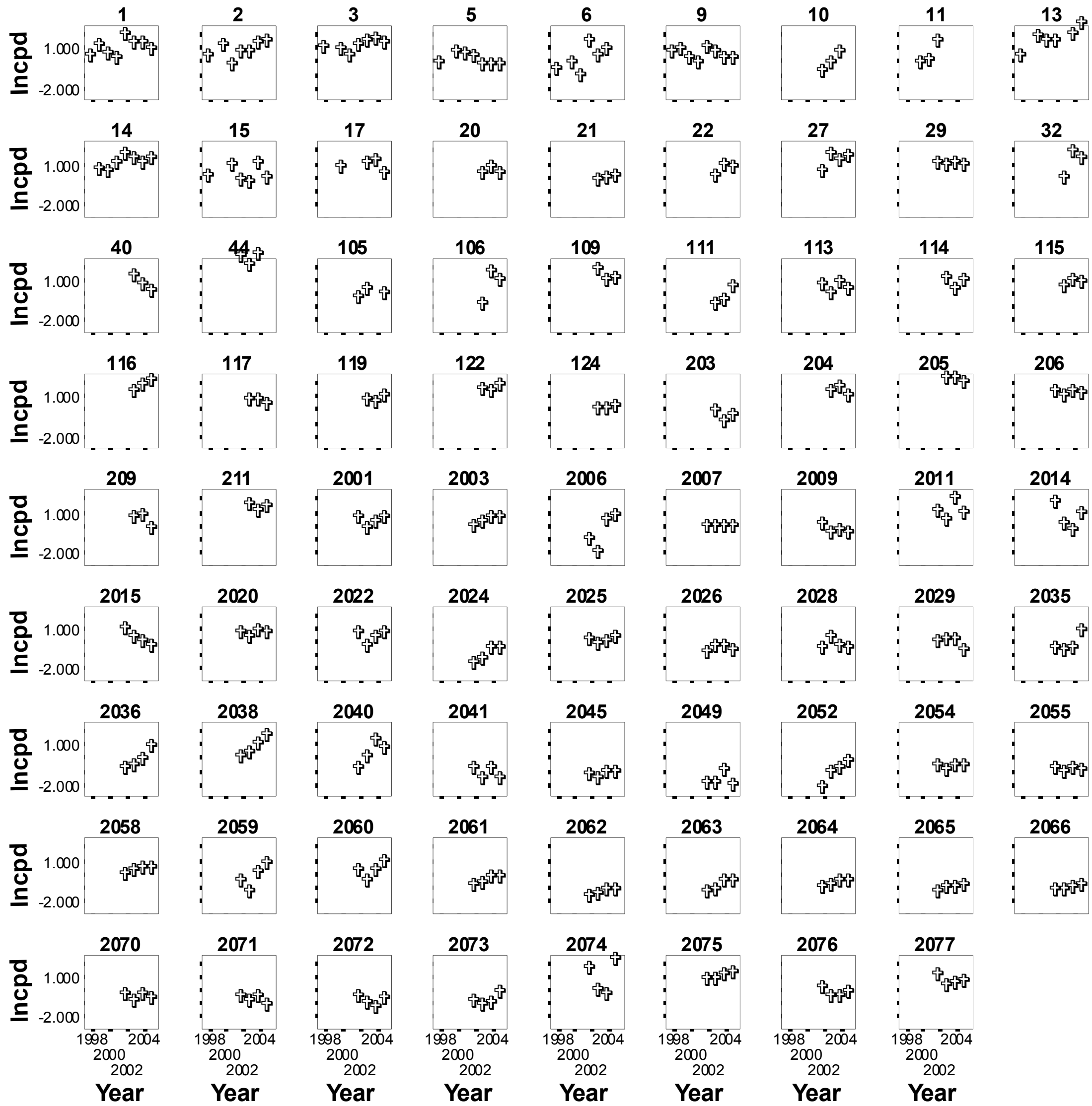

Figure 8 Estimates of loge transformed fish abundance index: CPD plotted as a function of time (year) for CBFM sites with at least 3 years of observations. Includes stocked waterbodies and control sites.

Table 9 Results of regression models to test for significant changes in loge transformed CPD with time. * significant at 5% level. ** significant at 1% level. † at α = 0.05.

Site code	N	Slope (b)	p	CPD Trend	Significance	Interpretation†	Power
1	9	0.071	0.36	Up		No change	0.14
2	8	0.104	0.19	Up		No change	0.24
3	8	0.101	0.05	Up	*	Up	0.56
5	8	-0.031	0.62	Down		No change	0.07
6	7	0.195	0.18	Up		No change	0.25
9	9	-0.089	0.16	Down		No change	0.28
10	3	0.661	<0.01	Up	*	Up	1.00
11	3	0.791	0.30	Up		No change	0.12
13	7	0.225	0.02	Up	*	Up	0.82
14	7	0.150	0.08	Up		No change	0.42
15	7	0.120	0.29	Up		No change	0.16
17	4	-0.012	0.94	Down		No change	0.05
20	3	-0.012	0.97	Down		No change	0.05
21	3	0.168	0.07	Up		No change	0.52
22	3	0.284	0.47	Up		No change	0.08
27	4	0.296	0.28	Up		No change	0.14
29	4	-0.024	0.60	Down		No change	0.07
32	3	0.728	0.47	Up		No change	0.08
40	3	-0.547	0.10	Down		No change	0.38
44	3	0.091	0.88	Up		No change	0.05
105	3	0.079	0.75	Up		No change	0.05
106	3	0.849	0.52	Up		No change	0.07
109	3	-0.310	0.43	Down		No change	0.08
111	3	0.636	0.23	Up		No change	0.16
113	4	0.006	0.98	Up		No change	0.05
114	3	-0.091	0.87	Down		No change	0.05
115	3	0.170	0.53	Up		No change	0.07
116	3	0.395	0.04	Up	*	Up	0.80
117	3	-0.183	0.24	Down		No change	0.16
119	3	0.125	0.63	Up		No change	0.06
122	3	0.199	0.47	Up		No change	0.08
124	3	0.049	<0.01	Up	**	Up	1.00
203	3	-0.180	0.71	Down		No change	0.06
204	3	-0.149	0.74	Down		No change	0.05
205	3	-0.153	0.41	Down		No change	0.09
206	4	-0.039	0.69	Down		No change	0.06
209	3	-0.443	0.38	Down		No change	0.10
211	3	-0.077	0.83	Down		No change	0.05
2001	4	0.049	0.81	Up		No change	0.05
2003	4	0.255	0.04	Up	*	Up	0.66
2006	4	0.803	0.22	Up		No change	0.19
2007	4	-0.006	0.88	Down		No change	0.05
2009	4	-0.193	0.16	Down		No change	0.25
2011	4	0.112	0.80	Up		No change	0.05
2014	4	-0.300	0.57	Down		No change	0.07
2015	4	-0.384	0.02	Down	*	Down	0.92
2020	4	0.044	0.73	Up		No change	0.06
2022	4	0.046	0.87	Up		No change	0.05
2024	4	0.410	0.04	Up	*	Up	0.70

2025	4	0.097	0.39	Up		No change	0.10
2026	4	0.072	0.60	Up		No change	0.07
2028	4	-0.048	0.84	Down		No change	0.05
2029	4	-0.186	0.32	Down		No change	0.12
2035	4	0.396	0.22	Up		No change	0.18
2036	4	0.581	0.05	Up	*	Up	0.59
2038	4	0.554	0.02	Up	*	Up	0.93
2040	4	0.571	0.17	Up		No change	0.23
2041	4	-0.175	0.52	Down		No change	0.08
2045	4	0.095	0.47	Up		No change	0.09
2049	4	0.010	0.97	Up		No change	0.05
2052	4	0.589	0.06	Up		No change	0.57
2054	4	0.007	0.94	Up		No change	0.05
2055	4	-0.019	0.86	Down		No change	0.05
2058	4	0.150	0.21	Up		No change	0.19
2059	4	0.526	0.22	Up		No change	0.18
2060	4	0.274	0.36	Up		No change	0.11
2061	4	0.239	0.04	Up	*	Up	0.73
2062	4	0.138	0.11	Up		No change	0.36
2063	4	0.312	0.10	Up		No change	0.39
2064	4	0.134	0.06	Up		No change	0.54
2065	4	0.117	0.11	Up		No change	0.35
2066	4	0.117	0.20	Up		No change	0.21
2070	4	-0.027	0.85	Down		No change	0.05
2071	4	-0.135	0.43	Down		No change	0.09
2072	4	-0.052	0.81	Down		No change	0.05
2073	4	0.207	0.38	Up		No change	0.10
2074	4	0.135	0.86	Up		No change	0.05
2075	4	0.155	0.08	Up		No change	0.44
2076	4	-0.120	0.48	Down		No change	0.08
2077	4	-0.153	0.47	Down		No change	0.08

4.2.2 Gillnet catch rates $GNCPUE_{8-9}$ time series (trend) analysis

Of the 86 sites with three or more years of observations, 32 showed an upward trend in gillnet catch rates during August and September ($GNCPUE_{8-9}$), 17 of which were significant ($p<0.05$). However, 54 sites exhibited downward trends, 34 of which were significant (Figure 9-13 and Table 10).

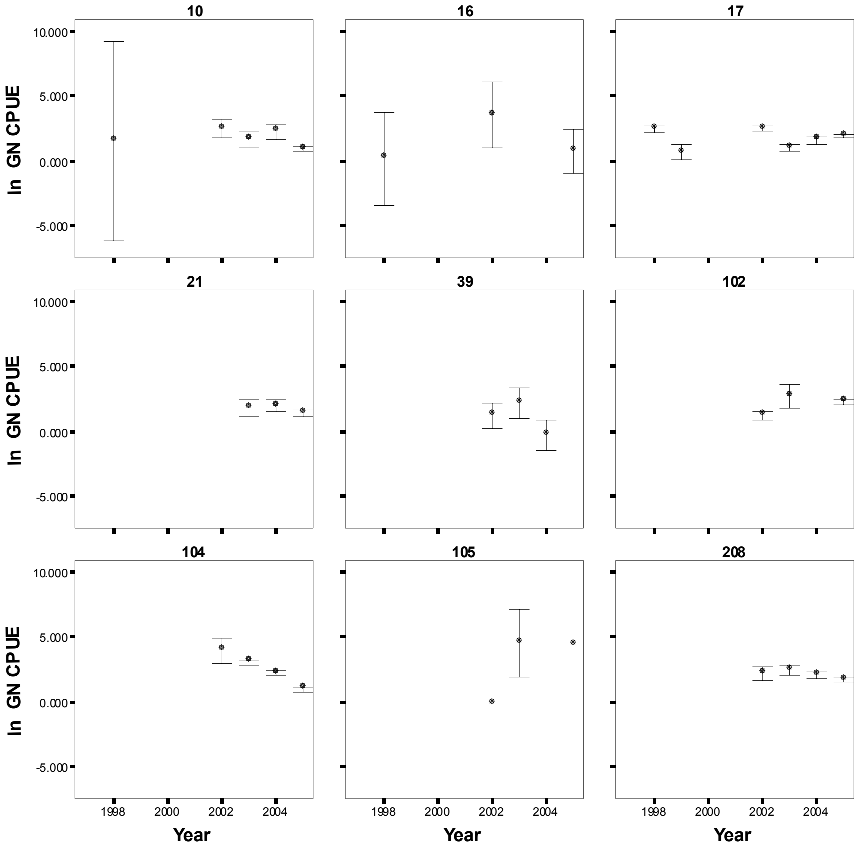

Figure 9 Estimates of mean loge transformed fish abundance index: effort standardised gillnet catch rate (LN $GNCPUE_{8-9}$) with 95% confidence intervals for closed beel habitat plotted as a function of time (year) for CBFM sites with at least 3 years of observations. Includes stocked waterbodies and control sites.

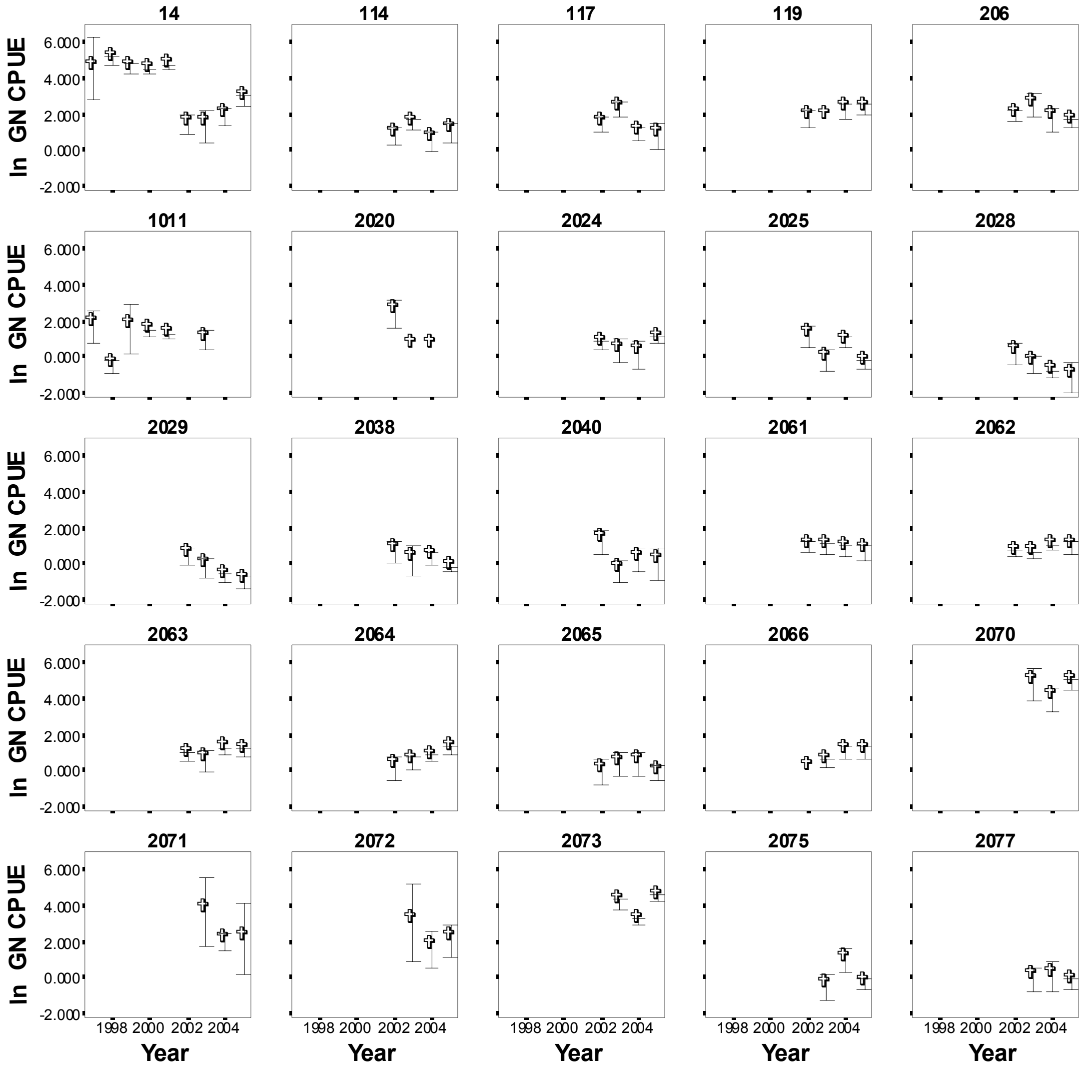

Figure 10 Estimates of mean loge transformed fish abundance index: effort standardised gillnet catch rate (LN GN $CPUE_{8-9}$) with 95% confidence intervals for floodplain beel habitat plotted as a function of time (year) for CBFM sites with at least 3 years of observations. Includes control sites.

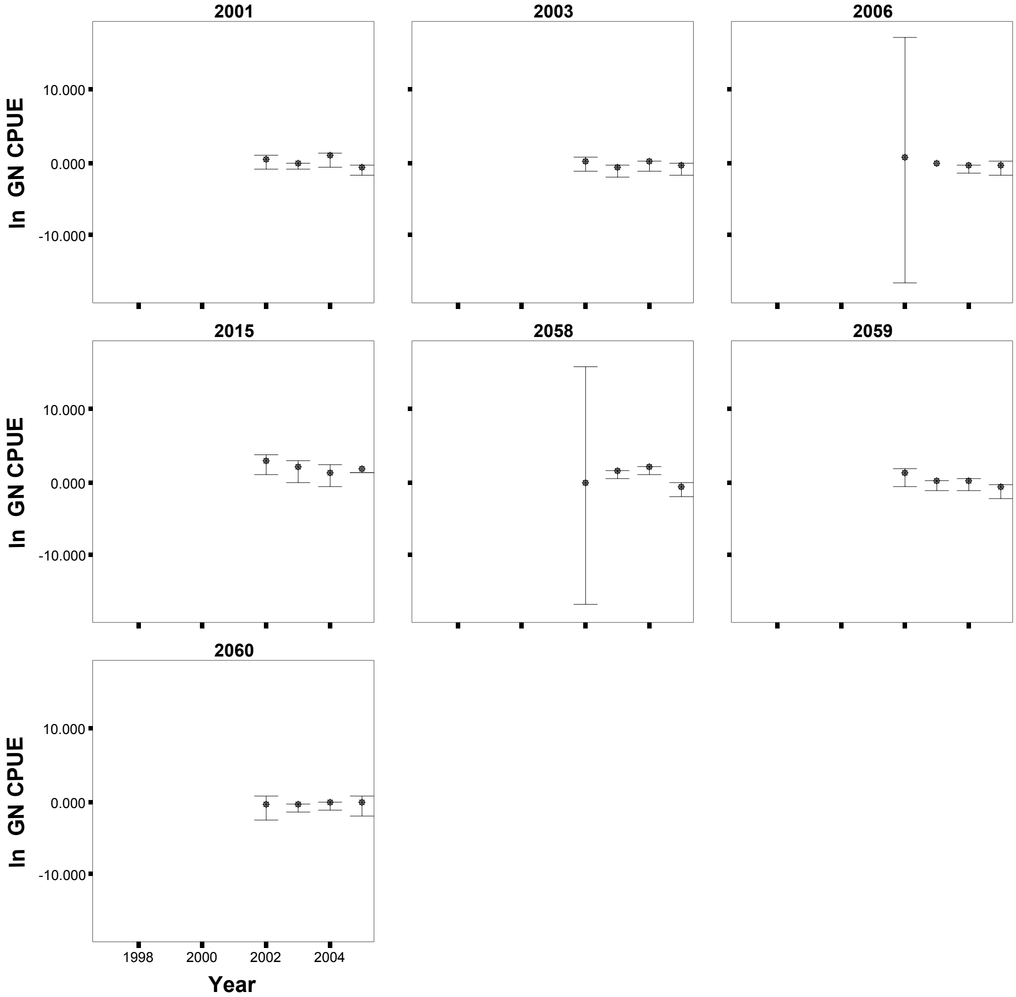

Figure 11 Estimates of mean loge transformed fish abundance index: effort standardised gillnet catch rate (LN GN $CPUE_{8-9}$) with 95% confidence intervals for Haor beel habitat plotted as a function of time (year) for CBFM sites with at least 3 years of observations. Includes control sites.

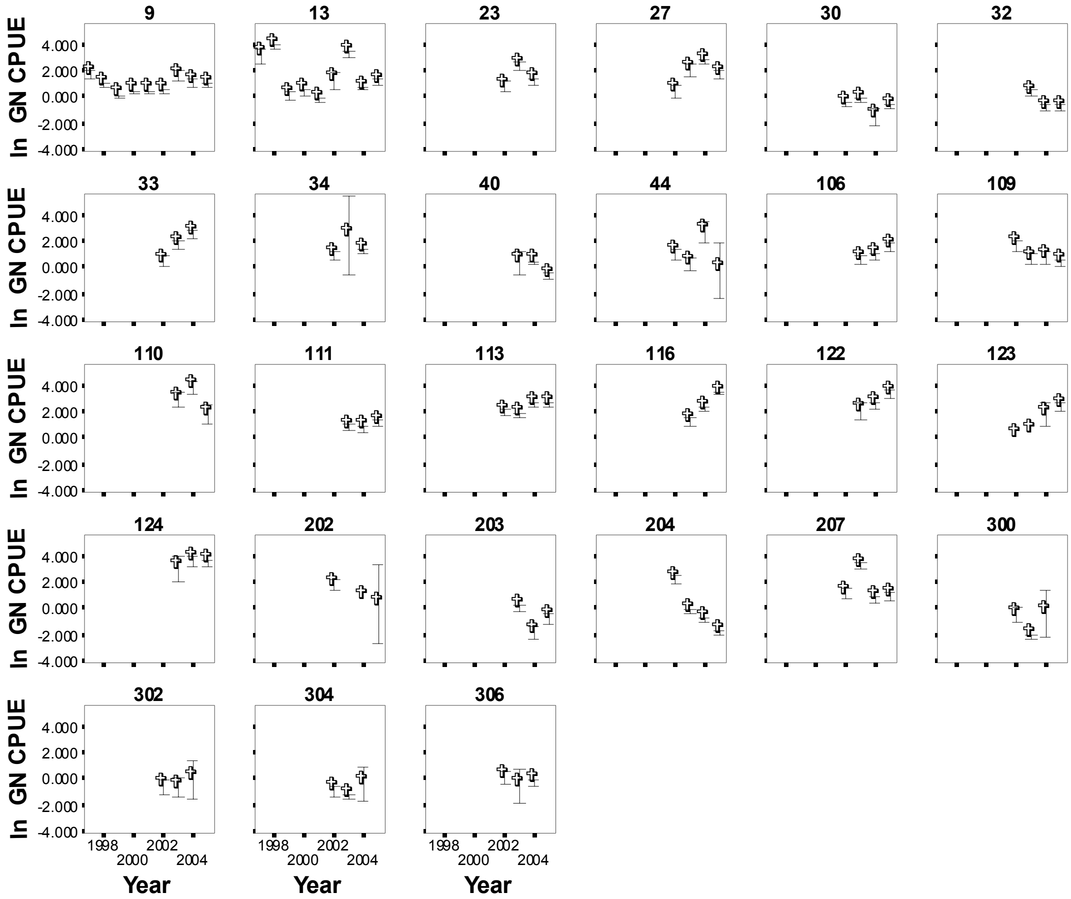

Figure 12 Estimates of mean loge transformed fish abundance index: effort standardised gillnet catch rate (LN GN $CPUE_{8\text{-}9}$) with 95% confidence intervals for open beel habitat plotted as a function of time (year) for CBFM sites with at least 3 years of observations. Includes control sites.

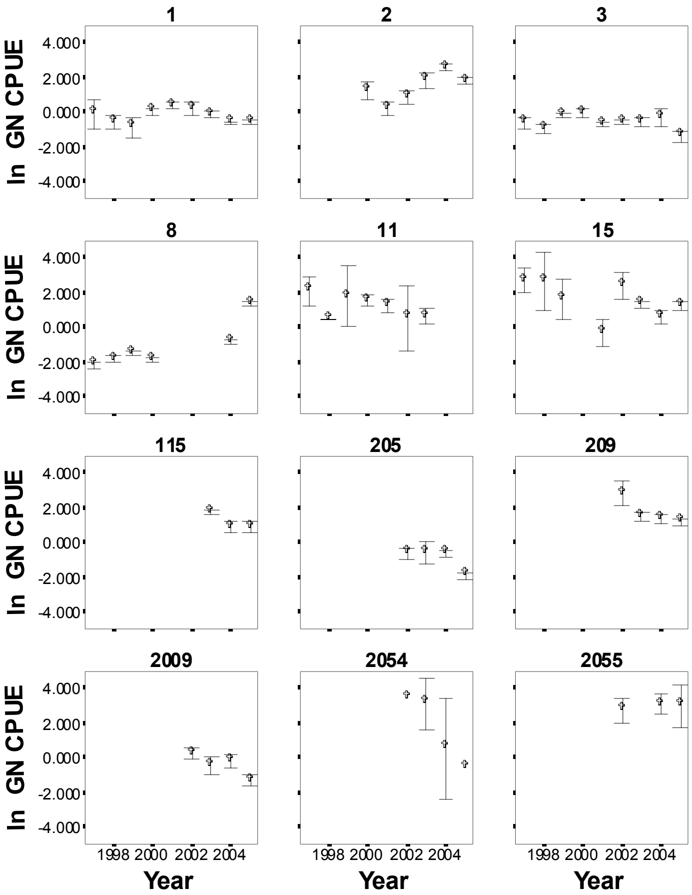

Figure 13 Estimates of mean loge transformed fish abundance index: effort standardised gillnet catch rate (LN GN $CPUE_{8\text{-}9}$) with 95% confidence intervals for river habitat plotted as a function of time (year) for CBFM sites with at least 3 years of observations. Includes control sites.

Table 10 Results of regression models to test for significant changes in loge transformed GN $CPUE_{8-9}$. * significant at 5% level. ** significant at 1% level. † at α = 0.05.

Site code	N	Slope (b)	p	CPUE Trend	Significance	Interpretation†	Power
1	305	-0.043	0.02	Down	*	Down	0.64
2	143	0.322	<0.01	Up	**	Up	1.00
3	167	-0.016	0.45	Down		No change	0.12
5	78	-0.009	0.75	Down		No change	0.06
6	65	0.159	<0.01	Up	**	Up	0.91
8	395	0.390	<0.01	Up	**	Up	1.00
9	335	0.013	0.34	Up		No change	0.16
10	72	-0.301	<0.01	Down	**	Down	0.97
11	40	-0.218	<0.01	Down	**	Down	0.96
13	276	-0.210	<0.01	Down		No change	1.00
14	164	-0.460	<0.01	Down		No change	1.00
15	110	-0.189	<0.01	Down		No change	1.00
16	9	0.062	0.82	Up		No change	0.05
17	159	-0.057	0.04	Down	*	Down	0.54
21	33	-0.211	0.14	Down		No change	0.31
23	47	0.203	0.17	Up		No change	0.28
24	28	0.319	0.22	Up		No change	0.23
27	58	0.575	<0.01	Up	**	Up	1.00
29	142	-0.352	<0.01	Down	**	Down	1.00
30	98	-0.140	0.01	Down	**	Down	0.70
32	158	-0.546	<0.01	Down	**	Down	1.00
33	69	1.004	<0.01	Up	**	Up	1.00
34	23	0.134	0.26	Up		No change	0.20
39	26	-0.736	0.06	Down		No change	0.48
40	37	-0.749	<0.01	Down	**	Down	1.00
44	47	0.421	0.09	Up		No change	0.40
102	79	0.331	<0.01	Up	**	Up	1.00
104	71	-0.974	<0.01	Down	**	Down	1.00
105	5	1.096	0.34	Up		No change	0.13
106	108	0.516	<0.01	Up	**	Up	0.99
109	134	-0.397	<0.01	Down	**	Down	0.98
110	16	-0.354	0.21	Down		No change	0.23
111	104	0.207	0.04	Up	*	Up	0.56
113	131	0.316	<0.01	Up	**	Up	1.00
114	87	-0.009	0.94	Down		No change	0.05
115	70	-0.426	<0.01	Down	**	Down	0.98
116	103	1.127	<0.01	Up	**	Up	1.00
117	64	-0.343	0.01	Down	**	Down	0.72
119	29	0.183	0.03	Up	*	Up	0.62
122	37	0.774	<0.01	Up	**	Up	1.00
123	20	0.789	<0.01	Up	**	Up	1.00
124	76	0.123	0.41	Up		No change	0.13
202	16	-0.479	<0.01	Down	**	Down	0.87
203	75	-0.446	<0.01	Down	**	Down	0.82
204	60	-1.220	<0.01	Down	**	Down	1.00
205	64	-0.416	<0.01	Down	**	Down	1.00
206	44	-0.205	0.05	Down	*	Down	0.52
207	79	-0.193	0.05	Down	*	Down	0.51
208	114	-0.224	<0.01	Down	**	Down	0.87

209	78	-0.291	<0.01	Down	**	Down	0.98
211	31	-0.052	0.73	Down		No change	0.06
300	16	-0.181	0.59	Down		No change	0.08
302	32	0.224	0.45	Up		No change	0.11
304	19	0.162	0.40	Up		No change	0.13
306	33	-0.201	0.13	Down		No change	0.32
1011	67	0.214	<0.01	Up	**	Up	0.81
2001	38	-0.247	0.15	Down		No change	0.29
2003	27	-0.124	0.46	Down		No change	0.11
2006	15	-0.273	0.26	Down		No change	0.19
2007	46	-0.596	<0.01	Down	**	Down	0.94
2009	46	-0.424	<0.01	Down	**	Down	0.99
2015	12	-0.448	0.04	Down	*	Down	0.59
2020	6	-1.100	0.03	Down	*	Down	0.72
2024	66	-0.042	0.67	Down		No change	0.07
2025	93	-0.445	<0.01	Down	**	Down	0.99
2028	55	-0.454	<0.01	Down	**	Down	0.97
2029	116	-0.508	<0.01	Down	**	Down	1.00
2038	37	-0.288	<0.01	Down	**	Down	0.77
2040	38	-0.379	0.02	Down	*	Down	0.66
2054	52	-1.753	<0.01	Down	**	Down	0.81
2055	25	0.132	0.43	Up		No change	0.12
2058	19	-0.457	0.22	Down		No change	0.23
2059	28	-0.491	<0.01	Down	**	Down	0.71
2060	22	0.069	0.69	Up		No change	0.07
2061	30	-0.098	0.13	Down		No change	0.32
2062	122	0.168	<0.01	Up	**	Up	0.95
2063	62	0.125	0.07	Up		No change	0.46
2064	54	0.321	<0.01	Up	**	Up	0.98
2065	36	-0.028	0.84	Down		No change	0.05
2066	41	0.378	<0.01	Up	**	Up	0.96
2070	48	0.151	0.60	Up		No change	0.08
2071	13	-0.756	0.07	Down		No change	0.46
2072	18	-0.301	0.41	Down		No change	0.12
2073	39	-0.039	0.79	Down		No change	0.06
2075	36	0.037	0.89	Up		No change	0.05
2077	30	-0.109	0.68	Down		No change	0.07

4.3 Fishing Intensity (DPUA)

4.3.1 Time series analysis

At 38 of the 80 sites examined, the trend in fishing intensity (DPUA) was upward, compared to 42 downward. Four of the upward and three of the downward trends were significant ($p<0.05$) (Figure 14 and Table 11).

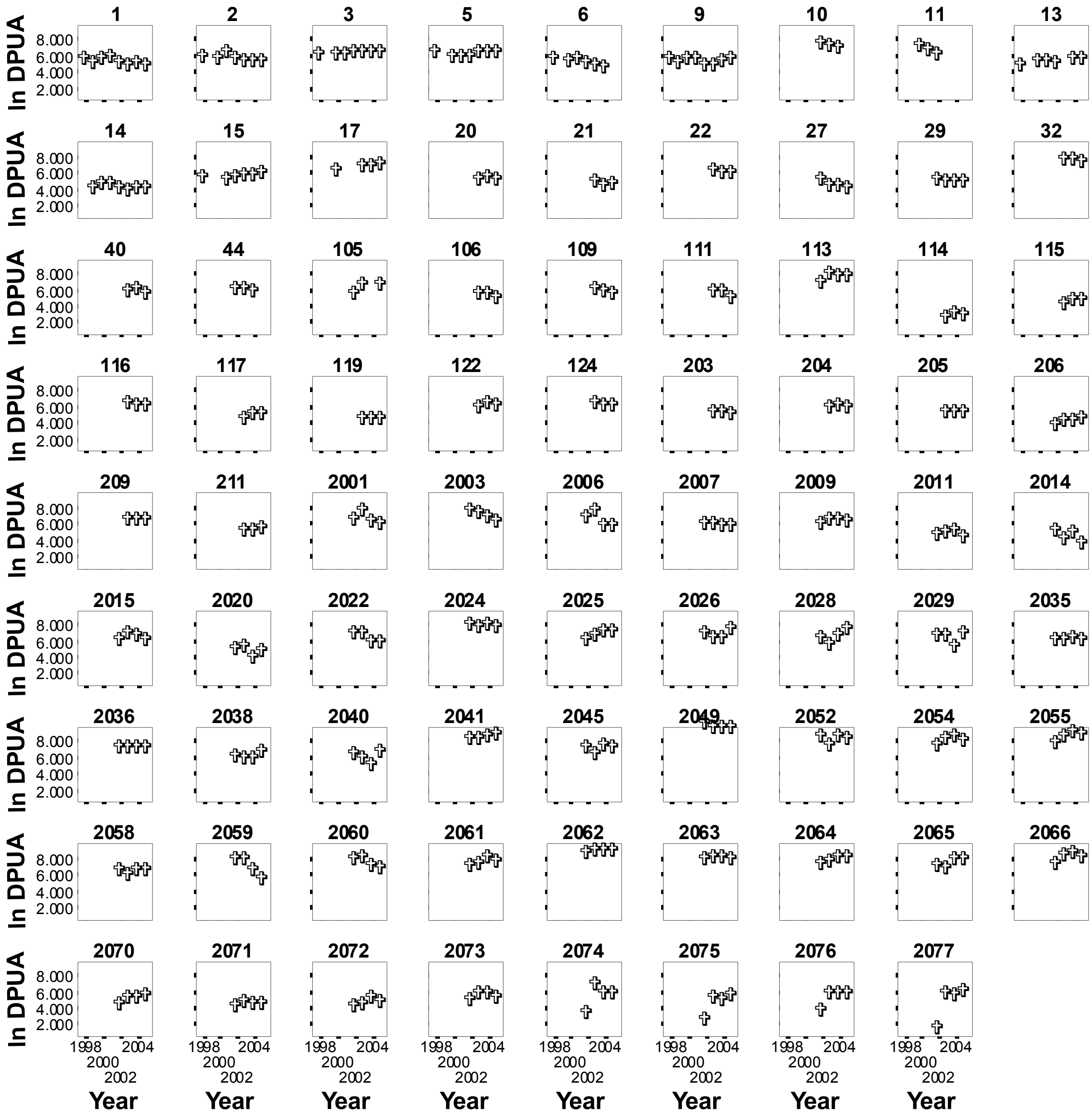

Figure 14 Estimates of loge transformed fishing intensity (DPUA) plotted as a function of time for CBFM sites with at least three years of observations.

Table 11 Results of regression models to test for significant changes in ln DPUA with time. * significant at 5% level. ** significant at 1% level. † at α = 0.05.

Site code	N	Slope (b)	p	DPUA Trend	Significance	Interpretation†	Power
1	9	-0.049	0.28	Down		No change	0.17
2	8	-0.033	0.55	Down		No change	0.08
3	8	0.084	<0.01	Up	**	Up	0.92
5	8	0.067	0.17	Up		No change	0.25
6	7	-0.065	0.42	Down		No change	0.11
9	9	0.010	0.86	Up		No change	0.05
10	3	-0.280	0.04	Down	*	Down	0.73
11	3	-0.521	<0.01	Down	**	Down	1.00
13	7	0.160	<0.01	Up	**	Up	0.89
14	7	-0.054	0.45	Down		No change	0.10
15	7	0.027	0.59	Up		No change	0.08
17	4	0.147	0.06	Up		No change	0.53
20	3	-0.017	0.95	Down		No change	0.05
21	3	-0.092	0.62	Down		No change	0.06
22	3	-0.048	0.80	Down		No change	0.05
27	4	-0.273	0.18	Down		No change	0.22
29	4	-0.004	0.91	Down		No change	0.05
32	3	-0.066	0.52	Down		No change	0.07
40	3	-0.067	0.76	Down		No change	0.05
44	3	-0.257	0.24	Down		No change	0.16
105	3	0.327	0.34	Up		No change	0.11
106	3	-0.224	0.53	Down		No change	0.07
109	3	-0.217	0.17	Down		No change	0.22
111	3	-0.329	0.42	Down		No change	0.09
113	4	0.204	0.43	Up		No change	0.09
114	3	0.120	0.74	Up		No change	0.05
115	3	0.165	0.34	Up		No change	0.11
116	3	-0.107	0.46	Down		No change	0.08
117	3	0.283	0.22	Up		No change	0.17
119	3	0.097	0.38	Up		No change	0.10
122	3	0.128	0.48	Up		No change	0.08
124	3	-0.056	0.13	Down		No change	0.29
203	3	-0.120	0.43	Down		No change	0.08
204	3	-0.067	0.56	Down		No change	0.07
205	3	0.061	0.14	Up		No change	0.28
206	4	0.280	0.04	Up	*	Up	0.69
209	3	0.124	0.33	Up		No change	0.11
211	3	0.074	0.59	Up		No change	0.06
2001	4	-0.312	0.41	Down		No change	0.10
2003	4	-0.434	0.02	Down	*	Down	0.93
2006	4	-0.529	0.28	Down		No change	0.14
2007	4	-0.072	0.43	Down		No change	0.09
2009	4	0.013	0.93	Up		No change	0.05
2011	4	-0.282	0.59	Down		No change	0.06
2014	4	-0.347	0.67	Down		No change	0.06
2015	4	-0.357	0.12	Down		No change	0.31
2020	4	-0.187	0.81	Down		No change	0.05
2022	4	-0.521	0.33	Down		No change	0.11
2024	4	-0.113	0.14	Down		No change	0.29
2025	4	0.348	0.04	Up	*	Up	0.72

2026	4	0.110	0.70	Up	No change	0.06
2028	4	0.449	0.24	Up	No change	0.17
2029	4	-0.039	0.94	Down	No change	0.05
2035	4	0.049	0.57	Up	No change	0.07
2036	4	-0.034	0.62	Down	No change	0.07
2038	4	0.122	0.52	Up	No change	0.08
2040	4	0.021	0.96	Up	No change	0.05
2041	4	0.179	0.08	Up	No change	0.43
2045	4	0.125	0.68	Up	No change	0.06
2049	4	-0.123	0.15	Down	No change	0.26
2052	4	-0.032	0.91	Down	No change	0.05
2054	4	0.225	0.41	Up	No change	0.10
2055	4	0.332	0.27	Up	No change	0.15
2058	4	0.050	0.78	Up	No change	0.05
2059	4	-1.212	0.08	Down	No change	0.47
2060	4	-0.674	0.30	Down	No change	0.13
2061	4	0.275	0.24	Up	No change	0.17
2062	4	0.107	0.26	Up	No change	0.16
2063	4	-0.025	0.79	Down	No change	0.05
2064	4	0.348	0.07	Up	No change	0.48
2065	4	0.319	0.23	Up	No change	0.17
2066	4	0.242	0.45	Up	No change	0.09
2070	4	0.204	0.33	Up	No change	0.11
2071	4	-0.248	0.19	Down	No change	0.20
2072	4	0.093	0.85	Up	No change	0.05
2073	4	-0.296	0.42	Down	No change	0.09
2074	4	-0.530	0.37	Down	No change	0.10
2075	4	0.185	0.60	Up	No change	0.06
2076	4	-0.006	0.96	Down	No change	0.05
2077	4	0.015	0.96	Up	No change	0.05

4.4 Destructive fishing effort ratio (DFER)

4.4.1 Time series analysis

Forty (half) of the 80 sites examined exhibited an upward trend in destructive fishing gear use, whilst the remaining 40 showed an decrease. Four upward and four downward trends were also significant at the p=0.05 level (Figure 15 and Table 12).

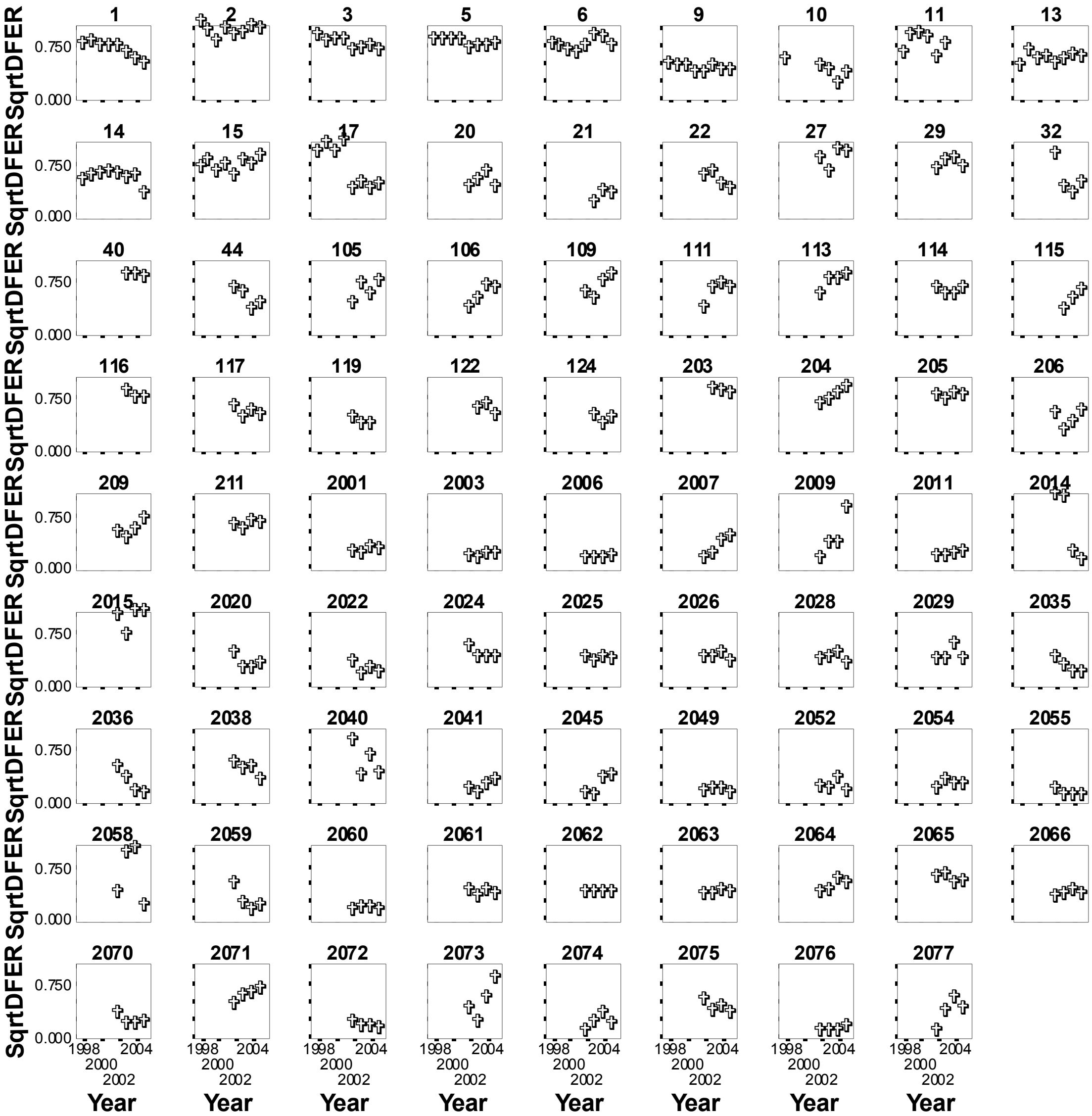

Figure 15 Estimates of square-root transformed destructive fishing gear effort ratio (SqrtDFER) plotted as a function of time (year) for CBFM sites with at least three years of observations.

Table 12 Results of regression models to test for significant changes in SqrtDFER with time. * significant at 5% level. ** significant at 1% level. † at α = 0.05.

Site code	N	Slope (b)	p	DFER Trend	Significance	Interpretation†	Power
1	9	-0.034	<0.01	Down	**	Down	0.99
2	8	-0.005	0.69	Down		No change	0.06
3	8	-0.017	0.07	Down		No change	0.44
5	8	-0.007	0.35	Down		No change	0.14
6	7	0.001	0.95	Up		No change	0.05
9	9	-0.012	0.07	Down		No change	0.46
10	3	-0.034	0.03	Down	*	Down	0.69
11	3	0.001	0.98	Up		No change	0.05
13	7	0.025	0.10	Up		No change	0.38
14	7	0.012	0.60	Up		No change	0.08
15	7	0.011	0.37	Up		No change	0.13
17	4	-0.076	0.03	Down	*	Down	0.63
20	3	0.014	0.82	Up		No change	0.05
21	3	0.065	0.46	Up		No change	0.08
22	3	-0.073	0.18	Down		No change	0.23
27	4	0.055	0.48	Up		No change	0.08
29	4	0.015	0.74	Up		No change	0.06
32	3	-0.135	0.33	Down		No change	0.12
40	3	-0.023	0.39	Down		No change	0.09
44	3	-0.095	0.18	Down		No change	0.22
105	3	0.071	0.35	Up		No change	0.11
106	3	0.101	0.08	Up		No change	0.46
109	3	0.093	0.19	Up		No change	0.21
111	3	0.089	0.24	Up		No change	0.17
113	4	0.092	0.09	Up		No change	0.42
114	3	-0.001	0.96	Down		No change	0.05
115	3	0.145	<0.01	Up	**	Up	1.00
116	3	-0.055	0.33	Down		No change	0.11
117	3	-0.031	0.46	Down		No change	0.09
119	3	-0.058	0.32	Down		No change	0.12
122	3	-0.043	0.64	Down		No change	0.06
124	3	-0.017	0.81	Down		No change	0.05
203	3	-0.035	0.21	Down		No change	0.18
204	3	0.085	<0.01	Up	**	Up	1.00
205	3	0.007	0.76	Up		No change	0.06
206	4	0.017	0.83	Up		No change	0.05
209	3	0.073	0.22	Up		No change	0.18
211	3	0.025	0.45	Up		No change	0.09
2001	4	0.019	0.45	Up		No change	0.09
2003	4	0.008	0.47	Up		No change	0.09
2006	4	0.004	0.56	Up		No change	0.07
2007	4	0.120	0.02	Up	*	Up	0.89
2009	4	0.209	0.09	Up		No change	0.41
2011	4	0.022	0.17	Up		No change	0.23
2014	4	-0.367	0.07	Down		No change	0.48
2015	4	0.051	0.59	Up		No change	0.07
2020	4	-0.043	0.45	Down		No change	0.09
2022	4	-0.040	0.36	Down		No change	0.11
2024	4	-0.045	0.23	Down		No change	0.17
2025	4	-0.004	0.85	Down		No change	0.05

2026	4	-0.010	0.77	Down		No change	0.06
2028	4	-0.013	0.69	Down		No change	0.06
2029	4	0.016	0.81	Up		No change	0.05
2035	4	-0.079	0.06	Down		No change	0.54
2036	4	-0.133	0.05	Down	*	Down	0.62
2038	4	-0.068	0.16	Down		No change	0.25
2040	4	-0.109	0.39	Down		No change	0.10
2041	4	0.049	0.16	Up		No change	0.25
2045	4	0.101	0.10	Up		No change	0.38
2049	4	-0.007	0.65	Down		No change	0.06
2052	4	-0.001	0.99	Down		No change	0.05
2054	4	0.009	0.79	Up		No change	0.05
2055	4	-0.033	0.20	Down		No change	0.20
2058	4	-0.050	0.84	Down		No change	0.05
2059	4	-0.105	0.19	Down		No change	0.21
2060	4	0.005	0.60	Up		No change	0.07
2061	4	-0.002	0.94	Down		No change	0.05
2062	4	-0.004	0.56	Down		No change	0.07
2063	4	0.023	0.18	Up		No change	0.23
2064	4	0.053	0.25	Up		No change	0.16
2065	4	-0.031	0.23	Down		No change	0.18
2066	4	0.016	0.50	Up		No change	0.08
2070	4	-0.037	0.35	Down		No change	0.12
2071	4	0.068	0.04	Up	*	Up	0.72
2072	4	-0.028	0.09	Down		No change	0.39
2073	4	0.169	0.20	Up		No change	0.20
2074	4	0.037	0.50	Up		No change	0.08
2075	4	-0.052	0.24	Down		No change	0.17
2076	4	0.014	0.23	Up		No change	0.18
2077	4	0.107	0.27	Up		No change	0.15

4.5 Biodiversity

4.5.1 Univariate Trend Analysis

Fifty-four of the 85 sites for which three or more estimates were available showed an upward trend in biodiversity (H') with time, eight of which were significant. Only two of the remaining 31 downward trends were significant (Figure 16 and Table 13).

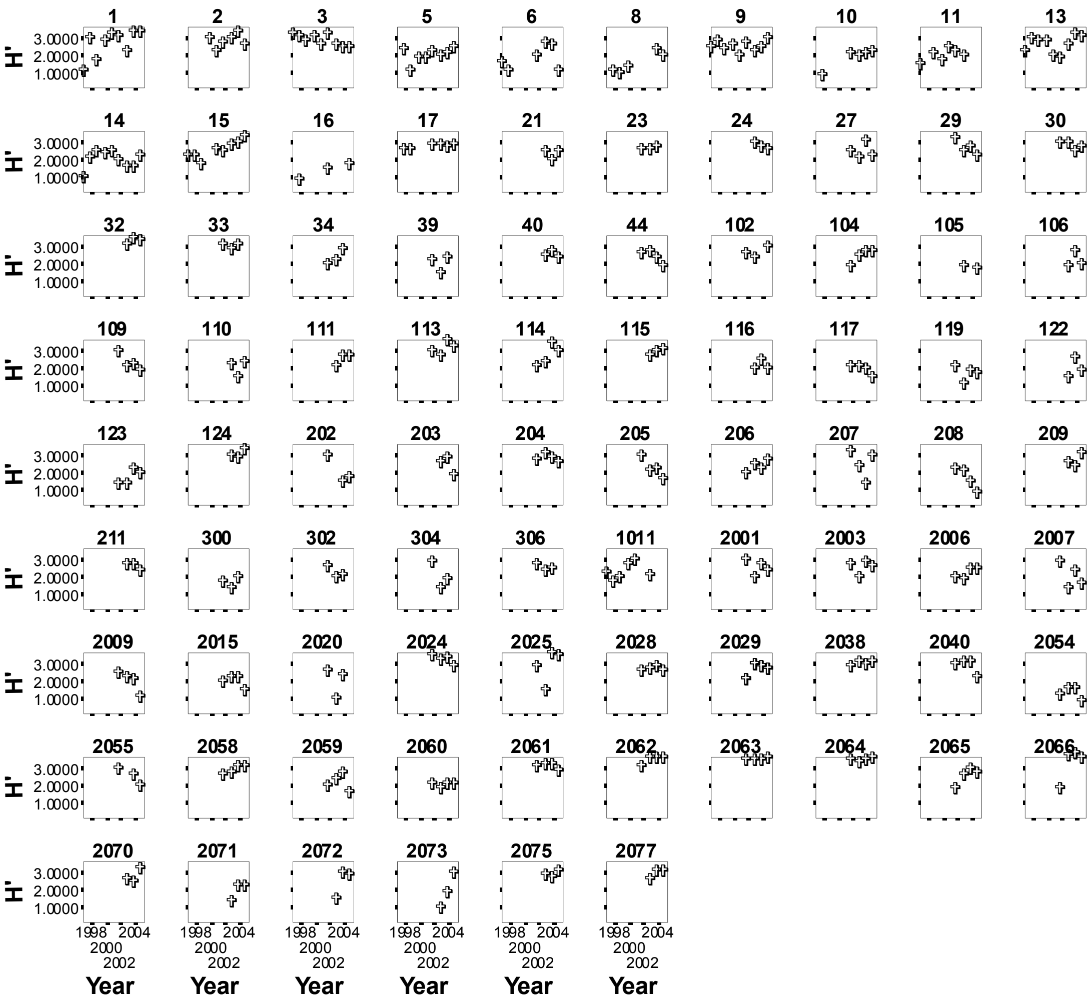

Figure 16 Estimates of mean H' (based upon $GNCPUE_{8-9}$) plotted as a function of time for sites with at least three years of observations.

Table 13 Results of GLM models to test for significant changes in H' with time. H' estimated using $GNCPUE_{8\text{-}9}$. * significant at 5% level. ** significant at 1% level. † at α = 0.05.

Site code	N	Slope (b)	p	H Trend	Significance	Interpretation†	Power
1	9	0.197	0.05	Up	*	Up	0.53
2	6	0.041	0.68	Up		No change	0.06
3	9	-0.092	0.01	Down	**	Down	0.83
5	8	0.074	0.27	Up		No change	0.18
6	6	0.082	0.45	Up		No change	0.10
8	5	0.183	0.02	Up	*	Up	0.79
9	9	0.011	0.80	Up		No change	0.06
10	5	0.194	0.03	Up	*	Up	0.76
11	6	0.112	0.15	Up		No change	0.28
13	9	0.051	0.46	Up		No change	0.10
14	9	0.025	0.73	Up		No change	0.06
15	8	0.149	<0.01	Up	**	Up	0.94
16	3	0.137	0.09	Up		No change	0.41
17	6	0.044	<0.01	Up	**	Up	0.89
21	3	0.033	0.93	Up		No change	0.05
23	3	0.073	0.29	Up		No change	0.13
24	3	-0.230	0.16	Down		No change	0.24
27	4	0.025	0.92	Up		No change	0.05
29	4	-0.293	0.18	Down		No change	0.23
30	4	-0.104	0.34	Down		No change	0.12
32	3	0.102	0.61	Up		No change	0.06
33	3	-0.058	0.73	Down		No change	0.06
34	3	0.412	0.17	Up		No change	0.23
39	3	0.050	0.93	Up		No change	0.05
40	3	-0.046	0.86	Down		No change	0.05
44	4	-0.263	0.10	Down		No change	0.36
102	3	0.149	0.49	Up		No change	0.07
104	4	0.261	0.12	Up		No change	0.32
106	3	0.033	0.96	Up		No change	0.05
109	4	-0.300	0.16	Down		No change	0.25
110	3	0.040	0.95	Up		No change	0.05
111	3	0.324	0.26	Up		No change	0.14
113	4	0.142	0.44	Up		No change	0.09
114	3	0.373	0.24	Up		No change	0.17
115	3	0.154	<0.01	Up	**	Up	1.00
116	3	0.036	0.93	Up		No change	0.05
117	4	-0.221	0.12	Down		No change	0.32
119	4	-0.038	0.89	Down		No change	0.05
122	3	0.196	0.79	Up		No change	0.05
123	4	0.264	0.22	Up		No change	0.19
124	3	0.196	0.45	Up		No change	0.08
202	3	-0.499	0.31	Down		No change	0.12
203	3	-0.333	0.53	Down		No change	0.07
204	4	-0.084	0.51	Down		No change	0.08
205	4	-0.410	0.07	Down		No change	0.48
206	4	0.203	0.21	Up		No change	0.20
207	4	-0.171	0.73	Down		No change	0.06
208	4	-0.449	0.05	Down	*	Down	0.63
209	3	0.274	0.50	Up		No change	0.07
211	3	-0.180	0.27	Down		No change	0.14

300	3	0.112	0.75	Up		No change	0.05
302	3	-0.213	0.44	Down		No change	0.08
304	3	-0.527	0.50	Down		No change	0.07
306	3	-0.134	0.49	Down		No change	0.07
1011	6	0.081	0.45	Up		No change	0.10
2001	4	-0.073	0.78	Down		No change	0.05
2003	4	0.025	0.92	Up		No change	0.05
2006	4	0.233	0.16	Up		No change	0.25
2007	4	-0.283	0.47	Down		No change	0.09
2009	4	-0.442	0.11	Down		No change	0.35
2015	4	-0.130	0.49	Down		No change	0.08
2020	3	-0.098	0.93	Down		No change	0.05
2024	4	-0.194	0.13	Down		No change	0.29
2025	4	0.389	0.47	Up		No change	0.09
2028	4	0.036	0.63	Up		No change	0.06
2029	8	0.182	0.12	Up		No change	0.33
2038	4	0.081	0.15	Up		No change	0.27
2040	4	-0.235	0.25	Down		No change	0.16
2054	4	-0.117	0.62	Down		No change	0.07
2055	3	-0.293	0.24	Down		No change	0.16
2058	4	0.190	0.04	Up	*	Up	0.66
2059	4	-0.050	0.87	Down		No change	0.05
2060	4	0.025	0.73	Up		No change	0.06
2061	4	-0.080	0.47	Down		No change	0.09
2062	4	0.142	0.27	Up		No change	0.15
2063	4	0.009	0.48	Up		No change	0.08
2064	4	0.044	0.39	Up		No change	0.10
2065	4	0.281	0.23	Up		No change	0.18
2066	4	0.553	0.24	Up		No change	0.17
2070	3	0.314	0.44	Up		No change	0.08
2071	3	0.418	0.28	Up		No change	0.13
2072	3	0.698	0.35	Up		No change	0.10
2073	3	1.026	0.03	Up	*	Up	0.95
2075	3	0.146	0.43	Up		No change	0.08
2077	3	0.290	0.33	Up		No change	0.11

4.5.2 Multivariate Analysis

Unlike the analysis described by Halls *et al* (1998), there were insufficient control sites to test whether species assemblages vary significantly among habitat type and geographic region. Therefore to ensure that the tests were robust, and based upon the conclusions of Halls *et al* 1998, differences in species assemblages between CBFM and control sites were tested for only within the same habitat and region.

Since only one control site was selected, differences in species assemblages between CBFM and control sites could not be tested for closed beel habitat. Significant ($p<0.05$) differences in species assemblages at CBFM and control sites were found only for floodplain beel habitat in the north, and river habitat in the east (Table 14 and Figure 17).

Table 14 Results from the one-way ANOSIM to test for differences in species assemblages between CBFM and Control sites. Only testable habitat and region combinations containing at least two control sites are shown.

Habitat	Region	n (CBFM sites)	n (Control sites)	R value	Possible permutations	Permutations used	Significant statistics	Significance level
FPB	N	13	2	0.250	560	560	25	**4.5%**
Haor	E	4	4	-0.021	35	35	25	71%
OB	N	12	2	0.102	91	91	31	34%
OB	NW	9	2	-0.246	55	55	48	87%
River	E	4	3	0.824	35	35	1	**2.9%**

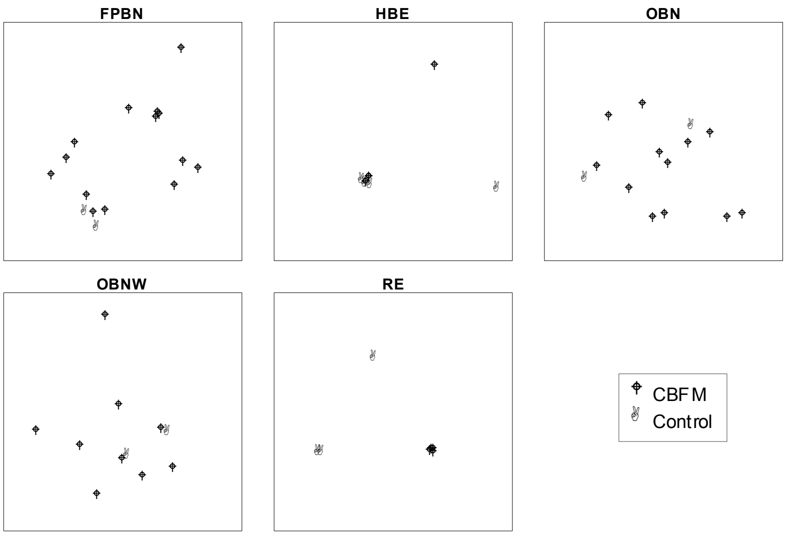

Figure 17 MDS ordinations comparing species assemblages at CBFM and control sites in each habitat/region combination. Stress values for each ordination from left to right and top to bottom: 0.08, 0.01, 0.16, 0.10, 0.01.

Floodplain Beel Habitat, North Region

For floodplain-beel habitat in the north region, more than 30 species representing both blackfish and whitefish were either absent or less abundant at the two control sites compared to the 13 CBFM sites (Figure 18). In descending order of importance these included the following whitefish (and river prawn) species: *Cirrhinus mrigala, mystus tengra, labeo rohita, puntius chola, Xenentodon cancila, Glossogobius giuris, macrobrachium macolmsonii, puntius conchonius, Ompok bimaculatus, Macrobrachium birmanicum, Nematopalaemon tenuipes, Catla catla, Notopterus notopterus, Puntius stigma*, and *Puntius ticto*. The absent or less abundant blackfish were, in descending order of importance: *Colisa fasciatus Amblypharyngodon mola, Colisa sota, Channa punctatus, Anabas testudineus, Nandus nandus, Channa barca, Chanda ranga, Colisa lalius* and *Channa striatus*.

Only nine species were more abundant at control compared to CBFM sites: *Labeo calbasu, Mastacembelus armatus, Cyprinus carpio, Mystus cavascius, Puntius gonionotus, Crossochelius latius, Gudusia chapra, Mytus bleekeri,* and *Leiognathus equulus.*

It is uncertain which management interventions may be responsible for these differences. All 13 CBFM sites employed gear bans and closed seasons, and three also employed harvest reserves. Given the potential difficulty in selecting comparable control sites, these differences in species assemblages may simply reflect differences in site habitat.

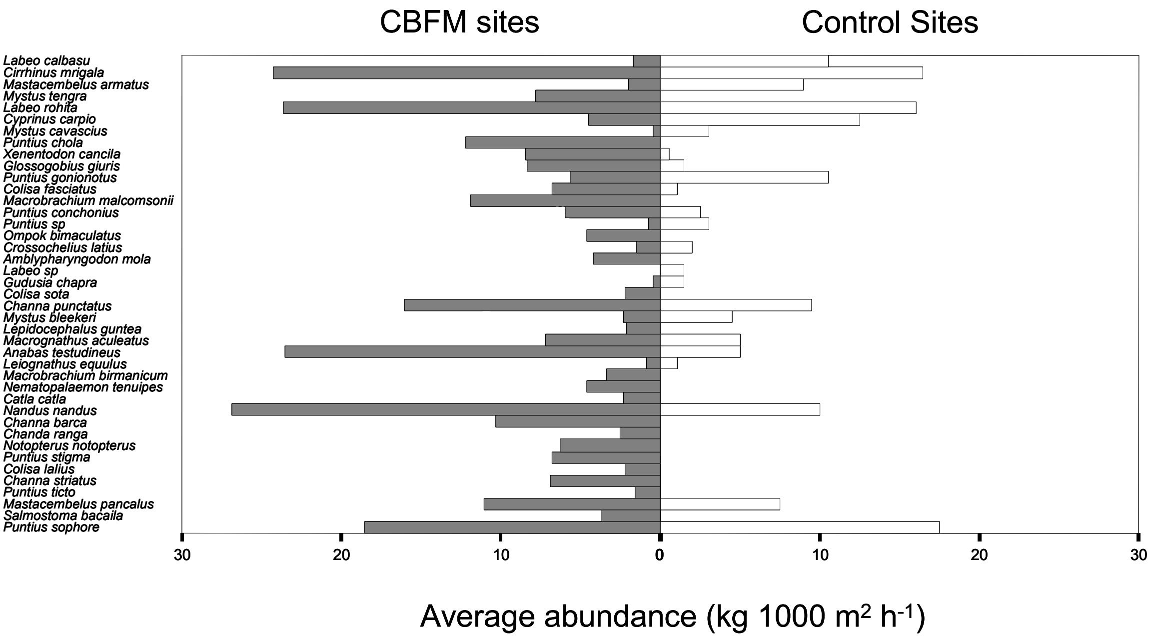

Figure 18 Average abundance [gillnet catch per unit effort (kg 1000 m^2 h^{-1})] of species caught from CBFM and control sites exploiting floodplain-beel habitat in the north region of the country. Species are arranged from top to bottom in descending order of their contribution to the average dissimilarity between the two groups (CBFM or control) of sites. Only those species contributing to 85% of the cumulative average dissimilarity are shown.

River Habitat in the East Region

Species assemblages at the CBFM sites comprised almost three times more species than those of the control sites (Figure 19). Of the 23 recorded species, 19 were present or more abundant at CBFM sites. These included, in descending order of their contribution to the average dissimilarity between the two groups of sites: *Puntius sophore, Nandus nandus, Pama pama, Mystus bleekeri, Mastacembelus pancalus, Glossogobius guiris, Clupisoma garua, Wallago attu, Macrognathus aculeatus, Pseudeutropius atherinoides, Mastacembelus armatus* and *Heteropneustes fossilis*. These species are also members of both *whitefish* and *blackfish*. Only four species were more abundant at the control sites: *Labeo calbasu, Mystus seenghala, Labeo gonius* and *Hilsa ilisha*. The latter two were absent from the CBFM sites.

All four CBFM sites employed gear bans and closed seasons, and three CBFM sites also employed harvest reserves to improve management performance. Two of the control sites also employed gear bans and closed seasons. However, because these interventions were not effectively implemented, project staff categorised these sites as 'Control sites' (Mustafa pers. comms.)

It is uncertain which management interventions may be responsible for these differences, if any, given the potential difficulty in selecting comparable control sites. These differences in species assemblages may therefore simply reflect differences in site habitat.

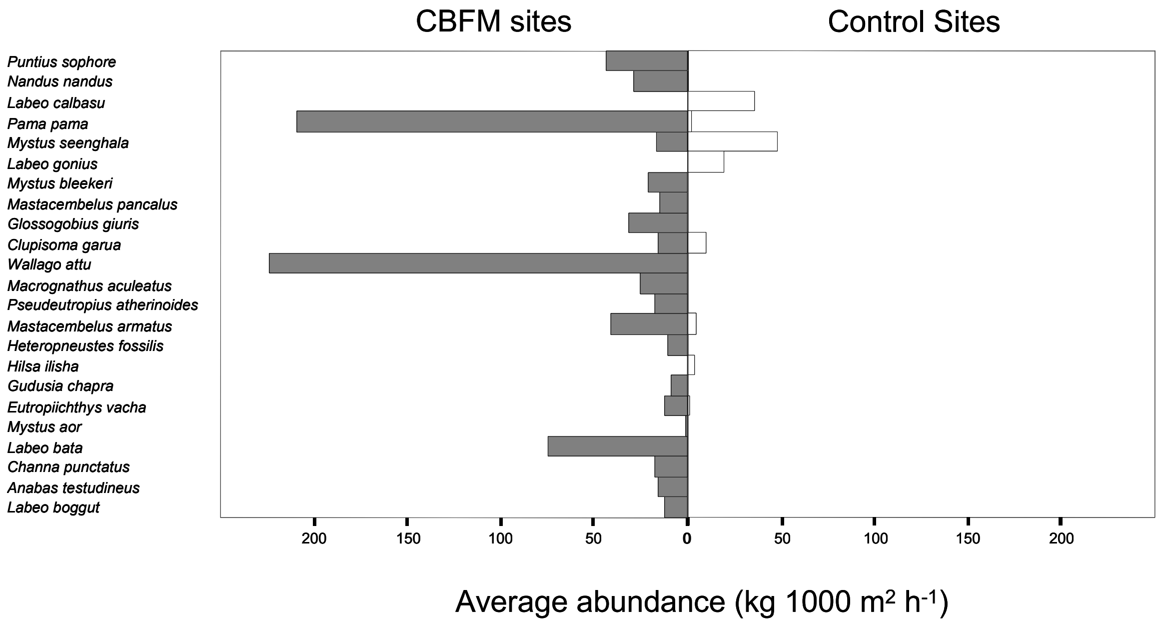

Figure 19 Average abundance [gillnet catch per unit effort (kg 1000 m^2 h^{-1})] of species caught from CBFM and control sites exploiting river habitat in the east region of the country. Species are arranged from top to bottom in descending order of their contribution to the average dissimilarity between the two groups (CBFM or control) of sites.

4.6 Results Synthesis

4.6.1 Indicator Trends

Taken at ‘face value’ , that is ignoring the statistical significance of the individual site trends, the number of upward compared to downward trends in CPUA, CPD and H’ at CBFM sites only would **not** be expected by chance (Table 15). The relative frequencies of these upward and downward trends indicate that CBFM activities have benefited production (CPUA), fish abundance measured in terms as catch per day (CPD) and biodiversity indicated by H’ at the majority (70-80%) of CBFM sites. The probability that this is a false conclusion if only significant trends are considered is less than 13%. Considering only significant trends the proportion of upward trends increases to approximately 90% for the three indicators.

Fishing intensity (DPUA) and destructive fishing practices (DFER) both declined at more CBFM sites than they increased at but these frequencies could be expected by chance.

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 also be expected by chance.

This apparent positive effect of the CBFM is further reflected in the indicator trends for the control sites. Downward trends in CPUA, CPD and H’ were more frequent than upward at control sites, but these relative frequencies could be expected by chance (Table 15). 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 15 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)					
	Trends	Total Up	55	52	32	40	38	54
		Total Down	25	28	54	40	42	31
		% Up	69	65	37	50	48	64
		Chi-squared (X2) (P)	<0.01	<0.01	0.02	1.00	0.65	0.01
Significant	**Trends**	Total Up	11	11	17	4	4	8
		Total Down	2	1	34	4	3	2
		Chi-squared (X2) (P)	0.08	0.04	0.09	1.00	0.79	0.18
			CBFM SITES ONLY					
	Trends	Total Up	49	46	30	29	30	48
		Total Down	15	18	40	35	34	21
		% Up	77	72	43	45	47	70
		Chi-squared (X2) (P)	<0.01	<0.01	0.23	0.45	0.62	<0.01
Significant	**Trends**	Total Up	10	11	17	2	3	7
		Total Down	1	1	23	4	3	1
		Chi-squared (X2) (P)	0.06	0.04	0.50	0.56	1.00	0.13
			CONTROL SITES ONLY					
	Trends	Total Up	**6**	6	2	11	8	6
		Total Down	10	10	14	5	8	10
		% Up	38	38	13	69	50	38
		Chi-squared (X2) (P)	0.32	0.32	<0.01	0.13	1.00	0.32
Significant	**Trends**	Total Up	1	0	0	2	1	1
		Total Down	1	0	11	0	0	1
		Chi-squared (X2) (P)	1.00	NA	0.02	0.32	0.48	1.00

Table 16 Summary of trends in performance indicators, site score and management interventions at each waterbody. Underline indicates significant trend at α=0.05 level. *Status in 2003

WBID	WBNAME	CBFM_OR	HABITAT	REGION	NGO	CPUA TREND	CPD TREND	CPUE TREND	DPUA TREND	DFER TREND	H' TREND	JALMOHAL CODE	MAXAREA	STOCKED*	CLOSED*	GEARBAN*	RESERVE*	Score
1	Kali Nodi JR (CBFM-1)	CBFM	R	N	Proshika	Up	Up	<u>Down</u>	Down	<u>Down</u>	<u>Up</u>	2	800	N	Y	Y	Y	0.67
2	Titas Nodi (ka) (CBFM-1)	CBFM	R	E	Proshika	Up	Up	<u>Up</u>	Down	Down	Up	2	425	N	Y	Y	Y	1
3	Titas Nodi (Gokon-Gosh.)	CBFM	R	E	Proshika	<u>Up</u>	<u>Up</u>	Down	<u>Up</u>	Down	<u>Down</u>	2	215	N	Y	Y	Y	0
5	Moisherkandi Boronpur Nodi	CBFM	R	N	Proshika	Up	Down	Down	Up	Down	Up	1	150	N	Y	Y	Y	0
6	Dhaleswari Nodi JR / NFMP	CBFM	R	E	Proshika	Up	Up	<u>Up</u>	Down	Up	Up	2	550	N	Y	Y	N	0.67
8	Tetulia River (CBFM-1)	CBFM	R	SW	Proshika			<u>Up</u>			<u>Up</u>	2	450	N	Y	Y	N	1
9	Ashurar Beel JB (CBFM-1)	CBFM	OB	NW	Caritas	<u>Down</u>	Down	Up	Up	Down	Up	1	400	N	Y	Y	Y	0
10	Hamil Beel JB (CBFM-1)	CBFM	CB	N	Caritas	<u>Up</u>	<u>Up</u>	<u>Down</u>	<u>Down</u>	<u>Down</u>	<u>Up</u>	1	20	Y	Y	Y	Y	0.67
11	Ubdakhali Nodi Jalmahal	CBFM	R	N	Caritas	Up	Up	<u>Down</u>	<u>Down</u>	Up	Up	1	68	N	Y	Y	N	0.33
13	Dikshi Beel reach 1 and 2	CBFM	OB	NW	Caritas	<u>Up</u>	<u>Up</u>	<u>Down</u>	<u>Down</u>	Up	Up	1	250	N	Y	Y	Y	0.33
14	Goakhola-Hatiara	CBFM	FPB	SW	Banchte Shekha	Up	Up	<u>Down</u>	Down	Up	Up	3	250	N	Y	Y	Y	0.33
15	Arialkha-Gangajoli River JR	CBFM	R	N	CRED	Up	Up	<u>Down</u>	Up	Up	<u>Up</u>	2	150	N	Y	Y	Y	0
16	Dum Nadi Beel JB (CBFM-1)	CBFM	CB	NW	BRAC			Up			Up	1	58	Y	Y	Y	N	1
17	Ruhia Baisha Beel (CBFM-1)	CBFM	CB	NW	BRAC	Up	Down	<u>Down</u>	Up	<u>Down</u>	<u>Up</u>	1	45	Y	Y	Y	N	0
20	Kafri Khal JB	CBFM	CB	NW	Caritas	Down	Down		Down	Up		1	70	Y	Y	Y	N	-0.5
21	Morlai Beel	CBFM	CB	NW	Caritas	Up	Up	Down	Down	Up	Up	1	150	N	Y	Y	Y	0.33
22	Tulshidanga Beel JB	CBFM	CB	NW	Caritas	Up	Up		Down	Down		1	30	Y	Y	Y	Y	1
23	Beel Shapla Fishery JB	CBFM	OB	E	Proshika			Up			Up	1	195	N	Y	Y	N	1
24	Norshingpur Nodi JR	CBFM	R	N	Proshika			Up			Down	1	400	N	Y	Y	Y	0
27	Beel Shakla Jalmahal	CBFM	OB	E	Proshika	Up	Up	<u>Up</u>	Down	Up	Up	1	180	N	Y	Y	N	0.67
29	Pagla Nodi	CBFM	R	E	Proshika	Down	Down	<u>Down</u>	Down	Up	Down	2	692	N	Y	Y	Y	-0.67
30	Beel Alaikhali Fishery	CBFM	OB	E	Proshika			<u>Down</u>			Down	1	24	N	Y	Y	Y	-1
32	Dopi Beel	CBFM	OB	N	Proshika	Up	Up	<u>Down</u>	Down	Down	Up	1	32	Y	Y	Y	Y	0.67
33	Beel Hatina Mural	CBFM	OB	E	Proshika			<u>Up</u>			Down	1	50	N	Y	Y	N	0
34	Beel Hural Fishery JB	CBFM	OB	E	Proshika			Up			Up	1	788	N	Y	Y	N	1
39	Mara Beel JB	CBFM	CB	N	Caritas			Down			Up	1	148	N	Y	Y		0
40	Meda Beel JB	CBFM	OB	N	Caritas	Down	Down	<u>Down</u>	Down	Down	Down	1	81	N	Y	Y	Y	-0.33
44	Haily Beel JB	CBFM	OB	N	Caritas	Up	Up	Up	Down	Down	Down	1	65	N	Y	Y	N	0.67
102	Serudanga Chakchaka Beel	CBFM	CB	NW	BRAC			<u>Up</u>			Up	1	84	N	Y	Y	Y	1

104	Saralar Beel JB	CBFM	CB	NW	BRAC			Down			Up	1	50	Y	Y	Y	Y	0
105	Chapandaha Beel JB	CBFM	CB	NW	BRAC	Up	Up	Up	Up	Up		1	90	Y	Y	Y	N	0.2
106	Nuruil Beel JB	CBFM	OB	NW	BRAC	Up	Up	Up	Down	Up	Up	1	130	N	Y	Y	Y	0.67
109	Raktadah Beel JB	CBFM	OB	NW	BRAC	Down	Down	Down	Down	Up	Down	1	140	N	Y	Y	Y	-0.67
110	Nandinar Beel	CBFM	OB	NW	BRAC			Down			Up	1	50	N	Y	Y	N	0
111	Kakrar Beel JB	CBFM	OB	NW	BRAC	Up	Up	Up	Down	Up	Up	1	100	N	Y	Y	Y	0.67
113	Kutir Beel	CBFM	OB	N	CRED	Up	Up	Up	Up	Up	Up	1	18	N	Y	Y	Y	0.33
114	Shuluar Beel	CBFM	FPB	SW	Banchte Shekha	Up	Down	Down	Up	Down	Up	3	1120	N	Y	Y	Y	0
115	Chitra River	CBFM	R	SW	Banchte Shekha	Up	Up	Down	Up	Up	Up	2	598	N	Y	Y	Y	0
116	Nalia Karma JB	CBFM	OB	N	BRAC	Up	Up	Up	Down	Down	Up	1	50	N	Y	Y	N	1
117	Debbhog Beel	CBFM	FPB	SW	Banchte Shekha	Up	Down	Down	Up	Down	Down	3	150	N	Y	Y	Y	-0.33
119	Kathuria Beel	CBFM	FPB	SW	Banchte Shekha	Up	Up	Up	Up	Down	Down	3	150	N	Y	Y	Y	0.33
122	Dubail Beel JB	CBFM	OB	N	BRAC	Up	Up	Up	Up	Down	Up	1	45	N	Y	Y	Y	0.67
123	Ghupchi Beel	CBFM	OB	NW	BRAC			Up			Up	1	200	N	Y	Y	N	1
124	Telian kalpani JB	CBFM	OB	NW	BRAC	Down	Up	Up	Down	Down	Up	1	70	N	Y	Y	Y	0.67
202	Shal river & Bamondaha Beel	Control	OB	NW				Down			Down	1	35	N	N	N	N	-1
203	Choto Dhiga and Boro Dhiga	Control	OB	N		Down	Down	Down	Down	Down	Down	1	121	N	N	N	N	-0.33
204	Nabagia Beel	Control	OB	N		Down	Down	Down	Down	Up	Down	2	40	N	N	N	N	-0.67
205	Meghna river	Control	R	E		Down	Down	Down	Up	Up	Down	2	300	N	N	N	N	-1
206	Sheikhati Beel	Control	FPB	SW		Up	Down	Down	Up	Up	Up	3	220	N	N	N	N	-0.33
207	Chiroil Beel	Control	OB	NW				Down			Down	2	15	N	N	N	N	-1
208	Lohoganj Beel	Control	CB	NW				Down			Down	1	60.7	Y	N	N	N	-1
209	Chitra Nadi Jalmahal	Control	R	SW		Down	Down	Down	Up	Up	Up	2	81	N	N	N	N	-0.67
211	Gumai River and Mandaura	Control	R	N		Down	Down	Down	Up	Up	Down	2	93	N	N	N	N	-1
302	SomaNodi Jalmohal	CBFM	OB	E	SUJON			Up			Down	1	20.3	N	Y	Y	N	0
304	Nainda Beel	CBFM	OB	E	SUJON			Up			Down	1	30	N	Y	Y	N	0
306	Shialmara Beel		OB	E	SUJON			Down			Down	1	28.4	N	Y	Y	N	-1
1011	Hogla beel	CBFM	FPB	N	Caritas						Up	1	8	N	Y	Y	N	1
2001	Shang Gang Kala Gang	CBFM	Haor b	E	CNRS	Down	Up	Down	Down	Up	Down	1	9.63	N	Y	Y	N	-0.33
2003	Surang-er Beel	CBFM	Haor b	E	CNRS	Down	Up	Down	Down	Up	Up	1	5.37	N	Y	Y	N	0
2006	Goniar Beel	CBFM	Haor b	E	CNRS	Up	Up	Down	Down	Up	Up	1	10.6	N	Y	Y	N	0.33
2007	Beheli Nodi Part 1 & Part 2	Control	R	E	CNRS	Down	Down	Down	Down	Up	Down	2	21.5	N	Y	Y	N	-0.67
2009	Horinagar Putia Nodi	Control	R	E	CNRS	Down	Down	Down	Up	Up	Down	2	15.2	N	Y	Y	N	-1
2011	Padma Beel	CBFM	Haor b	E	CNRS	Up	Up		Down	Up		1	16.7	N	Y	Y	N	0.5
2014	Pabijuri	CBFM	Haor b	E	CNRS	Down	Down		Down	Down		1	2.01	N	Y	Y	N	0
2015	Gaimara O Mekri	CBFM	Haor b	E	CNRS	Down	Down	Down	Down	Up	Down	1	1.09	N	Y	Y	N	-0.67
2020	Chirua O Baiya Beel	CBFM	FPB	E	CNRS	Down	Up	Down	Down	Down	Down	1	11.6	N	Y	Y	N	0
2022	Fata Beel	Control	FPB	E	CNRS	Down	Up		Down	Down		1	1.66	N	Y	Y	N	0.5

2024	Kaheterdi	CBFM	FPB	N	CNRS	Up	Up	Down	Down	Down	Down	3	54.8	N	Y	Y	Y	0.33
2025	Charan Beel	CBFM	FPB	N	CNRS	Up	Up	Down	Up	Down	Up	1	310	N	Y	Y	Y	0.33
2026	Posna Beel	CBFM	FPB	N	CNRS	Up	Up	_	Up	Down		3	88.2	N	Y	Y	N	0.5
2028	Joloi Beel	CBFM	FPB	N	CNRS	Up	Down	Down	Up	Down	Up	3	62.4	N	Y	Y	N	0
2029	Katara Beel	CBFM	FPB	N	CNRS	Down	Down	Down	Down	Up	Up	3	81.4	N	Y	Y	N	-0.33
2035	Fatikjani Nodi	CBFM	R	N	CNRS	Up	Up	_	Up	Down		2	26.5	N	Y	Y	N	0.5
2036	Sapai Nodi	CBFM	R	N	CNRS	Up	Up	_	Down	Down		2	8.99	N	Y	Y	N	1
2038	Kurumbi	CBFM	FPB	N	CNRS	Up	Up	Down	Up	Down	Up	3	40	N	Y	Y	N	0.33
2040	Boro Buira	CBFM	FPB	N	CNRS	Up	Up	Down	Up	Down	Down	3	68.2	N	Y	Y	N	0
2041	FNJ (Moshakhali)	CBFM	R	SW	CNRS	Up	Down	_	Up	Up		2	4.26	N	Y	Y	N	-0.5
2045	FNJ (Dakshin Dori Laxmipur)	CBFM	R	SW	CNRS	Up	Up	_	Up	Up		2	37.6	N	Y	Y	N	0
2049	FNJ (Arpara)	CBFM	R	SW	CNRS	Down	Up	_	Down	Down		2	4.26	N	Y	Y	N	0.5
2052	FNJ (Boroi Chara)	CBFM	R	SW	CNRS	Up	Up	_	Down	Down		2	7.96	N	Y	Y	N	1
2054	FNJ (Kuch. to D Shimulia)	CBFM	R	SW	CNRS	Up	Up	Down	Up	Up	Down	2	14.5	N	Y	Y	N	-0.33
2055	FNJ (Kuwatpur)	CBFM	R	SW	CNRS	Up	Down	Up	Up	Down	Down	2	9.02	N	Y	Y	Y	0
2058	*Andha beel	Control	Haor b	E	CNRS	Up	Up	Down	Up	Down	Up	1	8.25	N	N	N	N	0.33
2059	*Sindaikha group	Control	Haor b	E	CNRS	Down	Up	Down	Down	Down	Down	1	5.75	N	N	N	N	0
2060	*Keuti beel	Control	Haor b	E	CNRS	Down	Up	Up	Down	Up	Up	1	1.5	N	N	N	N	0.33
2061	Godi Beel	CBFM	FPB	N	CNRS	Up	Up	Down	Up	Down	Down	3	13.5	N	Y	Y	N	0
2062	Bahadia Beel	CBFM	FPB	N	CNRS	Up	Up	Up	Up	Down	Up	3	23.3	N	Y	Y	N	0.67
2063	Masti Beel	CBFM	FPB	N	CNRS	Up	Up	Up	Down	Up	Up	3	26.2	N	Y	Y	Y	0.67
2064	Dhuira Beel	CBFM	FPB	N	CNRS	Up	Up	Up	Up	Up	Up	3	12	N	Y	Y	N	0.33
2065	Garol Beel	CBFM	FPB	N	CNRS	Up	Up	Down	Up	Down	Up	3	9.49	N	Y	Y	N	0.33
2066	Goalgof Beel	CBFM	FPB	N	CNRS	Up	Up	Up	Up	Up	Up	3	18	N	Y	Y	N	0.33
2070	Dhanler Beel Sec1	CBFM	FPB	SW	CNRS	Up	Down	Up	Up	Down	Up	3	389	N	Y	Y	N	0.33
2071	Dhanler Beel Sec2	CBFM	FPB	SW	CNRS	Down	Down	Down	Down	Up	Up	3	389	N	Y	Y	N	-0.33
2072	Kumairar Beel Sec1	CBFM	FPB	SW	CNRS	Up	Down	Down	Up	Down	Up	3	389	N	Y	Y	N	0
2073	Kumairar Beel Sec2	CBFM	FPB	SW	CNRS	Up	Up	Down	Down	Up	Up	3	389	N	Y	Y	N	0.33
2074	*Katli Beel	Control	Haor b	E	CNRS	Up	Up		Down	Up		1	2	N	N	N	N	0.5
2075	Tallai Beel	Control	FPB	N	CNRS	Up	Up	Up	Up	Down	Up	3	118	N	N	N	N	0.67
2076	Haora Nadi	Control	R	N	CNRS	Up	Down		Down	Up		2	26.6	N	N	N	N	0
2077	Chordhara Beel	Control	FPB	N	CNRS	Up	Down	Down	Up	Up	Up	3	38.1	N	N	N	N	-0.33

4.6.2 Unit slope tests

The results of the unit slope tests presented below are consistent with the findings presented in the previous section.

Fish Production (CPUA)

Estimates of CPUA slope coefficients (cpuab) for each site 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. However, for CBFM sites, estimates of the mean slope coefficient (cpuab) 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 20) indicating increasing production through time. Average increases in CPUA ranged from approximately 20 to 30% per year (Table 19). The estimate of the mean slope coefficient for control sites was not significantly different from zero indicating no significant change in fish production (CPUA) at control sites (Figure 20).

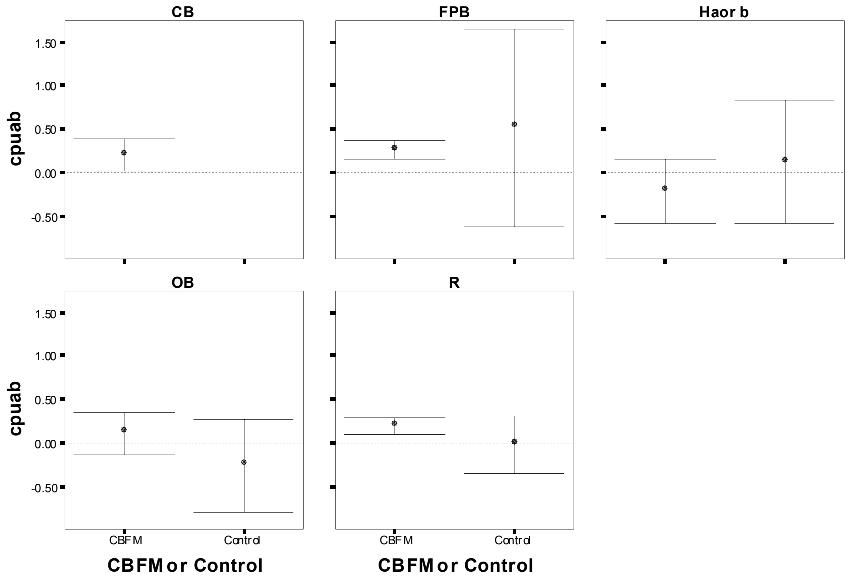

Figure 20 Unit slope estimates with 95% CI for the fish production indicator CPUA (cpuab) at CBFM and control sites for each habitat. Reference line at zero indicates no change in mean value of indicator.

Fish Abundance (CPD)

Estimates of the mean CPD slope coefficient for CBFM sites were greater than zero of all habitat, and with the exception of haor habitat, greater than those for control sites (Figure 21). 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 pooling the estimates of the CPD slope coefficients across habitat (Figure 22), the estimate of the mean slope coefficient was significantly higher (p=0.03) for CBFM compared to control sites, and significantly greater than zero (p<0.01). The mean slope coefficient for CBFM sites across all habitats translates to an increase in catch rates (CPD) of 16% per annum. Equivalent increases by habitat range from 10-20% per annum (Table 19).

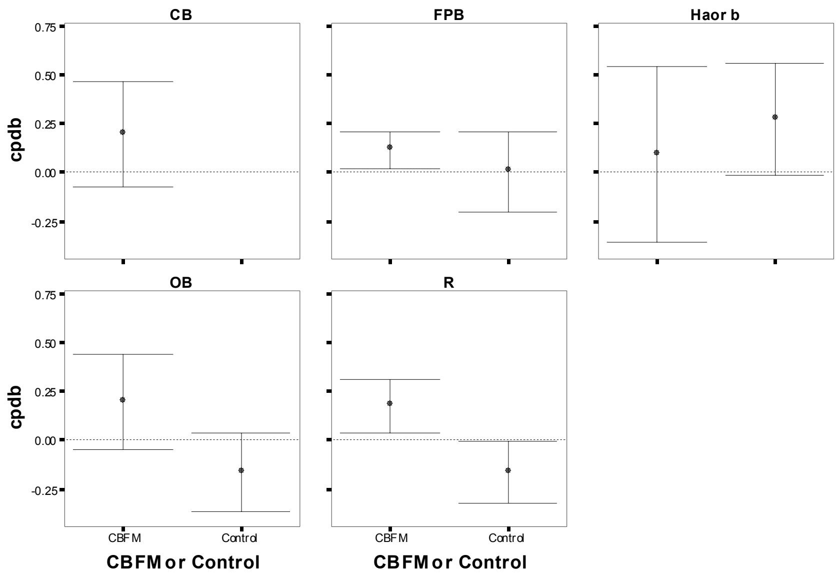

Figure 21 Unit slope estimates with 95% CI for the fish abundance indicator CPD (cpdb) at CBFM and control sites for each habitat. Reference line at zero indicates no change in the value of indicator with time.

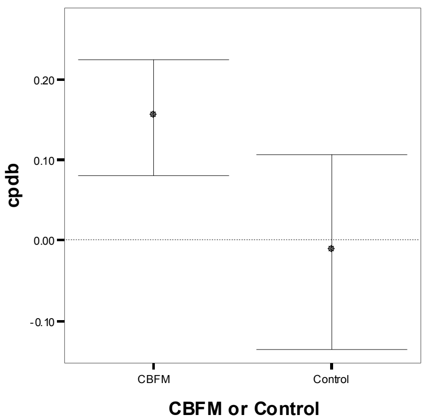

Figure 22 Unit slope estimates with 95% CI for the fish abundance indicator CPD (cpdb) at CBFM and control sites for all habitat sites combined. Reference line at zero indicates no change in the value of indicator with time.

Fish Abundance – Gillnet CPUE

Estimates of gillnet CPUE slope coefficients (cpueb) for each site representing annual rates of change in fish abundance were found to vary significantly between CBFM and control sites but not by habitat (Figure 23). After pooling the estimates across habitat (Figure 24), the estimate of the mean slope coefficient for CBFM sites was less than but not significantly different from zero, indicating no significant decline in mean catch rates at CBFM sites through time. 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 20).

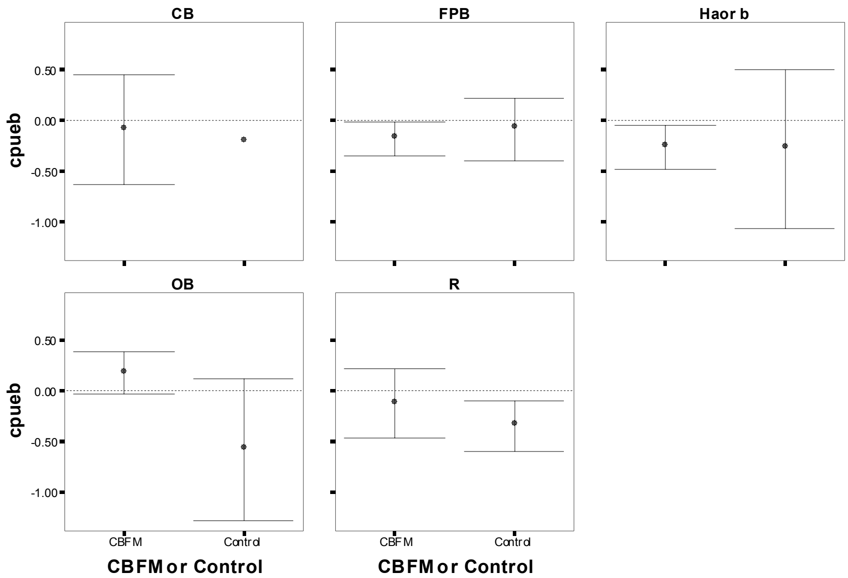

Figure 23 Unit slope estimates with 95% CI for the fish abundance indicator CPUE (cpueb) at CBFM and control sites for each habitat. Reference line at zero indicates no change in mean value of indicator.

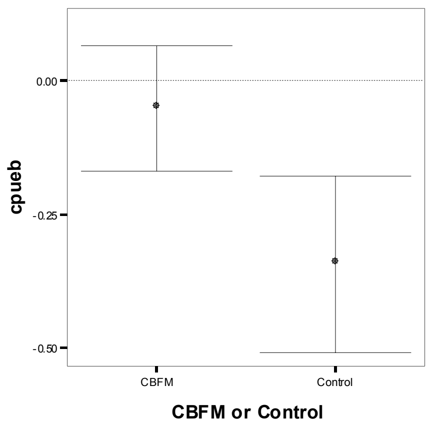

Figure 24 Unit slope estimates with 95% CI for the fish abundance indicator CPUE (cpueb) at CBFM and control sites for all habitat. Reference line at zero indicates no change in mean value of indicator.

Fishing Intensity (DPUA)

Estimates of fishing intensity (DPUA) slope coefficients (dpuab) for each site representing annual rates of change in fishing effort were found to vary significantly by habitat but not between CBFM and control sites (Figure 25). For floodplain beel habitat, the estimate of the mean dpuab slope coefficient was significantly greater than zero (p<0.05), indicating that fishing effort has increased significantly through time for CBFM sites. However, this increase, equivalent to approximately 10% per annum was not significantly different from the estimated mean change in DPUA at control sites. For haor beel habitat, the estimate of the mean dpua slope coefficient for CBFM sites was significantly less than zero, equivalent to a decline in fishing effort of more than 30% per year (Table 19), but similarly, not significantly different than the control sites. The remaining combinations indicated no significant change in DPUA through time.

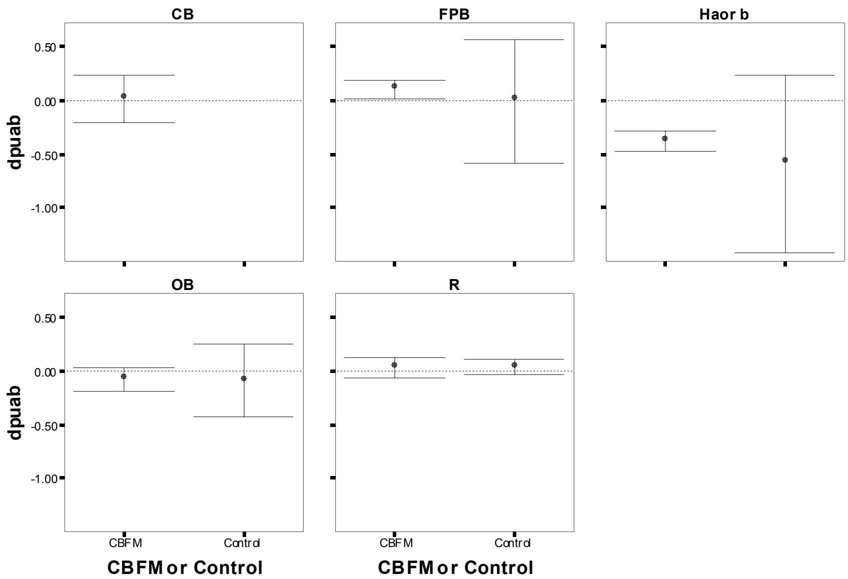

Figure 25 Unit slope estimates with 95% CI for the fishing effort indicator DPUA (dpuab) at CBFM and control sites for each habitat. Reference line at zero indicates no change in mean value of indicator.

Biodiversity (H')

Estimates of slope coefficients (hb) for each site representing annual rates of change in biodiversity were found to vary significantly (p<0.05) with habitat and between CBFM and control sites (Figure 26).

Estimates of the mean slope coefficient for CBFM sites for both closed and floodplain beel habitat were significantly greater than zero (p<0.05), indicating significant improvements in biodiversity through time. However, the estimate of the mean slope coefficient for control sites in floodplain beel habitat was also significantly greater then zero equivalent to an annual rate of increase in H' of 0.21 compared to 0.17 for CBFM sites (Tables 19 & 20).

Judging by the estimates of the mean slope coefficient, no significant (p<0.05) changes in biodiversity were detected through time for CBFM or control sites in Haor, open beel or river habitat. However, the estimate of the mean slope coefficient for control sites was lower (but not significantly) than those for CBFM sites for open beel and river habitat. Estimates of the annual rates of change in H' for each habitat and management combination are provided in Table 19 below.

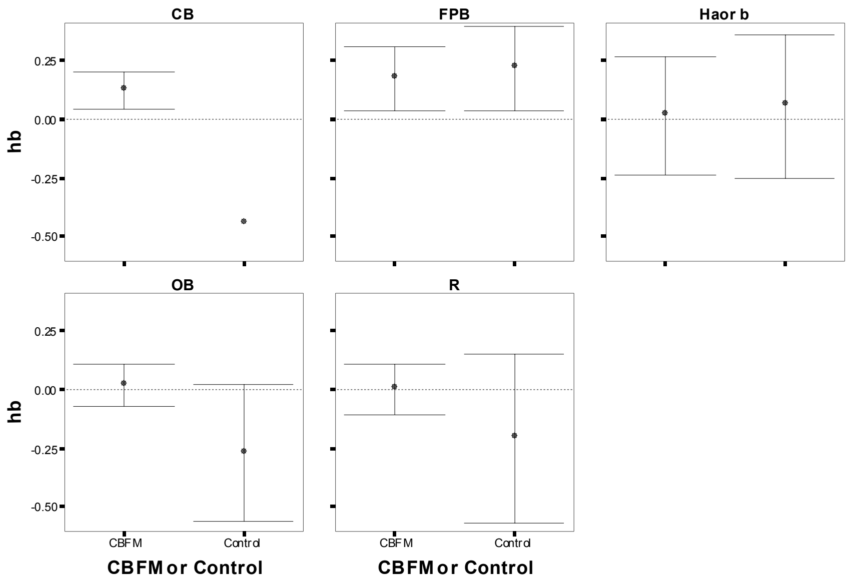

Figure 26 Unit slope estimates with 95% CI for the fish biodiversity indicator H' (hb) at CBFM and control sites for each habitat. Reference line at zero indicates no change in mean value of indicator.

Table 17 Estimated mean (unit) slopes (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 habitat are provided in those cases where habitat was found not to be a significant factor in determining unit slope values.

Habitat	b CPD	b CPUA	b CPUE	b DPUA	b H'
CB	0.19458	**0.20061**	-0.0987	0.00603	**0.12389**
FPB	**0.1166**	**0.25798**	**-0.18689**	**0.09908**	**0.17203**
HAOR	0.08918	-0.20695	**-0.27329**	**-0.37677**	0.0136
OB	0.19425	0.11014	0.16563	-0.0841	0.01613
RIVER	**0.175293**	**0.198339**	-0.1296	0.023046	-0.00252
All	**0.152701**	-	-0.05337	-	-

Table 18 Estimated mean (unit) slopes (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 habitat are provided in those cases where habitat was found not to be a significant factor in determining unit slope values.

Habitat	b CPD	b CPUA	b CPUE	b DPUA	b H'
CB			-0.22421		-0.4491
FPB	0.002237	0.515763	-0.09247	-0.01016	**0.213**
HAOR	0.271305	0.123793	-0.29309	-0.5917	0.054967
OB	-0.16477	-0.25792	-0.5845	-0.09314	-0.27184
RIVER	**-0.16539**	-0.01672	**-0.35556**	0.03239	-0.20833
All	-0.01423		**-0.34354**		

Table 19 Predicted annual change in performance indicator values by habitat for CBFM sites. Bold and underlined values are significantly (p<0.05) different from zero. Estimates for all habitat are provided in those cases where habitat was found not to be a significant factor in determining unit slope values.

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

Table 20 Predicted annual change in performance indicator values by habitat for control sites. Bold and underlined values are significantly (p<0.05) different from zero. Estimates for all habitat are provided in those cases where habitat was found not to be a significant factor in determining unit slope values.

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

4.6.3 Mean site scores

Ignoring habitat type, mean site score was significantly (p<0.01, 1-β=0.99, d.f.=98) higher for CBFM sites than control sites (Figure 27). Taking account of habitat type, significant (p<0.05) differences in mean site score were detected for closed beel (p=0.03, 1-β =0.60, d.f.=9), open beel (p<0.01, 1-β =0.86, d.f.=25 and river habitat (p<0.01, 1-β =0.98, d.f.=23) (Figure 28).

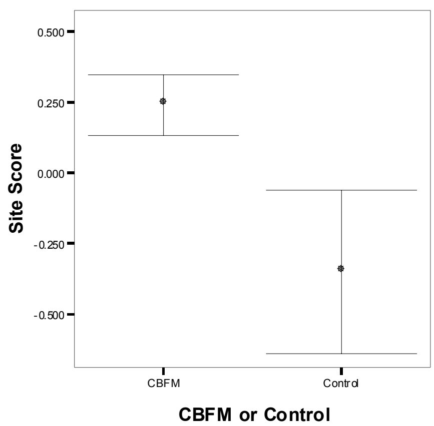

Figure 27 Mean site score with 95% CI for CBFM and control sites.

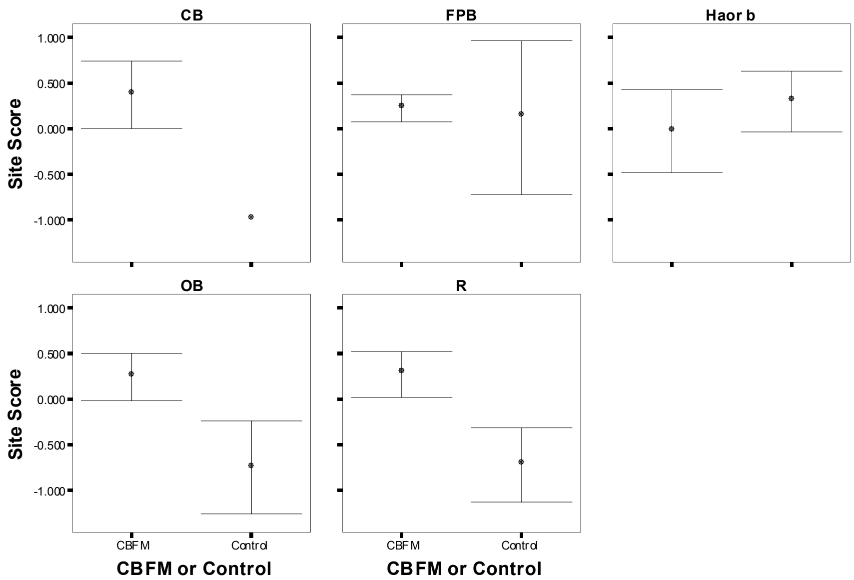

Figure 28 Mean site score with 95% CI for CBFM and control sites by habitat type.

For CBFM sites only, site score varied among habitat type. The CBFM appears to work best in closed beel and river habitat, although the differences were not significant (p=0.64; 1-β =0.2, d.f.=76) (Figure 29). No significant differences in site score were detected among region (p=0.17, 1-β =0.43, d.f.=77).

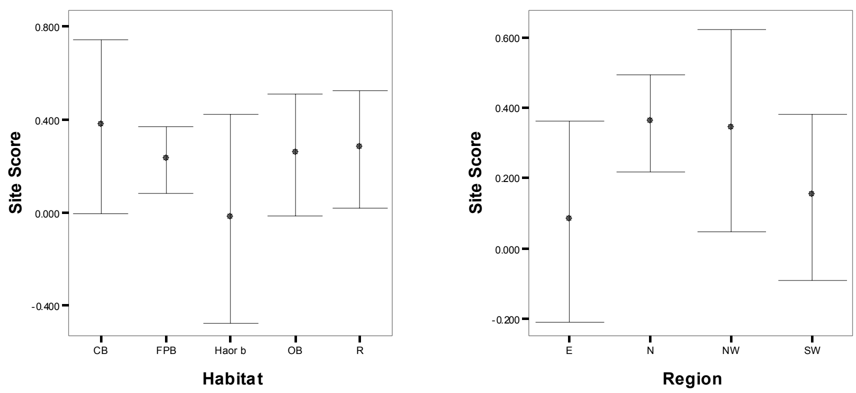

Figure 29 Mean site scores for CBFM sites by habitat type (left) and region (right).

Site size, measured in terms of waterbody area, was found to be not significant in determining management performance at CBFM sites measured by site score (p=0.35, 1-β =0.15, d.f.=79). (Figure 30)The NGO facilitating the site management was also found to be not significant in determining management performance (p=0.18, 1-β =0.56, d.f.=74) (Figure 30). These conclusions remained unchanged after variation among habitat type was accounted for.

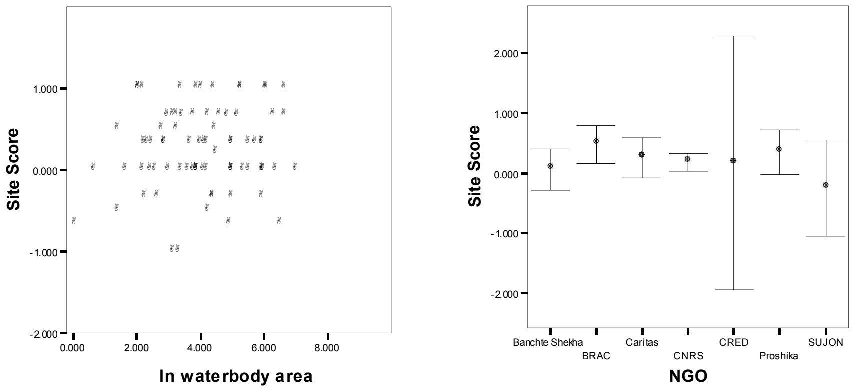

Figure 30 Variation in CBFM site score with (loge) transformed waterbody area (left) and NGO (right).

The type of resource ownership rights also had no significant affect on management performance after accounting for variation among habitat type ($p=0.60$, $1-\beta =0.13$, d.f.=74) (Figure 31).

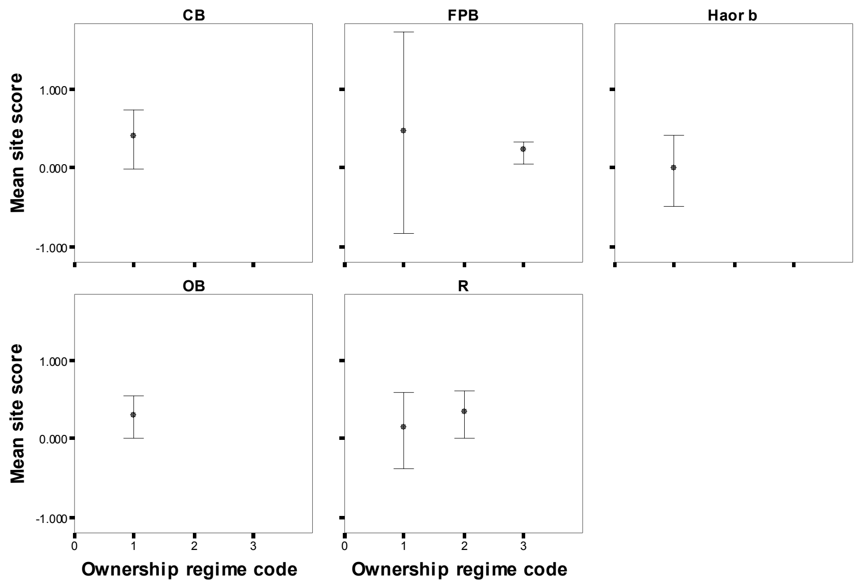

Figure 31 Variation in CBFM site score with ownership regime. 1=Jalmohol, 2=Jalmohol (no fee); 3=private land.

All the factors were entered in different combinations to find the best fitting model. The most significant factor was NGO although this was found to be not significant in determining management performance at the 5% level (see above).

4.6.4 Predictors (explanatory factors) of trends in performance indicators

(i) Production (CPUA) trends

Trend in fish abundance (CPDT) and trend in fishing intensity (DPUAT) were found to be highly significant ($p<0.01$) in predicting trends in CPUA through time although these two explanatory variables are not strictly independent (Table 21). Trend in fish abundance, measured in terms of gillnet catch rates (GNCPUE) was found not to be significant in determining trend in production. This suggests that this measure may not be a reliable indicator of fish abundance.

Table 21 Parameter estimates of the binary logistic regression model for CPUA trend. CPDT- Catch per fisher per day trend. DPUA- Annual fishing days per unit area trend.

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	CPDT	1.799	.539	11.154	1	.001	6.042
	DPUAT	-1.786	.553	10.453	1	.001	.168
	Constant	.875	.326	7.209	1	.007	2.399

The probability of an upward trend in production (CPUA) is 99% when the trend in fish abundance (CPD) is upward and when the trend in fishing intensity is downward (Table 22). Conversely, when trends in fishing intensity (DPUA) and fish abundance (CPD) are upward and downward respectively, the probability of an upward trend in production is just 6%.

Table 22 Predicted probability (P) of an upward trend in CPUA for combinations of trends in fish abundance (CPD) and fishing intensity (DPUA).

CPD Trend	DPUA Trend	P (CPUA Up)
Up	Up	0.71
Down	Down	0.70
Down	Up	0.06
Up	Down	0.99

(ii) Fish Abundance (CPD and GNCPUE) trends

Closed seasons and gearbans were always employed at CBFM sites together during 2003 making it impossible to separate the effects of each factor. For the purposes of the analysis, the effects of closed seasons and gearbans were therefore considered simultaneously. Other predictors that were included in the analysis were: stocking, reserve presence/absence, and trends in destructive fishing (DFER) and fishing intensity (DPUA).

CPD

Closed seasons and/or gearbans were found to be the only significant predictors of trends in fish abundance measured in terms of catch per day (CPD) (Table 23). When closed seasons/gear bans were present, the probability of an increase in CPD rises from approximately 40% to 70% (Table 24). However, because closed seasons and gears bans were employed only at CBFM sites, these results are equivalent to testing the effect of the sum of CBFM activities on fish abundance compared to control sites.

Table 23 **Parameter estimates of the binary logistic regression model for CPD trend**

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	CLOSE SEASON	1.324	.630	4.426	1	.035	3.760
	Constant	-.470	.570	.680	1	.410	.625

Table 24 Predicted probability (P) of an upward trend in CPD when closed seasons/gearbans are present or absent.

Closed Season/Gear Ban	P (CPD Up)
Present	0.70
Absent	0.38

GNCPUE

No significant predictors for GNCPUE could be identified.

(iii) Fishing Intensity (DPUA) trends

Habitat was found to be the only significant predictor of fishing intensity (Table 25). The probability of an upward trend in fishing intensity at river and floodplain beel sites (Habitat 4) is almost 60% and 70% respectively compared to only 10% for other habitats (Table 26).

Table 25 **Parameter estimates of the binary logistic regression model for DPUA trend.**

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	HABITAT			12.018	4	.017	
	HABITAT(1)	-2.460	1.135	4.697	1	.030	.085
	HABITAT(2)	-1.186	1.205	.968	1	.325	.306
	HABITAT(3)	-1.504	1.364	1.216	1	.270	.222
	HABITAT(4)	-3.008	1.137	7.006	1	.008	.049
	Constant	2.197	1.054	4.345	1	.037	9.000

Table 26 Predicted probability (P) of an upward trend in DPUA in river, floodplain-beel and other habitat.

Habitat	P (DPUA Up)
River	0.57
Other	0.10

Habitat	P (DPUA Up)
Floodplain Beel	0.69
Other	0.10

(iv) Destructive fishing (DFER) trends

No significant predictors for trends in DFER could be identified at α=0.05.

(v) Biodiversity (H') trends

Trend in fish abundance indicated by trend in fisher daily catch rates (CPDT) was found to be significant ($p<0.05$) in predicting trends in H' through time (Table 27) although the effect is small. The probability of an upward trend in H' is 76% when the trend in CPD is up, compared to 64% when the trend in CPD is down (Table 28). Trend in fish abundance, measured in terms of gillnet catch rates (GNCPUE) was found to be marginally not significant ($p=0.06$) in determining the trend in H'.

Table 27 Parameter estimates of the binary logistic regression model for H' trend.

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	CPDT	.566	.273	4.282	1	.039	1.761
	Constant	.566	.273	4.282	1	.039	1.761

Table 28 Predicted probability (P) of an upward trend in H' when trends in fish abundance (CPD) are up and down.

CPD Trend	P (H' Up)
Up	0.76
Down	0.64

5 Management Models

5.1 Surplus Production (Catch vs Effort) Models

5.1.1 Introduction

The control of fishing mortality via fishing effort is fundamental to most fisheries management strategies even under community-based management regimes. Unsurprisingly, Section 4.6 found that trends in fish production (CPUA) were dependent upon trends in both fish abundance measured in terms of CPD and trends in fishing intensity (DPUA).

Decisions concerning the control of fishing effort to maximize yield require knowledge of the underlying response of the catch to changes in effort. Under adaptive management strategies, even imprecise knowledge of the response is likely to help accelerate the adaptive learning process. Several multispecies biomass dynamics and age structured models have been developed to elucidate such responses to guide the setting of fishing effort to achieve common target and limit reference points.

The most rudimentary approach to elucidating the relationship between catch and effort in multispecies fisheries is to ignore any species interactions and fit some form of production model to catch and effort data aggregated across all species (e.g. Ralston & Polovina, 1982). Such an approach assumes that any species interaction effects and changes in catchability are captured in an overall relationship between catch and effort (Halls *et al* 2006).

When little or no data are available, among fishery, or, in this case, among site comparisons of catch and effort data can provide an indication of the likely response. The results of such comparisons can provide guidance to managers regarding potential yield and corresponding required fishing effort. This comparative approach assumes that observations from discrete fisheries (sites) can be treated as samples from a hypothetical fishery. Assuming the fishery covers the entire area, differences in scale are accounted for by standardizing both yield (catches) and effort by area. The approach does, however, assume that the observed catches are sustainable at the observed levels of effort, i.e. the stock is at equilibrium.

5.1.2 Materials and methods

Data

The dataset contains 264 estimates of catch per unit area (CPUA) and corresponding effort measured as annual fishing days per hectare per year for floodplain beel (108), haor beel (40) and river (116) site/year combinations. Three to four (but up to a maximum of 9) observations for each site corresponding to different years are included in the dataset.

No attempt was made to fit models to data for closed and open beel habitat because of the absence of any significant stock depletion, i.e. a decline in catch rates (CPD) with fishing effort per unit area.

Fitted Models

Following the approach described by Halls *et al* (2006), three alternative surplus production models were fitted to the untransformed data by non-linear least squares (SPSS v11.5): the Scheafer (Schaefer, 1967) and Fox (Fox, 1970) models (Eqs (1) and (2), respectively), and an asymptotic model after Lae (1977) (Eq. (3)):

$$CPUA = ai + bi^2 \quad (1)$$

$$CPUA = i \exp(a + bi) \quad (2)$$

$$CPUA = a(1 - \exp(bi)) \quad (3)$$

Where *i* is the fishing effort per unit area, and *a* and *b* are fitted parameters.

Halls *et al* (2006) describes and illustrates the form of each model. The best model was judged on the basis of the coefficient of determination, R^2, the residual plot and a comparison of the 95% confidence range (upper minus lower confidence interval) of the estimates of the maximum yield (MY) and fishing intensity at MY (i_{MY}).

5.1.3 Results

Closed Beel
The Scheafer model provided the best description of the catch effort response (Figure 32, Table 29). Fishing effort explained almost 50% of the variation in CPUA (R^2=0.48). The model predicts a maximum yield of 540 kg ha^{-1} yr^{-1} (95% CI [160, 2335]) at 633 fishing days ha^{-1} yr^{-1} (95% CI[272,2085]).

Floodplain Beel
Excluding three outliers, the asymptotic model provided the best description of the catch effort response. Fishing effort explained almost 70% of the variation in CPUA (R^2=0.66). The model predicts a maximum yield of 531kg ha^{-1} yr^{-1} (95% CI [440, 621]). No estimates of iMY are available for this model. The next best fitting model (R^2=0.64), the Fox, predicts a similar MY at 552 kg ha^{-1} yr^{-1} (95% CI [370, 881]) corresponding to a level of effort of 3008 fishing days ha^{-1} yr^{-1} (95% CI[2396,4040]).

Haor Beel
The asymptotic model also provided the best description of the catch effort response for haor beel habitat (R^2=0.33). The model predicts a maximum yield of 487 kg ha^{-1} yr^{-1} (95% CI [330, 644]). The Fox was the next best fitting model (R^2=0.32), predicting a similar MY at 516 kg ha^{-1} yr^{-1} (95% CI [239, 1442]) corresponding to a level of effort of 1072 fishing days ha^{-1} yr^{-1} (95% CI [727, 2049]).

Open Beel
All three models explained the same amount of variation in CPUA (32%), although the 95% confidence range was smallest for the Fox model. This predicts a maximum yield of 1293 kg ha^{-1} yr^{-1} (95% CI [530, 5477]) corresponding to a level of effort of 1242 fishing days ha^{-1} yr^{-1} (95% CI [753, 3559]).

River
The asymptotic model provided the best description of the catch effort response (R^2=0.41). The model predicts a maximum yield of 936 kg ha^{-1} yr^{-1} (95% CI [749, 1125]). The Fox was the next best fitting model (R^2=0.38), predicting a similar MY at 1128 kg ha^{-1} yr^{-1} (95% CI [704, 1962]) corresponding to a level of effort of 7246 fishing days ha^{-1} yr^{-1} (95% CI [5657, 10067]).

Table 29 Summary of model fits

Model	Ecosystem	n	r2	Parameter Estimates a	b	Upper 95% CI a	b	Lower 95% CI a	b	MSY	MSY (upper)	MSY (lower)	iMSY	iMSY (upper)	iMSY (lower)
SCHAEFER	Closed beel	27	0.48	1.70639	-0.001348	2.2396	-0.00054	1.17316	-0.002157	540	2335	160	633	2085	272
FOX	Closed beel	27	0.44	0.6091	-0.001261	1.11034	-0.0003	0.10787	-0.002218	536	3685	185	793	3300	451
ASYMPTOTIC	Closed beel	27	0.42	615.558	0.003021	984.57	0.006595	246.54	-0.000551	616	985	247	-	-	-
SCHAEFER	FPB	108	0.33	0.557	-0.00011	0.683	-0.00007	0.432	-0.00015	712	1767	305	2555	5175	1409
FOX	FPB	108	0.35	-0.278	-0.00046	0.039	-0.00027	-0.595	-0.00064	613	1403	319	2198	3667	1570
ASYMPTOTIC	FPB	108	0.35	594.140	0.00157	769.270	0.00266	419.000	0.00049	594	769	419	-	-	-
SCHAEFER	FPB*	105	0.61	0.402	-0.00007	0.458	-0.00005	0.347	-0.00009	608	1102	352	3023	4817	2029
FOX	FPB*	105	0.64	-0.696	-0.00033	-0.523	-0.00025	-0.869	-0.00042	552	881	370	3008	4040	2396
ASYMPTOTIC	FPB*	105	0.66	530.840	0.00119	621.000	0.00162	439.950	0.00075	531	621	440	-	-	-
SCHAEFER	Haor beel	40	0.23	0.944	-0.00038	1.227	-0.00016	0.660	-0.00060	586	2398	181	1242	3908	548
FOX	Haor beel	40	0.30	0.269	-0.00093	0.649	-0.00049	-0.110	-0.00138	516	1442	239	1072	2049	727
ASYMPTOTIC	Haor beel	40	0.33	486.790	0.00359	643.970	0.00645	329.610	0.00074	487	644	330	-	-	-
SCHAEFER	Open beel	77	0.32	2.628	-0.00135	3.444	-0.00046	1.813	-0.00223	1282	6426	368	976	3732	406
FOX	Open beel	77	0.32	1.040	-0.00081	1.431	-0.00028	0.649	-0.00133	1293	5477	530	1242	3559	753
ASYMPTOTIC	Open beel	77	0.32	1452.790	0.00203	2155.350	0.00376	750.240	0.00031	1453	2155	750	-	-	-
SCHAEFER	River	116	0.35	0.330	-0.00002	0.391	-0.00001	0.270	-0.00003	1275	2633	644	7727	13479	4775
FOX	River	116	0.38	-0.860	-0.00014	-0.635	-0.00010	-1.084	-0.00018	1128	1962	704	7246	10067	5657
ASYMPTOTIC	River	116	0.41	936.000	0.00070	1124.760	0.00102	748.660	0.00039	936	1125	749	-	-	-

* 3 OUTLIERS EXCLUDED

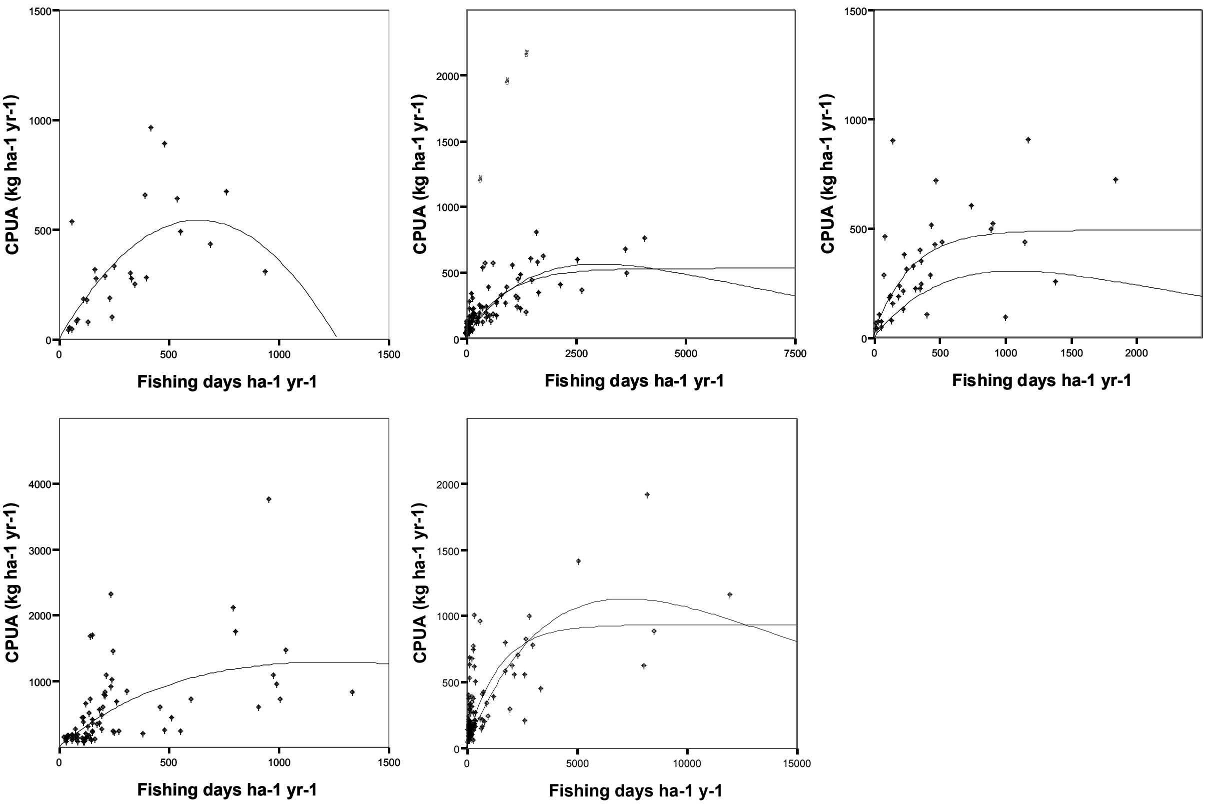

Figure 32 CPUA vs. fishing effort for left to right and top to bottom: closed beel, floodplain beel, haor beel, open beel and river habitat with best fitting models. Outliers (open circles) not included in model fits.

5.2 A simple stocking Model

5.2.1 Introduction

The aim of most fish farmers is to maximize profit rather than simply yield. Profit (P) is a function of harvest revenue (R) and stocking costs (C):

$$P = R - C$$

Revenue, R

Revenue is the product of the total weight of fish harvested (kg) per hectare, *Hwt* and the market unit price (Tk/kg) of the harvested fish received, *Mp:*

$$R = Hwt.Mp$$

Generally speaking, harvest yields (weights) will increase with the numbers of fingerlings stocked, but the relationship is unlikely to remain linear due to density-dependent effects arising from competition for food and shelter. Stocking larger fingerlings may also yield greater harvests due to their lower mortality rates compared to smaller fingerlings (Lorenzen 2005), but are more expensive to stock (see below).

Costs, C

The main factors affecting variable costs are the numbers of fingerlings stocked and the average size of the stocked fingerlings. Larger fingerlings tend to have a higher market value reflecting their higher cost of production.

The cost of stocking, *C* can therefore be defined as the product of the number of fingerlings stocked of size *s*, NS_s and the unit price of the fingerling of size *s*, FP_s:

$$C = NS_s.FP_s$$

Other costs, such as harvesting and guarding costs may also be important, but these are unlikely to vary significantly on a per unit area basis unlike the selected stocking strategy (stocking density, size of fish stocked, species stocked etc).

Maximising Profit

Farmers must therefore attempt to select combinations of stocking densities and mean fingerling stocking sizes to maximize their profits. Farmers may attempt to informally experiment themselves to find the optimum combination. However this type of passive adaptive learning process can take several years of experimentation and learning and can be wasteful. Furthermore, unless undertaken formally, more general guidance on selecting the best combinations may not be generated. For example, suppose that only a certain size of fingerling is available from a hatchery. How many fingerlings of that size should be stocked to maximize profit? The model described below, attempts to aid such decision-making processes.

5.2.2 Materials and methods

Data

The stocking model was developed using stocking and harvest data collected between 1989 and 2005 for 15 water bodies monitored under the CBFM Project. Much of the data has relates to stocking and harvesting activities at Hamil, Rajdhola, Dum Nadi and Ruhia Baisha Beels. The following variables were available, although not for all stocking events:

Table 30 Variables used to develop the stocking model.

Variable Description	Variable Name	Units
Harvest weight	Hwt	Kg ha-1
Total number of fingerlings stocked	NS	ha-1
Total weight of stocked fingerlings	WS	Kg ha-1
Mean fingerling size stocked	FS	cm
Number of species stocked	NSS	-
Secchi depth of stocked waterbody	SD	Cm
Stocking duration	StkD	months
Stocking cost	StkC	Tk
Harvest revenue	R	Tk
Unit market value (price) of harvested fish =R/Hwt	Mp	Tk/kg
Unit price of stocked fingerlings=StkC/NS	FP	Tk

Model Fitting

Multiple linear regression was used to identify a linear model that best described the variation in harvest weight per unit area (Hwt) using NS, WS, FS, NSS, SD, and StkD as explanatory variables. This model was then used to predict revenues when combined with estimates of unit market value (Mp). Linear regression was also used describe the relationship between the unit price and the size of fingerlings stocked. These two models were then used to predict harvest weights, stocking costs and profit under a range of different stocking strategies. Contour plots were used to aid the identification of optimal stocking strategies. Variables were loge transformed where necessary to meet the normality assumptions of the model fitting method.

5.2.3 Results

Harvest weight

Based upon 23 stocking and harvesting events, the best fitting model describing variation in harvest weight was:

$$\ln Hwt = \alpha + \beta_1 \ln NS + \beta_2 \ln FS$$

Where *NS* is the number of fish stocked per hectare, and *FS* is the average size (cm) of the fingerlings stocked. The values for α, β_1 and β_2 are given in Table 31. The model explained 70% of the variation in harvest weight and the residuals were reasonably well behaved (Figure 33).

Table 31 Parameter estimates of the regression model describing variation in loge transformed harvest weight with loge transformed stocking density (NS) and size of fingerlings stocked (FS).

Model Summary(b)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.837(a)	.701	.673	.950042

a Predictors: (Constant), LNFS, LNNS
b Dependent Variable: LNHWT

ANOVA(b)

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	44.443	2	22.221	24.620	.000(a)
	Residual	18.954	21	.903		
	Total	63.397	23			

a Predictors: (Constant), LNFS, LNNS
b Dependent Variable: LNHWT

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.013	.837		-1.210	.240
	LNNS	.545	.121	.562	4.505	.000
	LNFS	1.571	.411	.477	3.820	.001

a Dependent Variable: LNHWT

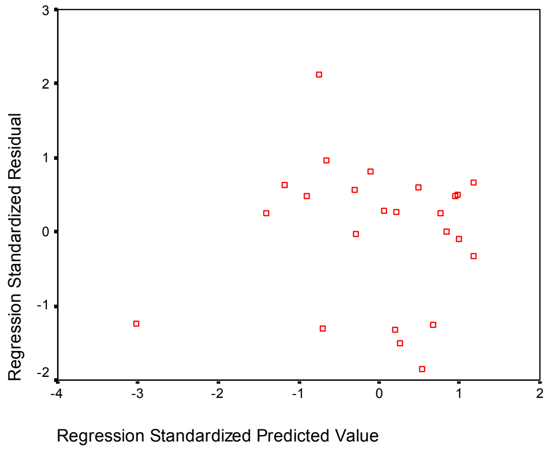

Figure 33 Standardised residuals plotted as a function of standardised predicted values.

Market Price (*Mp*)

The market price, *Mp* received per kg ranged from 15-94 Tk/kg, with a mean of 45Tk/kg (n=65, S.D=14.26) (Table 32).

Table 32 Descriptive statistics for market price of harvested fish, Mp.

	N	Minimum	Maximum	Mean	Std. Deviation
Mp	65	14.837	94.143	45.18331	14.262138
Valid N (listwise)	65				

The market price of harvested fish (Tk/kg) was found not to vary significantly ($p>0.05$) either with fry stocking size or stocking duration (or any other factors with cost implications examined). The unit value is likely to be dictated by market forces more than stocking costs.

Stocking Costs

The unit price of stocked fingerlings was found to vary with fry size, *FS* according to the following model:

$$FP = 0.01 + 0.33.FS$$

The model explained 44% of the variation in the unit price (cost) of fingerlings (Table 33 and Figure 34).

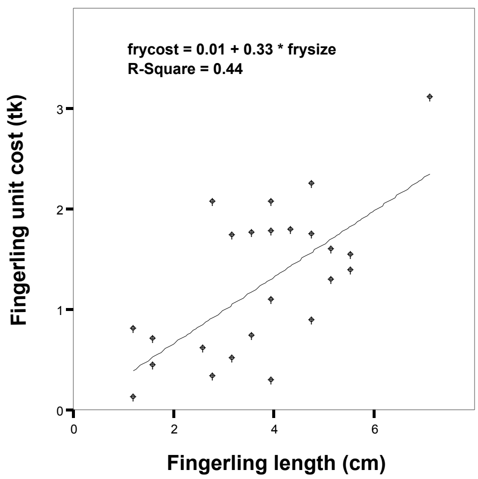

Figure 34 Average (unit) fingerling price (cost) (Tk) plotted as a function of fingerling size with fitted regression model.

Table 33 Parameter estimates of the regression model of fingerling price (FP) vs fingerling size (FS).

Dependent Variable: FP

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power(a)
Corrected Model	5.609(b)	1	5.609	17.065	.000	.437	17.065	.976
Intercept	.000	1	.000	.001	.980	.000	.001	.050
FS	5.609	1	5.609	17.065	.000	.437	17.065	.976
Error	7.232	22	.329					
Total	49.912	24						
Corrected Total	12.841	23						

a Computed using alpha = .05
b R Squared = .437 (Adjusted R Squared = .411)

Parameter Estimates

Dependent Variable: FP

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared	Noncent. Parameter	Observed Power(a)
					Lower Bound	Upper Bound			
Intercept	.008	.321	.026	.980	-.657	.674	.000	.026	.050
FS	.331	.080	4.131	.000	.165	.497	.437	4.131	.976

a Computed using alpha = .05

Maximising profit

Both harvest revenue and stocking costs increase with both increasing fingerling stocking size and stocking density (Figure 35). However, for a given fingerling size, the rate of increase in harvest revenue begins to slow with increasing stocking density. The resulting profit contours indicate that fingerling size should be the primary factor determining stocking density decisions because profit is more sensitive to the size of the fish stocked compared to the stocking density.

Particularly for larger fingerings, profit is almost independent of the stocking density above intermediate stocking densities. To minimize credit burden and financial risk, minimum stocking densities should be selected according to the size of fish available that maximize profit. For example, for a 6cm fingerling, profit can be maximized and risk minimized by stocking at approximately 6,000, instead of 21,000 fingerlings per hectare. Generally speaking, profit increases with the size of fingerling stocked, and to a lesser extent, the stocking density. No benefits accrue from stocking beyond intermediate densities (approximately 2,000 – 3,000 fingerlings per ha).

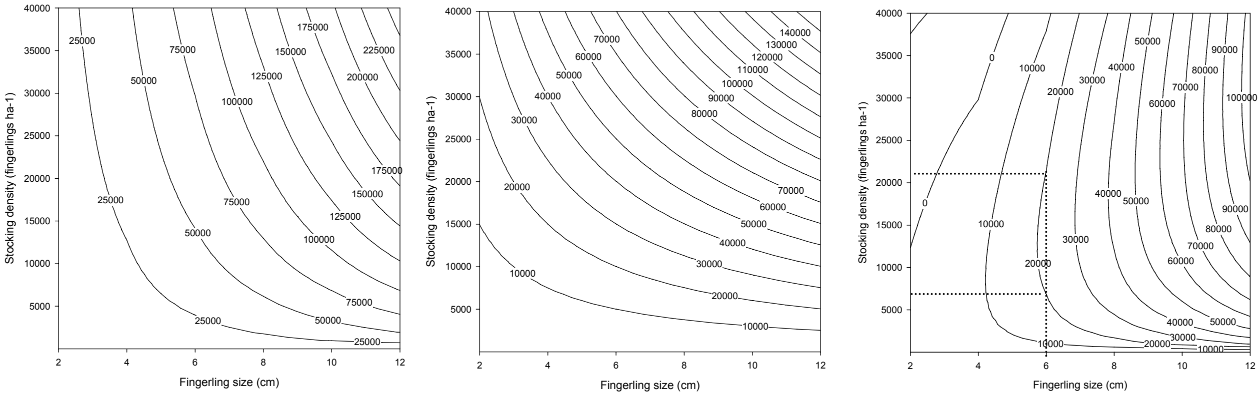

Figure 35 From left to right: Contours of harvest revenue, stocking costs and profit per hectare (Tk) as a function of size of stocked fingerling and stocking density (numbers stocked per hectare).

It should be borne in mind that this is an empirical model. The model recommendations may not be applicable beyond the project sites that generated the data to construct the model. As more data becomes available from future stocking events, the model should be updated.

6 Summary, Conclusions and Recommendations

6.1 Does the CBFM work?

6.1.1 Fish Production (CPUA)

Taken at 'face value', that is ignoring the statistical significance of individual site trends (slope coefficients), the number of upward compared to downward trends in fish production measured in terms of annual catch per unit area (CPUA) would **not** be expected by chance at the 5% level (Table 15). Trends in CPUA were upward at almost 80% of CBFM sites compared to only 38% at control sites.

If only significant trends are considered, 10 of the 11 CBFM sites exhibited an upward trend. The probability of observing these relative frequencies by chance is only 6%.

The results of the more formal unit slope tests in Section 4.6.2 tell a slightly different story. These indicate that site slope coefficients, indicating annual rates of change in the performance indicator, in this case CPUA, vary significantly among habitat, but not between CBFM or control sites. However, estimates of the mean slope coefficient for CBFM sites were found to be significantly greater than zero ($p<0.05$) for closed and floodplain beel, indicating real increases in production within these habitats, equivalent to between approximately 20-30% per annum. Furthermore, for the remaining habitat type, no significant decreases in CPUA were detected, i.e. no estimates of the mean slope coefficient were significantly different from zero.

At the same time, no significant increases in CPUA were detected at control sites of any habitat type (Section 4.6.2).

<u>Overall, therefore, production appears to have increased significantly at CBFM sites exploiting closed floodplain beel habitat, and has been sustained at CBFM sites of other habitat type and at un-managed control sites.</u>

6.1.2 Fish Abundance (CPD and GNCPUE)

Two indicators of fish abundance were employed: catch per fisher per day or catch per day (CPD) and effort standardized gillnet catch rates during August and September (GNCPUE or abbreviated to CPUE).

Concern was expressed over the reliability of CPD as an indicator of fish abundance given the assumption that fishing power remains constant through time. Whilst fishing power (averaged across sites of the same habitat) did increase during the CBFM project period, the increases were not significant at the 5% level (Section 3.1.1).

The trend in CPD (regardless of its statistical significance) was upward at 72% of CBFM sites compared to only 38% of control sites. The relative frequencies of upward and downward trends at CBFM sites (either significant or not) would not be expected by chance ($p=0.04$ in both cases).

Estimates of the CPD slope coefficient (indicating the average annual rate of change in CPD) were found not to vary significantly among sites of different habitat. After pooling the estimates across habitat, the mean slope coefficient, i.e. the annual rate of change in fish abundance was found to be significantly higher for CBFM compared to control sites and significantly greater than zero.

This translates to an increase in catch rates (CPD) of 16% per annum averaged across habitat type. Equivalent increases by habitat range from 10-20% per annum (Table 19).

No significant annual changes in fish abundance were detected at the control sites when averaged across habitat, but significant declines were detected for control sites in river habitat.

Combined, these results indicate that fish abundance, indicated by CPD has increased significantly at CBFM sites, but has remained unchanged at control sites. The results of the analysis based upon the alternative indicator of abundance – GNCPUE imply a slightly less positive conclusion.

Downward trends in GNCPUE were observed at nearly 60% of CBFM sites, but the relative frequencies of upward or downward trends could be expected by chance ($p=0.23$ to 0.50). In contrast, taken at face value, almost all (90%) of control sites exhibited a downward trend in GNCPUE and all sites if only significant trends are considered.

Consistent with CPD, estimates of GNCPUE slope coefficients were found vary significantly between CBFM and control sites but not among habitat. After pooling the estimates across habitat, the mean slope coefficient, i.e. the annual rate of change in fish abundance, was found to be significantly higher for CBFM compared to control sites but not significantly greater than zero. For control sites GNCPUE was found to decline significantly ($p<0.05$), equivalent to almost 30% per year.

These findings are therefore very consistent with the indicator trend results, implying that fish abundance has declined through time at some CBFM sites but increased in others. Averaged across habitat, the overall picture is one of a decline in fish abundance through time but not significantly at the 5% level. There is, however, evidence that fish abundance has declined at CBFM sites of floodplain and haor beel habitat - note the relatively narrow confidence range for the mean estimates.

On the other hand, there is strong evidence to suggest that fish abundance has declined significantly at control sites, far more than at CBFM sites and particularly within river habitat.

Which indicator should be relied upon?
Whilst there is a strong correlation ($R=0.77$) between the CPD and GNCPUE estimates of the mean slope coefficients by habitat, it would be prudent to place greater emphasis/trust on the GNCPUE indicator results given it's relative robustness as an index of fish abundance (see Section 3.1.2). These GNCPUE results indicate that the CBFM has at least had some positive effect on sustainability (maintaining fish abundance) particularly in OB habitat, but that further measures may be necessary to ensure that this is the case across all habitat type. Monitoring of GNCPUE at CBFM sites should continue, perhaps more intensively, to confirm or reject these conclusions.

6.1.3 Fishing Effort (DPUA)

The frequency of upward and downward trends in fishing effort, indicated by annual nominal fisher fishing days per hectare or simply days per unit area (DPUA) was approximately equal at both CBFM and control sites regardless of the statistical significance of the trends (Section 4.6.1).

Consistent with these findings, estimates of DPUA slope coefficients were found to vary significantly between habitat, but not between CBFM and control sites (Section 4.6.2). The results indicate that fishing effort increased significantly ($p<0.05$) by 10% per annum at CBFM sites exploiting floodplain beel habitat, but decreased significantly by 30% per annum in haor beel habitat although this is based upon observations from only a maximum of 7 haor beel sites over a four year period.

For the remaining habitat, no significant changes in fishing effort through time were detected either at CBFM or control sites. Combined, these results imply that the CBFM has had little effect on fishing effort.

6.1.4 Destructive Fishing Practices (DFER)

Similar to fishing effort, the frequency of upward and downward trends in destructive fishing indicated by the destructive fishing ratio (DFER) was approximately equal at CBFM regardless of the statistical significance of the trends (Section 4.6.1). However, at control sites, the trend in the ratio was upward at almost 70% of sites, but the frequency could be expected by chance (p=0.13).

This implies that gear bans are ineffectively implemented at CBFM sites. Furthermore, that gear bans are unlikely to have been instrumental in effecting trends in performance indicators.

6.1.5 Biodiversity

Taken at ‘face value’, that is ignoring the statistical significance of individual site trends (slope coefficients), the number of upward compared to downward trends in fish biodiversity indicated by the Shannon-Weiner Index (H’) would **not** be expected by chance at the 1% level (Table 15). Trends in H’ were upward at 70% of CBFM sites compared to only 38% at control sites. If only significant trends are considered, 7 of the 8 CBFM sites exhibited an upward trend. The probability of observing these relative frequencies by chance is only 13%.

Estimates of the mean slope site slope coefficients for H’, indicating annual rates of change in biodiversity at each site, varied significantly (p<0.05) among habitat and between CBFM or control sites.

Similar to CPUA, estimates of the mean slope coefficient for CBFM sites were found to be significantly greater than zero (p<0.05) for closed and floodplain beel, equivalent to increases in the biodiversity indicator H’ of 0.12 and 0.17 per annum. However, H’ also increased significantly at control sites in floodplain beel habitat by 0.21 per annum.

No significant changes in biodiversity were detected at either CBFM or control sites in haor, open beel or river habitat, although the trend was downward at control sites in open beel and river habitat.

Where comparisons could be made, significant differences in species assemblages were found to exit between CBFM and control sites in floodplain beel and river habitat in the north and east regions of the country respectively (Section 4.5.2). Assemblages at CBFM sites were significantly richer and more abundant than those at control sites. Both whitefish and blackfish appear to benefit from the CBFM interventions.

Considered together, this evidence suggests that CBFM benefits biodiversity.

6.1.6 Mean Site Score

Mean site score summarizing the trends in all performance indicators was found to be significantly greater for CBFM compared to control sites (Section 4.6.3).

6.1.7 Conclusions

The evidence presented here indicates that the community based fisheries management (CBFM) approach in Bangladesh "works" in respect of improving or sustaining production fish abundance and biodiversity **relative** to unmanaged control sites:

- Production has, on average, either increased or been sustained at CBFM sites. Whilst production has also been sustained at control sites, no significant increases were detected.
- Based upon the more prudent indicator (GNCPUE), fish abundance, irrespective of habitat, declined by 5% per annum but this decline was judged to be not significant at the 5% level. On the other hand, there is strong evidence to suggest that fish abundance has declined significantly at control sites, far more than at CBFM sites and particularly within river habitat. It would therefore appear that CBFM is better than no management in terms of sustaining fish abundance. Monitoring of GNCPUE at CBFM and control sites should continue, perhaps more intensively, to confirm or reject this important conclusion.
- The alternative indicator (CPD) suggests that fish abundance increased significantly across CBFM sites and by as much as 20% per year in river habitat, but has remained unchanged at control sites.
- Changes in abundance are unlikely to have resulted from changes in fishing effort (except in floodplain beel habitat) or destructive fishing gear use since changes to these two factors have been largely insignificant.
- Biodiversity at CBFM sites increased with time in two habitats, but remained unchanged in the remainder. Biodiversity at control sites remained unchanged in all habitats. Species assemblages are richer and more abundant at CBFM compared to control sites in floodplain beel and river habitat in the north and east regions of the country respectively. Considered together, this evidence suggests that CBFM benefits biodiversity.
- The mean site score, encapsulating the trends of all the performance indicators, was also found to be significantly greater at CBFM compared to control sites.

6.2 Why does it work and how can performance be improved?

Unsurprisingly, fish abundance, indicated by catch per day (CPD) and fishing effort (DPUA) were found to be the best predictors of trends in fish production (CPUA). The probability of an upward trend in CPUA was 99% when the trend in CPD was upward and the trend in DPUA was downward, although the two factors are not independent (Section 4.6.1). Guidance relating to levels of effort to maximize catch (production are provided in Section 5.1 and summarized below in Section 6.4.1.

No significant predictors of trends in fish abundance measured in terms of gillnet catch rates (GNCPUE) were identified. Closed seasons and/or gearbans were found to be the only significant predictors of trends in fish abundance measured in terms of catch per day (CPD). When closed seasons/gear bans were present, the probability of an increase in CPD rises from approximately 40% to 70%. However, because closed seasons and gears bans were employed only at CBFM sites and typically size-by-side, these results are equivalent to testing the effect of the sum of CBFM activities on fish abundance compared to control sites. Trend in CPD was found to be the only significant ($p<0.05$) factor in predicting trends in biodiversity H' through time although the effect is small.

A great deal of uncertainty surrounds which factors or CBFM management interventions are responsible for the observed CBFM effects. Future studies/project should encourage greater variation in management interventions applied at the site level to help identify which interventions have the greatest effect on management performance indicators. Consideration might be given to planned or formal adaptive learning programmes or experiments (see Halls *et al* 2005 for further advice).

6.3 What factors affect the overall success of the CBFM?

Comparisons of mean site scores (an overall measure of management performance) among habitat type suggests that the CBFM works best in closed beel and river habitat, although the differences were not significant ($p>0.05$). Furthermore, management performance was found not to vary significantly among region, or with site (waterbody) size, facilitating NGO or ownership regime (see Section 4.6.3).

6.4 Management Models

6.4.1 Surplus Production (Catch vs Effort) Models

Whilst a great deal of uncertainty surrounds which CBFM interventions were responsible for the observed improvements in the management performance indicators (see Section 4.6.4 above), the control of fishing effort should be fundamental to any management approach. Indeed, CPUA was unsurprisingly, found to be dependent upon fishing effort (DPUA) and fish abundance (CPD), the latter also being dependent upon fishing effort.

The data generated by the project provided an opportunity to explore the response of catch to effort based upon among site comparisons. Such models can provide estimates of maximum yields and corresponding levels of effort.

Three types of production model were fitted to the data, stratified by habitat. Except for closed beel habitat, there was little evidence of a decline in yields with increasing fishing effort. This may reflect the existence of external sources of recruitment in these habitats.

For closed beel habitat, the best fitting (Schaefer) model predicted a maximum yield of 540 kg ha^{-1} yr^{-1} (95% CI [160, 2335]) at 633 fishing days ha^{-1} yr^{-1} (95% CI[272,2085]).

For the remaining habitats, an asymptotic model was the best fitting model in all cases. However, this model cannot provide estimates of fishing effort that maximize yield. Therefore, in addition to this asymptotic model, the next best fitting model (the Fox) which predicts a decline in catch with effort, was also fitted, to provide some guidance of levels of effort that maximize yields.

6.4.2 A Simple Stocking Model.

Stocking waterbodies with fingerlings is a common form of fisheries management in Bangladesh. Whilst there were too few control sites to determine if stocking programmes under CBFM were more effective than under non-CBFM, data from stocking events recorded under the Programme were used to develop a simple bio-economic stocking model (see Section 5.2).

This model offers managers guidance on selecting stocking densities depending upon the (available) size of fingerlings to maximize profit (harvest revenues-stocking costs) whilst minimizing risk. The model is an empirical type and therefore the model recommendations may not be applicable beyond the project sites that generated the data to construct the model. As more data becomes available from future stocking events, the model should be updated.

6.5 Recommendations for further work

- Given the fundamental importance of sustaining fish abundance, future CBFM programmes should focus attention towards monitoring fish abundance in a reliable and precise manner. This might include either employing routinely collected catch statistics from a standard gear or by periodically (annually) undertaking dedicated surveys such as depletion estimates.
- Any future CBFM programmes should consider designing and implementing experiments or adaptive learning programmes to identify effective management interventions (closed seasons, gear bans, mesh regulations etc) and thresholds such as minimum reserve size in relation to explicitly defined management objectives.
- The CBFM is a unique study in terms of its duration, coverage, and the quantity of data generated. Consideration should be given to publishing the main findings of this report in mainstream journals to disseminate the findings and encourage lesson learning among stakeholders. Suggested themes/titles might include:
    - Does community-based fisheries management work? Experiences of the CBFM project in Bangladesh.
    - An empirical bio-economic stocking model for inland waters of Bangladesh
    - Empirical surplus production models for inland fisheries in Bangladesh
    - Impact of the CBFM on fish biodiversity and species assemblages in Bangladesh.

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Annex 1 Management performance indicators and explanatory variables used in the analysis

Management Theme	Performance variable	Indicator	Calculation	Units	Comments
1. Production	Production per unit area (Catch per unit area, CPUA)	Annual multispecies CPUA $_{s,y}$	$\frac{\sum_{i=1}^{n}\sum_{m=Jan}^{m=Dec}\sum_{g=1}^{n} Catch_{s,y,i,m,g}}{Area_s}$	Kg ha^{-1} y^{-1}	Only sites monitored every month each year were included.
	Stocking yield per unit area (YPUA)	Multispecies YPUA $_{s,y}$	$\frac{Yield_{s,y}}{Area_s}$	Kg ha^{-1} y^{-1}	
2. Sustainability	Fish Abundance	Two alternative estimates were used. (i) Multispecies catch rate by gillnet catch rates in August and September $GNCPUE_{8-9,i,s,y}$ (ii) Average annual multispecies catch per fisher per day, $CPD_{s,y}$.	$GNCPUE_{8-9,i,s,y} = \frac{Catch_{8-9,i,s,y}}{NetArea_{8-9,i,s,y} * Hours_{8-9,i,s,y}}.1000$ $CPD_{s,y} = \frac{Catch_{s,y}}{Annual\ Fishing\ Days_{s,y}}$	Kg m^{-2} hour^{-1} (x1000) Kg fisher^{-1} day^{-1}	Gillnets were selected because they are used at most sites. Comparisons were made between the same month (September) in each year because gear catchability varies through time in response to hydrological conditions. September was selected because most gillnet catch rate observations were made during this month but also because catch rate variance is also low during this month thereby helping to maximise the power of statistical comparisons. Where $GNCPUE_{8-9,i,s,y}$ is the catch rate for gillnet *i*, sampled at site *s* between August and September of year *y*. The CPD indicator assumes that relative fish effort among different gear types remains fixed through time (month and year) at each site. Being based upon a large number of samples of catch rates and effort throughout the year, it should be more accurate than the GNCPUE indicator which relies upon a small number of samples in September of each year. However, the GNCPUE indicator does not make the same assumptions about constant relative fishing effort among gear types and does not take account of any changes in gear size.
	Fishing Intensity	Person fishing days per year per unit area, DPUA $_{s,y}$	$\frac{Person\ fishing\ days_{s,y}}{Area_s}$	Days y^{-1} ha^{-1}	Only sites monitored every month each year were included.
		Mean gillnet effort per unit area in September EPUA $_{s,y,GN,Sept}$	$\frac{Fishing Hours_{s,y,GN,Sept}}{Area_s}$	Hours ha^{-1}	Gillnets were selected because they are used at most sites. Selecting only observations made in September provides an explanatory variable that can be used to help interpret changes in fish abundance.
	Prevalence of destructive fishing practices	Destructive fishing effort ratio, DFER $_{s,y,dg/g}$	$\frac{\sum_{dg=1}^{n}\sum_{m=Jan}^{m=Dec} Fishing\ Hours_{s,y,m,dg}}{\sum_{g=1}^{n}\sum_{m=Jan}^{m=Dec} Fishing\ Hours_{s,y,m,g}}$	Ratio	Ratio of total annual effort with destructive gears, *dg* as a proportion of total annual effort with all gears, *g*. Gears classified as destructive are listed in Annex 3. Only sites monitored every month each year were included.

	Biodiversity	Various univariate indicators (eg H', S) calculated from: Catch rates for each species, *i* by gillnet (GN) fishers in September, $CPUE_{s, y, i, GN, Sept}$	$\frac{Catch_{s,y,i,GN,Sept}}{Fishing\ Hours_{s,y,GN,Sept}}$	Kg $hour^{-1}$	See comments for fish abundance. Indicator also used for multivariate analyses.
3. Fisher Wellbeing	HH Net Income	Annual household income from fishing less total annual expenditure on fishing and management related activities, $HHI_{s, hh, y}$	$\sum_{m=Jan}^{m=Dec} Income_{s,hh,y,m} - \sum_{m=Jan}^{m=Dec} Expenditure_{s,hh,y,m}$	Tk y^{-1}	-
	HH Fish Consumption	Bi-monthly household fish consumption, $HHFC_{s, hh, y.}$	$\sum_{m=Jan}^{m=Dec} Quantity\ consumed_{s,hh,y,m}$	Kg mm^{-1}	-

Table 2 Explanatory variables hypothesised to affect management performance

Management Theme	Performance (dependent) variable	Explanatory variables to consider	Indicator	Units/Scoring	Comments
1. Production	Production per unit area (CPUA) (or harvest per unit area when considering the relative performance of stocking programmes)	Region	Region code	North (N); North West (NW); South (S); East (E); SouthWest (SW)	
		Habitat type	Habitat code	Floodplain Beel (FPB); Open Beel (OB); Closed Beel (CB); River (R).	
		Hydrology	Flooded Area Ratio (FAR)	Ratio	
			Flood Index (FI)	m days flooding	
		Management Type	Code	CBFM (CBFM); none (control)	
		Years under CBFM	Years	Number of years	Effect of CBFM may take several years to become detectable.
		Production potential	Secchi depth	(m)	Simple index of primary production
		Stocking intensity	Stocking density	Kg $ha^{-1}y^{-1}$ and N $ha^{-1}y^{-1}$	
			Mean length of stocked fish	cm	Natural mortality rate highly correlated with fish length
		Closed season duration	Duration of closed season	Months	Set to zero if closed seasons are not implemented.
		Gear bans	Gear bans implemented	No (0); Yes (1)	
		Harvest reserve area	Reserve area expressed as a proportion of the minimum surface area of the waterbody.	Ratio	
		Fishing intensity	Fishing days per unit area (DPUA) and Gill net effort per unit area (EPUA)	Days y^{-1} ha^{-1} or Hours ha^{-1}	(see Table 1)
		Illegal fishing/poaching	Incidence of illegal fishing/poaching	Low (0); Medium (1); High (2)	Scored by WorldFish Centre.
		Closed Season fishing	Incidence of fishing during closed season	Low (0); Medium (1); High (2)	Scored by WorldFish Centre.
		Destructive fishing	Destructive gear effort ratio (DFER)	Ratio	(see Table 1)
2. Sustainability	Fish Abundance (CPUE)	As for CPUA	As for CPUA	As for CPUA	As for CPUA
	Fishing Intensity	Stocking	See above	See above	See above
		Management type	See above	See above	See above
	Destructive fishing practices	Management type	See above	See above	See above
	Biodiversity	As for CPUA	See above	See above	See above
3. Fisher Wellbeing	HH net income	Habitat type	See above	See above	See above
		CPUA	See above	See above	
		Stocking	See above	See above	See above
		Control/CBFM	See above	See above	See above
	HH Fish Consumption	As for HH net income	See above	See above	See above

Annex 2 Destructive Gears

Gear	Code
Current jal	104
Moshari jal	201
Bhadi	201
Kawri	201
Chat jal	202
Gancha ber jal	205
Net jal	201
Bada jal	301
Beddi jal	301
Behundi jal	301
Binti jal	301
Behuti jal	301
Bhem jal	301
Bhim jal	301
Door jal	301
Baila jal / Tona jal	302
Banna/pati	1201
De-watering	1201