FLOODS, FISH AND FISHERMEN

EIGHT YEARS EXPERIENCES WITH FLOOD PLAIN FISHERIES, FISH MIGRATION, FISHERIES MODELLING AND FISH BIO DIVERSITY IN THE COMPARTMENTALIZATION PILOT PROJECT, BANGLADESH

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ABSTRACT

This book presents the results of a fisheries monitoring program carried out from 1992 – 2000 in the Compartmentalisation Pilot Project, Tangail, Bangladesh. A habitat related fisheries monitoring program using Geographical Information Systems was applied for estimating the impact of water management on floodplain fisheries and results are described. An in-depth analysis of Catch and Effort Data in relation with the annual flood pulse was carried out. Length based stock assessment data were analysed and related with the flood pulse. The results Indicated that growth of most species is positively related to the extend of flooding. The consequences for fisheries are discussed. The major conclusion was that fishing effort is the major driving force between floodplain fisheries in the CPP. Fishing mortality of different species was strongly positively related to the flood pulse. Results of the length based fish stock assessment program were used for the development of an adapted Yield per Recruit model. This model uses fishing effort and the extent of flooding as input parameters and Yield per Recruit as output. Fish bio-diversity and the different stages of flood control were studied and resulted in the development of a Fish Rapid Bio diversity Appraisal, which was applied in and outside the CPP project area. A predictive floodplain fisheries model was made and the principles of the model are presented in the form of a case study.

The original data set of the CPP fisheries monitoring program in a user-friendly format on CD-Rom is available at CEGIS, the Bangladesh Water Development Board (BWDB), or the Dutch embassy, Dhaka, Bangladesh.

For information on the results or data set please contact the main author at deGraaf@nefisco.org.

Key words: Bangladesh, flood plain fisheries, flood pulse, catch and fishing effort GIS, decision support modelling, stock assessment, fish migration, economics, hydrological models.

Cover photo: Dr. Munir Ahmed.

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Glossary

Aquaculture	cultivation of aquatic products (mainly fish and shrimp)
Frame Survey	a survey for estimating the number of fishermen or gears
Beel	a small lake, low-lying depression, a permanent body of water in a floodplain or a body of water created by rains or floods.
Beel resident species	fish species mainly living in the Beel area
Compartment	a (semi) protected area or part thereof in which effective water management, particularly through controlled flooding and controlled drainage, is made possible through physical and institutional arrangements. A compartment will be subdivided into sub-compartments and operational water management units.
Compartmentalisation	establishment of inter-linked (sub) compartments in the flood plains, with the objective to provide a more secure environment for agriculture, fisheries and integrated rural and urban development through water management (controlled flooding and drainage, flood control), while allowing seasonal beneficial flooding.
Controlled drainage	control of the water flow out of a (sub) compartment according to the local or regional requirements.
Controlled flooding	spreading of the monsoon flood over the land in a (semi) controlled way with the help of provisions incorporated in compartments, embankments, roads etc.
Catch Assessment	determination of the daily catch of the fishermen
Catch per unit of effort	quantification of fish caught by the fisherman in unit time and effort (Fishing gears)
Flood Control	protection against harmful flooding.
Habitat	living place
Khal	channel.
Pagar	small water body, generally excavated near a homestead, which is used for fish stocking as well as for household activities.

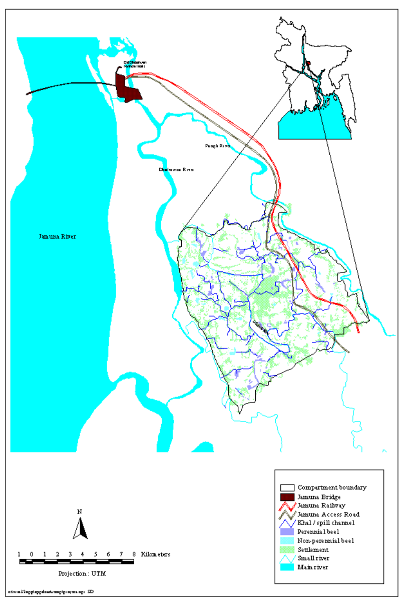
1 THE CPP PROJECT

1.1 Introduction

The floods in Bangladesh in 1987 and 1988 were catastrophic. Many people lost their lives, thousands became homeless, crops in the fields were destroyed and infrastructure was severely damaged all over Bangladesh, including Tangail district. Immediately after the 1988 flood disaster, several studies were carried out by the Government of Bangladesh (GoB) and the international community to find a lasting solution for the flood problem. In June 1989, the World Bank agreed with the GoB to co-ordinate the various flood control and related initiatives from which the Flood Action Plan (FAP) emerged.

The Compartmentalisation Pilot Project (CPP, also called FAP 20), that started in 1991, is a water management project situated on the East bank of the Jamuna river, with Tangail Town in its centre (Figure 1).

Figure 1: The Compartmentalisation Pilot Project



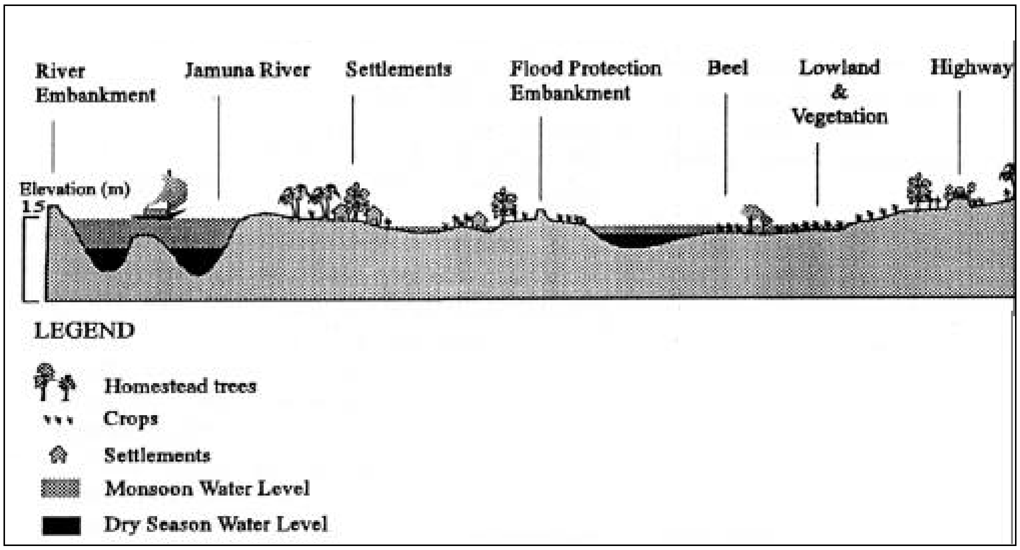
The overall objective of the Compartmentalisation Pilot Project was to develop appropriate water management methods for protected areas so that criteria for design, implementation and operation can be made available for similar settings in floodplains in Bangladesh.

The project area is situated in the Young Brahmaputra Flood Plain. The natural drainage pattern is away from the Brahmaputra (Jamuna) and Dhaleswari rivers towards low-lying land in the southeast. Land elevation varies between 14 and 7 m+PWD. Large depressions (Beels) are found throughout the project area. Although the overall topography is rather flat, local landscapes are very diverse. Local differences are due to the following features:

Floodwater courses of natural rivers
Terraces and ridges of different levels, due to large extensions of the old and active floodplains
Artificially levelled homesteads
Roads, flood protection, embankments, etc.
Different levels of cropping fields, which is a sequence of small terraces built for water management.

A typical cross-section profile of the study area from west to east is presented in Figure 2.

Figure 2: A typical cross section of the CPP area from west to east (source: EGIS)



The objectives of CPP were:

To test the viability, sustainability and replicability of compartmentalisation as an approach for developing protected areas.
To develop integrated water resource management options for different sections of the rural population, with specific attention to be paid to the needs of women, landless, farmers, fishermen and boatmen.
To develop water management systems especially for agricultural production systems based on the total hydrological setting for maintaining the quality and quantity of water for domestic use and sanitation.
To develop policies and guidelines for the development of integrated water resources management in protected areas.

The basic aim of CPP was to control the unpredictable and variable flooding patterns and improve the drainage congestion. In June 1992 the Flood Plan Co-ordination Organisation (FPCO) decided that this was to be obtained through flood protection at the peripheral embankment. It was expected that fisheries would be affected by interventions such as construction of gated regulators in the main river and the peripheral embankment, improvement of drainage through excavation of canals and the construction of minor regulators within the project area. Fisheries aspects have therefore been included in the project since its start.

1.2 The fisheries monitoring programme of CPP

The objectives of the fisheries component of CPP were to increase the availability of fish by securing fisheries production and by improving aquaculture production by focusing on the following aspects:

- Determining the impact of CPP on natural fisheries production.
- Determining hatchling migration patterns and incorporation of the results in water management options and design of water management structures.
- Development and implementation of mitigation measures to compensate eventual negative impacts of the implementation of CPP.
- Development of proper water management scenarios for fisheries production.

Continuously monitoring of tropical floodplain fisheries for eight years is not only unique for Bangladesh but most likely it is the first time a floodplain fisheries system has been followed that long. Monitoring fisheries that long had the following major benefits:

A more reliable estimate of the different production parameters could be obtained as the effect of extreme values caused years of high or low floods were tempered by the average years
Interactive relations between biological, human and physical processes became visible and were statistically significant.
A number of methods developed and applied by CPP were adjusted and refined over time and their merits proved to be important.

CPP looked upon fisheries from different angles, applied a number of known methods, developed some new methods and tried to integrate them in a consistent way. The most important aspects were:

Modification of traditional a Catch and Effort recording system into a habitat related Catch and Effort recording system, whereby the total catch was obtained by applying Geographical Information Systems (GIS).
Analysis of all data in relation to fishing effort and the intensity of the annual flooding.
Incorporation from the beginning of the project of a length based stock assessment program for the major species.
Development of simple predictive models using GIS, hydrological models and the results of the habitat related catch and effort and the length based fish stock assessment program.
Detailed studies of riverine fish larvae migration and using the results in adaptive design and management of regulators.

The major results were presented in a final report (CPP, 2000) but It was felt that the results obtained and experiences gained on fisheries in the CPP project went beyond the original scope of the program for CPP. Some of them are of importance for inland fisheries in Bangladesh and tropical floodplain fisheries in general and were not covered in the annex on fisheries of the main final report. This book presents more detailed information on the different methods applied, results obtained and insight gained on floodplain fisheries in Bangladesh.

In Chapter 2, general characteristics of inland fisheries in Bangladesh are provided.

Chapter 3 describes the developed habitat related floodplain fisheries monitoring in detail. It discusses the results and provides suggestions as to how it could be improved and applied on a national level.

Chapter 4 presents the results of the monitoring programme; catch statistics are provided and discussed in terms of economic and socio-economic importance

Chapter 5 presents a summary of the two basic tools for fisheries management: Holistic tools applied with Catch and Effort Data, and Analytical tools applied with length based stock assessment data, as CPP collected both types of data and used holistic as well as analytical tools for analysis of the data.

In Chapter 6, an in-depth analysis of the Catch and Effort data is presented together with the consequences of the results for floodplain fisheries management.

Chapter 7 presents the results of the length based stock assessment and tries to explain the basic interactive processes steering floodplain fisheries and presents the basic set-up of a new predictive model in fishing effort and hydrology related to fish catch.

In Chapter 8 Fish bio diversity of floodplain fisheries in relation to water management in Bangladesh is discussed. A Rapid Fish Bio diversity Appraisal was developed and applied inside and outside the CPP project area.

Chapter 9 presents a predictive floodplain fisheries model as developed by CPP. The model estimates the impact of different water management scenarios on fisheries and agriculture and the distribution of the profits and losses over the different social strata of rural areas of the CPP.

Chapter 10 presents the results of the monitoring programme of riverine fish larvae and the consequences for the design and management of a regulator.
It is realised that some of the methods applied, especially the Length Based Stock Assessment, are not yet commonly used by fisheries biologists in Bangladesh; therefore, where necessary, additional background information is provided.

2 GENERAL CHARACTERISTICS OF INLAND FISHERIES IN BANGLADESH.

Being a country of rivers and floodplains with a high potential of aquatic resources, fish plays a very important role in daily life of many people in Bangladesh. The Bengali expression *“Mache Bhate Bengali”, “Fish and Rice make a Bengali”,* expresses this importance. Bangladesh produce 1,400,000 Mt. of fish annually. Inland fisheries and aquaculture are the main contributors to this production, with respectively 53% and 24% of the total. The total fish production accounts for 6% of GDP and 12% of the export earnings. About 12 million people depend on fisheries, of which 1.2 million people are dependent full-time on fish and fishing activities. Sixty percent of the animal protein consumption comes from fish. With a total population of 117.5 million, the availability is 32 gram of fish/person/day or 5.6 gram of fish protein/person/day[1].

A progressive decline in protein intake over the last 30 years has been previously indicated (INFS, 1983), and at present we have arrived at a situation of protein deficiency (Table 1).

	1962-64	1975-76	1981-82	1995-96	Requirement
Protein intake (g/capita/day)	57.9	58.5	48.4	40.0	43.3

Table 1: Changes in average per capita protein intake in Bangladesh.

Fish production in Bangladesh, like in other floodplain areas in the world, cannot be properly considered without knowing the hydrological features of those areas. In Bangladesh, extensive seasonal flooding by high water levels during the monsoon generally occurs between July and November. This flooding has a high variation in terms of timing, duration and intensity, which is caused by interaction of the three river systems - Ganges, Brahmaputra (Jamuna) and Meghna - which have independent cycles. Together with the extremely high monsoon rainfall in some years, it creates a highly dynamic floodplain system. In contrast to the abundance of water in the monsoon, water areas decline rapidly during the dry season (December-April), which is characterised by very low rainfall and high evaporation rates. This contraction and expansion of aquatic habitats greatly influences fisheries production.

Fish and prawn populations in Bangladesh are adapted to these variations, and their life cycles are tuned to it. Breeding and growth are strongly related to the sequence of flooding. The floodplains, which inundate during monsoon, are nutrient- and food-rich and play a significant role for 4-5 months of the year. Larvae, juveniles and adults grow in this habitat, after which they migrate back to rivers or depressions at the end of the monsoon, when waters recede. They become concentrated in channels and Beels in this period, and are more vulnerable to fishing activities.

On the basis of their behaviour, mainly related to migration and reproduction, the fish species of Bangladesh can be divided into two groups:
The so-called **"white fish"** migrate upstream and laterally to the inundated oxbow lakes and floodplains adjacent to the river channel in the late dry season or early rainy season in order to spawn in the quiet sheltered and nutrient-rich waters. The eggs and newborn larvae of these species are transported passively by the flood into the floodplain area, where they feed on the developed plankton. At the end of the

[1] One kilogram of fish contains 17-18% protein

rainy season, the adults and young of the year escape to the main channel and most likely the deeper Beels, in order to avoid the harsh conditions of the floodplain during the dry season. "White" fish belong mainly to Cyprinidae and Pangasidae, (Mrigal, Rui, Catla, Pangash, etc). Further in this book this group will be referred as **"riverine fish"**.

The so-called **"black fish"** are mainly omnivorous/carnivorous bottom dwellers; they reproduce at the onset of the pre-monsoon as the water level in the "Beels" starts rising due to the congestion of rainwater. At the end of the rainy season the young of the year and adults migrate back to, or get trapped in, the low-lying Beels, where they can survive the harsh conditions of these permanent water bodies during the dry season. They are adapted to resist low dissolved oxygen concentration and high water temperatures. The main adaptation is their auxiliary respiratory organ used for the uptake of atmospheric oxygen. The main species of the "black" fish are belonging to the Clariidea (Magur), Ophiocephalidea (Taki, Shol) and Anabantidae (Koi, Kholisha). Further in this book this group will be referred to as **"Beel fish"**.

3 FLOODPLAIN FISHERIES MONITORING AND GEOGRAPHICAL INFORMATION SYSTEMS

To assess the impact of CPP on fisheries in 1992 a fisheries monitoring program was started. Fisheries is traditionally monitored through so-called *“Catch and Effort”* monitoring systems, in which “effort” is the number of fishermen or gears operated in a water body and “catch” is the daily catch obtained by the fishermen or gear. The total catch is obtained by multiplying the Catch with the number of gears or fishermen. A prerequisite for a “Catch and Effort” monitoring system is that the total effort and the total number of fishermen or gears operated is known. For CPP it would have meant that the total number of fishermen and the number of used gears, which was impossible. This as preliminary survey executed in 1991 indicated that almost 68% of the rural population, or about 17,000 households, were engaged in some kind of fishing (subsistence fishing) and that this activity varied highly throughout the year. This means a large number of households had to be followed throughout CPP if a traditional Catch and Effort monitoring program would be used, and practically, this was impossible. Therefore a more practical monitoring system was implemented: *“ A Habitat Fisheries Monitoring Program”,* which is based on traditional Catch and Effort data recording and combined with hydrological developments[2] analysed in a Geographical Information Systems (GIS) environment.

3.1 Basic principles of habitat stratified floodplain fisheries monitoring

The principle of the used Fisheries Monitoring Program of CPP is a stratification of Catch and Effort Monitoring. Stratification along types of water bodies is needed to scale down the inputs/field staff for the monitoring program, while the results remain reliable and representative. This means that the monitoring program is divided into several representative smaller parts, for each of which the fisheries are followed and finally the overall picture is obtained by adding the results of all the small parts together. The estimation of the total catch follows three steps:

First the Catch per Unit of Area (CPUA) for each type of water body is determined as accurately as possible with traditional Catch and Effort monitoring
Secondly the total inundated area for each type of water body is determined as accurate as possible with GIS
The total catch per type of water body is determined by multiplying the Catch per Unit of Area with the area

3.2 Stratification or criteria and principles.

The type of water bodies in the floodplain of Bangladesh can be classified as:

Beels: These are the low-lying depressions in the floodplain (small lakes). They may have a permanent character, containing water throughout the year (**perennial Beels**) or dry completely out during a part, mostly 4-5 months, of the year (**seasonal Beels).**

Floodplains: Inundated land formed during the monsoon as a result of rainwater congestion and river flooding.

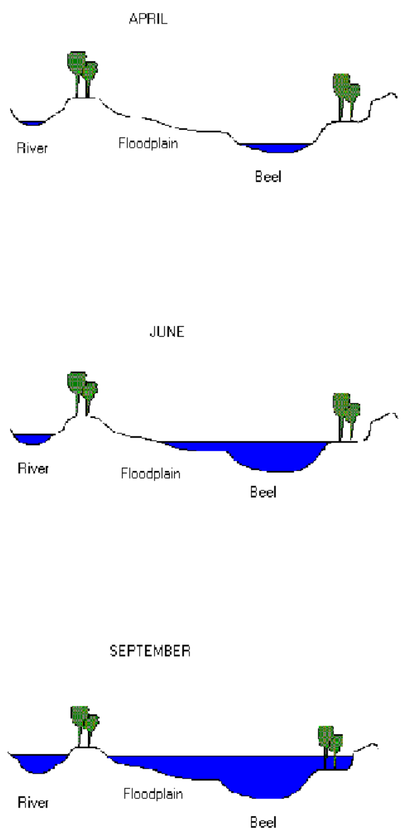
[2] Spatial and temporal

Rivers and canals: Classification and selection of rivers and canals is straightforward but the classification and selection of Beels/Floodplains is more complicated as they are hydrologically linked and highly dynamic. The National Water Development Plan (WARPO, 1999) states that water bodies can be classified with flood extent, depth, duration, timing and connectivity within the water resource system. The number of parameters needed to classify indicates that classification could be perplexing. The following statement can best describe this perplexity:

"A floodplain or a Beel does not have a specified area or water depth."

The latter is explained in Figure 3, Flood levels and the inundated area of a floodplain during the months April, June and September are presented.

Figure 3: Water level and inundated area of a floodplain system at three moments during the year.



In April there is no floodplain. The water depth in the Beel is 1 meter, while the Beel covers an area of 100 ha. Two months later, in June, there is 0.3 meters of water in the floodplain, which covers an area of 1200 ha, while the water depth in the Beel has increased to 2 meters and covers area of 150 ha. Another two months later, in September, there is 0.3-1.5 meters of water in the floodplain, depending on where you are, and it covers an area 2000 ha. In this example, we looked at water levels given at dates rather far apart, but even within one month during the flood season the water level varies significantly. This phenomenon makes it difficult to use water level as selection criteria for habitat fisheries monitoring, as it would mean that these habitats are moving on the map.

In principle, criteria that can be quantified, can be replicated, can be used all over Bangladesh and are practical for implementation of fisheries monitoring programs have to be used. It was concluded by CPP that the land type classification as defined by the Master Plan Organisation (MPO, 1988) was the best and most practical way to define fisheries habitats and well because:

- The classification is well known by large groups of planners, scientists, departments, etc.
- The classification is precisely defined and uniform for the whole of Bangladesh, with as a basic input a Digital Elevation Model (DEM) or Topographic maps, a 1 in 5 years maximum water level and a 1 in 5 years 3 days maximum rainfall.
- Land types have a fixed position and will only change due to water management interventions, such as the construction of embankments and regulators.
- The impact of water levels is incorporated as the classification works with maximum water levels.

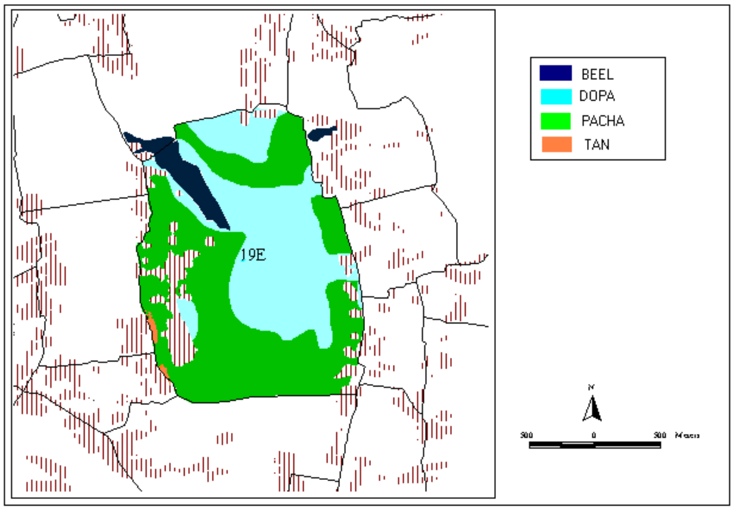
The land type classification as defined by Master Plan Organisation is presented in Table 2 with other classification methods such as the general water body classification and the classification of the farmer, which in general use the terms; Tan Jomi (highland), Pachot Jomi (medium) and Dopa Jomi (lowland) to indicate the suitability of their land for different agricultural practices.

Table 2: MPO land type classification

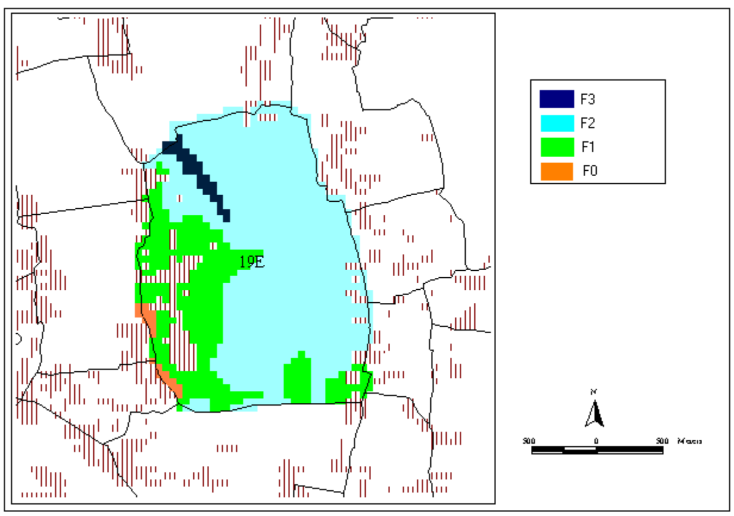
Inundation depth (cm)	MPO Land Type	Water Type	Farmers Classification	Land use during the monsoon
0-30	F0	Dry	Tan Jomi	Sugarcane, Vegetables, T Aman HYV
30-90	F1	Dry	Pachot Jomi	T. Aman, Local and T. Aman HYV
90-180	F2	Floodplain Seasonal Beel	Dopa Jomi	T. Aman, Local, DW Aman, Fish
> 180	F3	Perennial Beel	Beel	DW Aman, Fish

The MPO classification follows well the general classification of the farmers, which can be seen in Figure 4, where the two are compared. Using the MPO classification has the advantage that it is precisely defined and therefore applicable and comparable for the whole of Bangladesh**.**

Figure 4: A comparison between the MPO land use classification and the farmer's concept of land use in Chawk 19E in the CPP project area.



FARMERS LANDTYPE

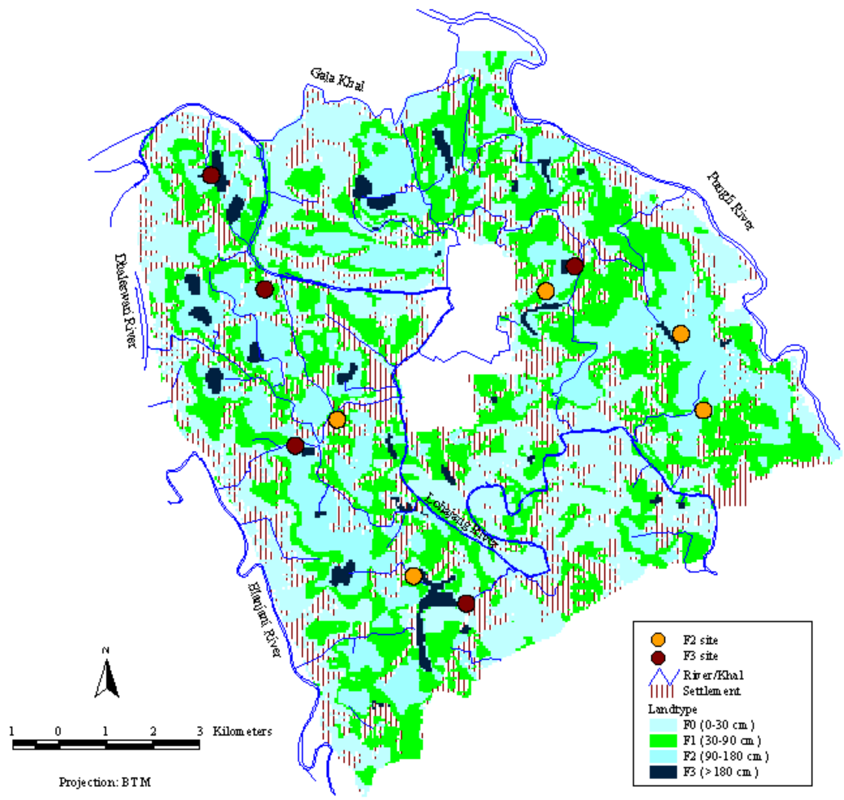


MPO LAND CLASSIFICATION

Habitat stratified floodplain fisheries monitoring further uses the principle that fisheries data obtained from a site, within a certain land type, irrespective of the actual water level measured at the site, is representative for the total inundated area of this land type, i.e. if the catch in 10 ha of F2 land is well monitored during a certain period, it is representative for the total area of inundated F2 land during this period. This principle allows concentrating the monitoring program at fixed sites within a project area, and even with a limited number of field staff, a statistically sound analysis with a large number of observations/samples, can be carried out.

In Figure 5 the location of the representative sites for F3 and F2 land types and the MPO land type map for the CPP project area is presented.

Figure 5: The sampling sites in the CPP project area



3.3 *The actual monitoring program of CPP*

The actual monitoring consists of a catch assessment and frame survey within a **fixed area** at the selected sites:

Catch Assessment Survey: The daily catch of every individual fisherman[3] (CPUE) is monitored regularly at each site. The numbers and weight of the dominant species in the catch are recorded. Furthermore, the gear-type, its mesh size, owner status and the number of units used per fisherman were recorded.

The Frame Survey: regular standardised counting of the number of fishermen and the number of gears used at the different sampling sites.

Again, to keep the program practical, the habitat fisheries monitoring program of CPP followed only the most dominant species and the most common gears. In Table 3 and in Table 4 the gears and species monitored by CPP are presented.

Bengali name	English name
Taki Jal	Cast Net
Thella Jal	Scoop Net
Dhorma Jal	Lift Net
Ber Jal	Seine Net
Kerrent Jal	Gill Net
Borshi	Lining
Darki	Traps
Others (Khata, De-watering, Hand-picking etc.)	Others (Khata, De-watering, Hand-picking etc.)

Table 3: Specified gears for fish catch monitoring by CPP

[3] To keep things simple the fisheries monitoring programme was “fishermen” based this in contrast with most fisheries monitoring programmes which are “gear-based”.

Beel resident fish species		Riverine fish species	
Common name	Scientific name	Common name	Scientific name
Baim	Mastacembelus pancalus	Baila	Glossogobius giurus
Gutum	Lepidocephalus guntea	Boal	Wallago attu
Kolisha	Colisha fasciatus	Catla	Catla catla
Puti	Puntius sophore	Mrigal	Cirrhinus mrigola
Shing	Heteropneustes fossilis	Rui	Labeo rohita
Koi	Anabas testudineus	Titputi	Puntius ticto
Taki	Channa punctatus	Ayre	Mystus aor
		Kalibaus	Labeo calbasu
Others	Pisces anonymus	Others	Pisces anonymus

Table 4: Specified fish species for fish catch monitoring in the CPP area

3.4 Data analysis and estimation of annual catch

The principle of data analysis and estimation of annual catch is visualised in the relational diagram (Figure 6):

First, the Catch per Unit of Area (CPUA) for each type of water body is determined as accurately as possible on a monthly basis with traditional Catch and Effort monitoring.
Secondly, the total inundated area (A) for each type of water body is determined as accurately as possible with GIS on a monthly basis.

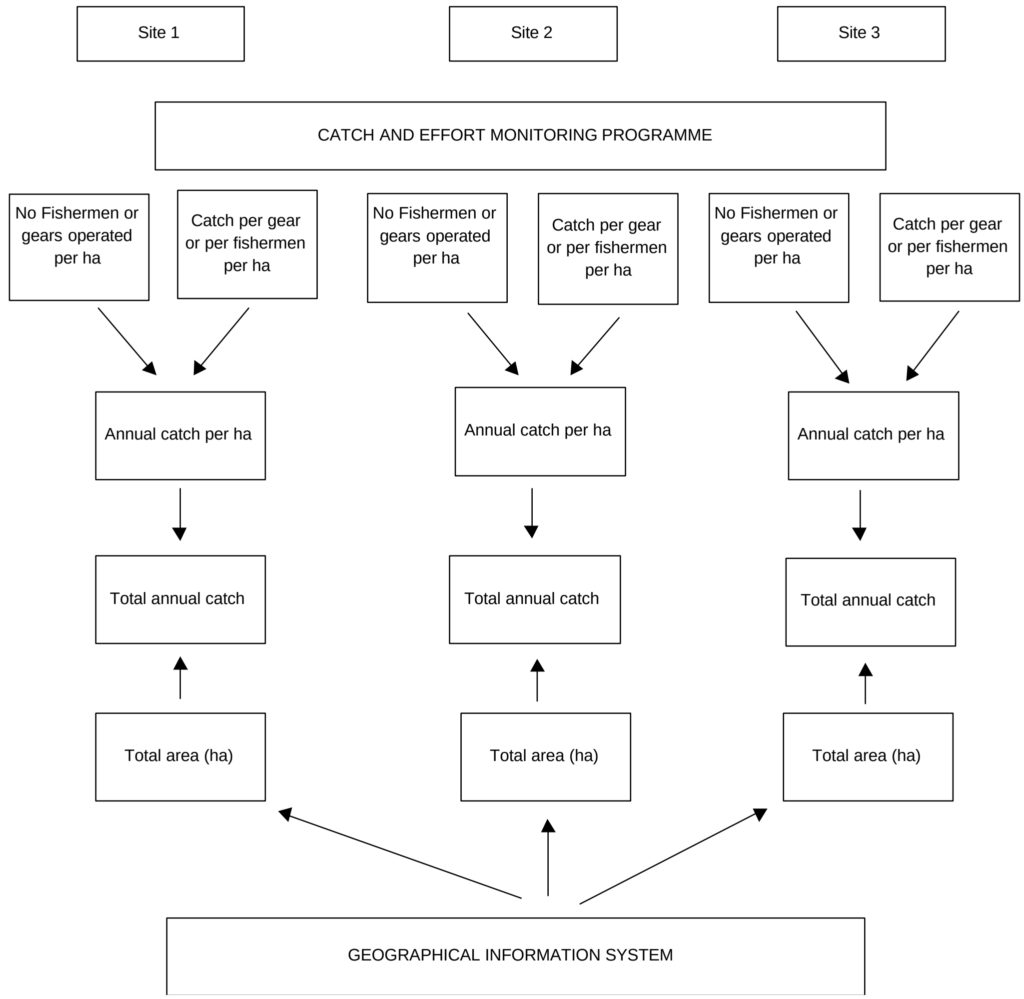
The total annual catch for the different land types is estimated by multiplying the monthly catch per unit of area with the monthly flooded area and summing them for the whole year or;

$$Annual\ Catch\ per\ site = \sum_{i}^{n} CPUA_i . Area_i$$

The total annual catch for the monitored area is the sum of the annual catches of the different land types, or

$$Total\ Catch = \sum_{i=1}^{n} Annual\ Catch\ per\ site_i$$

Figure 6: Relational diagram of annual catch estimation with Habitat stratified floodplain fisheries.



3.4.1 Determination of Catch per Unit of Area

The catch assessment survey provides information on the average monthly catch per fisherman and per gear (CPUE), within a selected site. Differentiation between gears and fishermen is essential as professional fishermen catch more with a certain gear if compared with occasional or subsistence fishermen, because of his skills or because he fishes longer.

The frame survey provides information on the average number of fishermen or gears operating (f) within a selected site. By multiplying the two parameters for the different types of fishermen and types of gears and summing them, the monthly catch for each site is estimated; or;

$$Monthly\ Catch\ per\ site = \sum_{i,j=1}^{n} \overline{f}_{i,j},*\overline{cpue}_{i,j}$$

At each site monitoring was carried out within a well-marked and fixed location with a known area or length, which allowed us to calculate the monthly fish **Catch Per Unit of Area** (**CPUA**) for F3, F2 and F1 or per unit of length for the khals and rivers by dividing the average total monthly catch with the fixed sampled area or sampled length:

$$CPUA = \frac{Monthly\ catch\ per\ site}{Sampled\ area}$$

3.4.2 Determination of monthly inundated areas

In order to determine the total catch for each month, the total inundated area for each habitat/land type has to be calculated. This can be done in GIS with the following inputs:

A Digital Elevation Model (DEM) or Digital Terrain Model (DTM)
Monthly water levels as registered within the area
A land use map based on MPO (1988) criteria

3.5 Digital Elevation Model

A Digital Elevation Model is a digitised topographic map of the area, it can be presented as a contour map (Figure 7) or in the form of a three-dimensional map (Figure 8).

Figure 7: Contour map of Garinda Beel in CPP

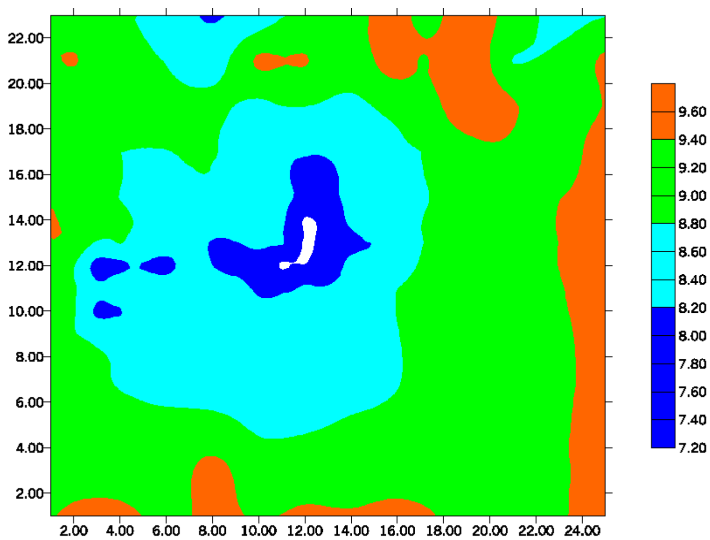
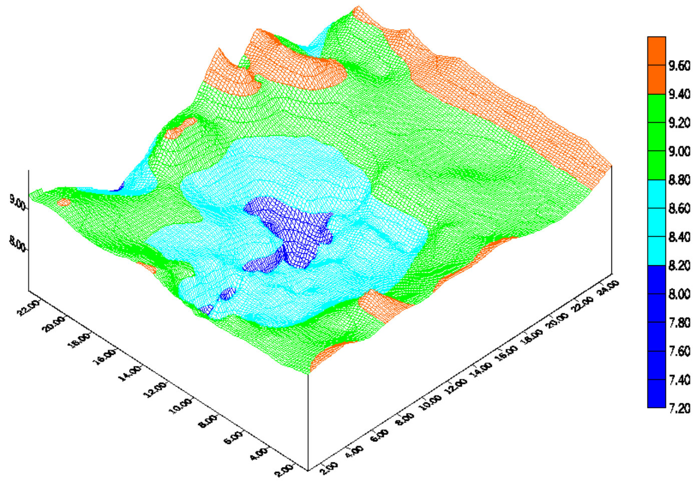
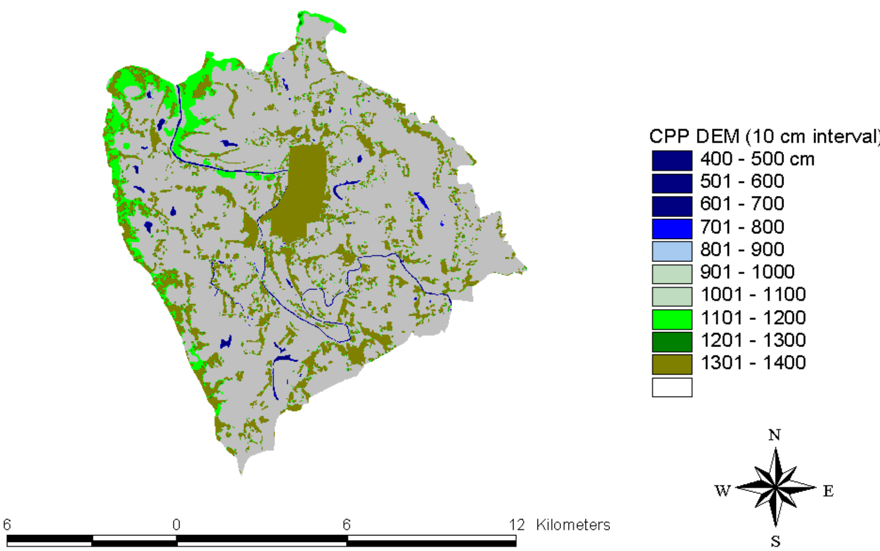


Figure 8: Three-dimensional DEM of Garinda Beel



(1991, scale 1:20.000) with a 10- Figure 9
used for the analysis of the fisheries data

Figure : The Digital Elevation Model of the CPP area



3.6

project. Since 1992 CPP installed water gauges throughout the area, which were

basis, the water level (m+PWD) is known. For all locations, the average monthly water level was calculat [4] with the

the water level layer with a certain gradient was obtained in the form of a surface grid (see 10 and 11).

Figure : Interpolation between monthly readings of different gauges

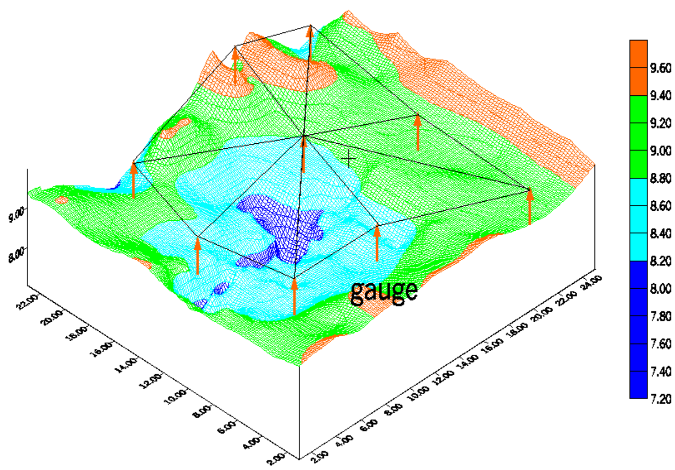
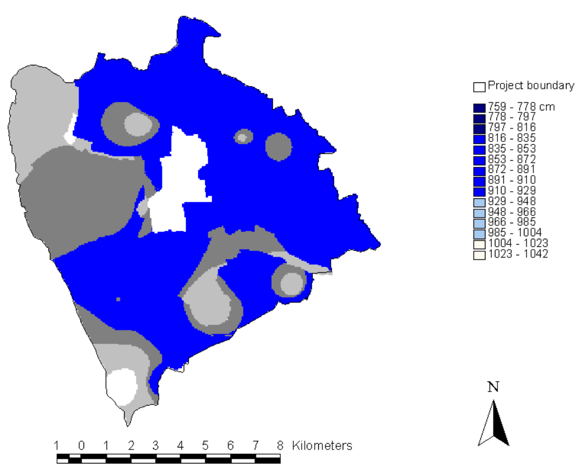


Figure 11: A water level surface grid as calculated for CCP, June 1998

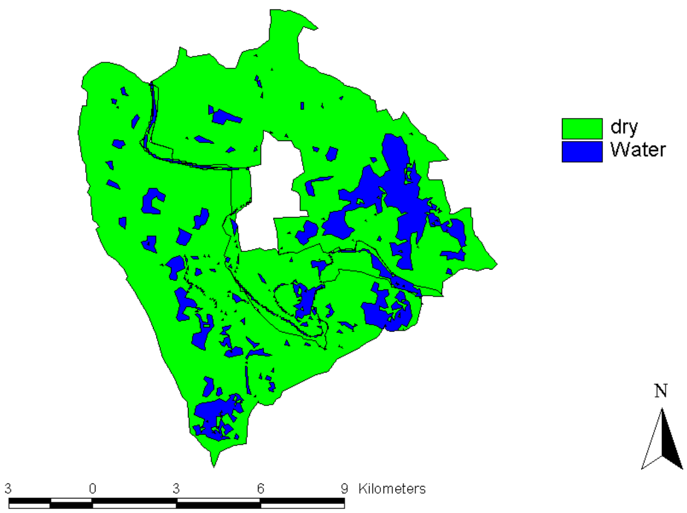


This water level surface layer is placed on top of the DEM, and the inundated areas were calculated by subtracting the water level layer from the DEM elevation level. Negative values indicate a water level higher than the DEM elevation level, which

[4] This analysis requires "Spatial analysis" in GIS.

means that the location was covered with water**.** The resulting inundated area for CPP for June 1998 is presented as an example in Figure 12.

Figure 12: Inundated area of CPP as calculated with the Digital Elevation Model for June 1998

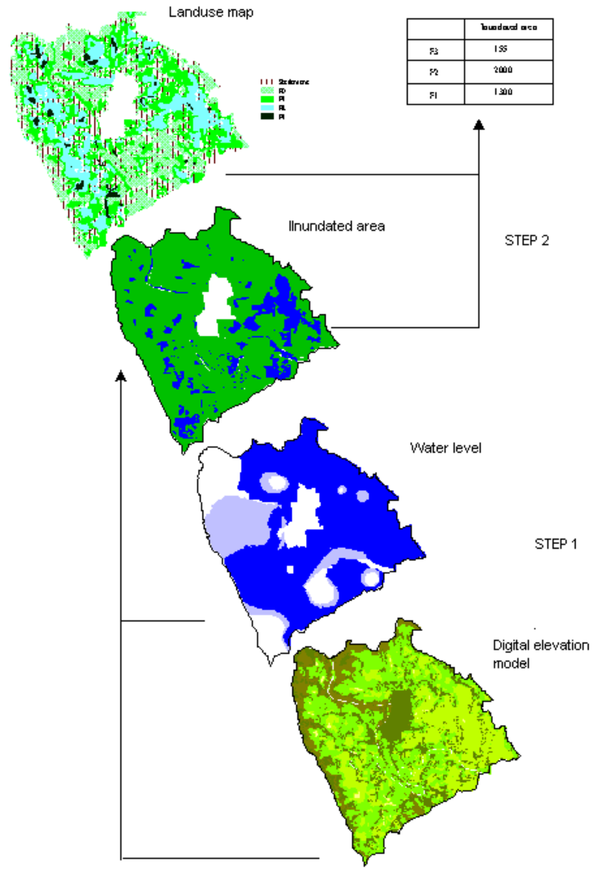


Land use map

Finally, the grid of the total inundated area was placed on top of the land type map nd type (F0, F2, F1, and F3).

All steps for the analysis are summarised in 13

Figure : Pathway of determination of monthly inundated area per habitat in the CPP project area.



3.7

areas obtained from optical satellite images (dry season, March 1994 and January 1999) and radar satellite images (monsoon season, August 1998). comparison are presented in Table and Figure

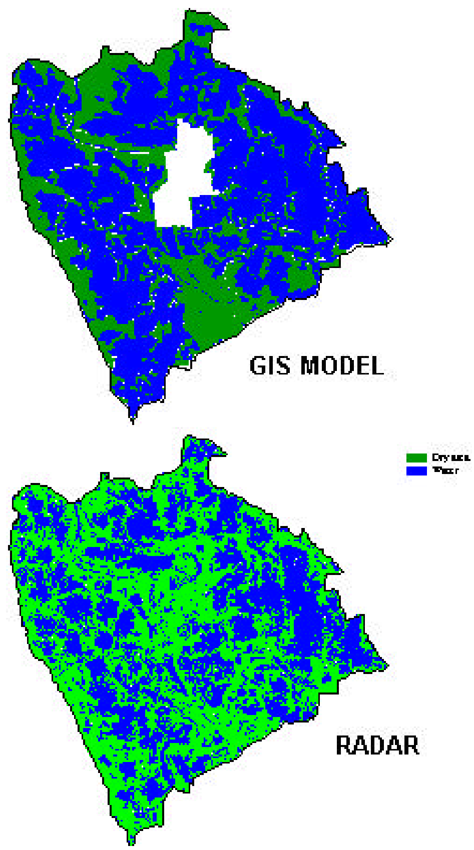
	August 98 area (ha)	March 1994 right bank (ha)	January 1999 (ha)
Model		1028	686
images	5012		1000

Table 5

the DEM and inundated as calculated with classified radar satellite images (source: EGIS).

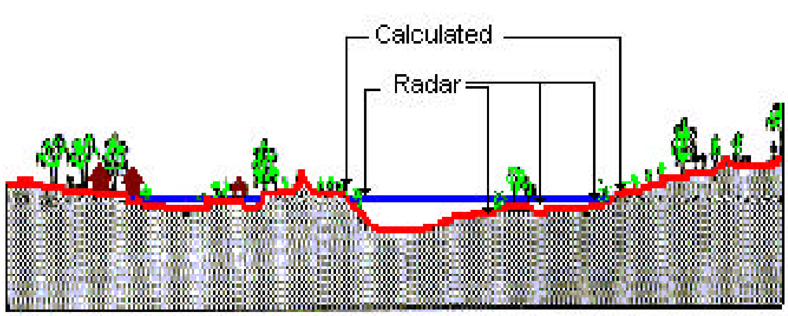
The difference between the calculated flooded areas and the real flooded areas were within an acceptable range, but it should be remarked that the radar image gives the flooded area as observed on a particular day, while the model works with monthly averages.

Figure 14: Inundated areas as calculated with the GIS model with an overlay of the classified radar image (source: EGIS, 1998) for August 1998.



During the monsoon the GIS model gives a larger flooded area then if radar images are used as the latter can not distinguish the very shallow inundated areas with some vegetation, they recognise mainly clear water (Figure 15)

Figure 15: Difference between flooded areas as calculated with GIS and with radar images



3.8 Results

In Table 6 the results of the estimation of the total catch for F3 land type during the season 1993/94 are presented.

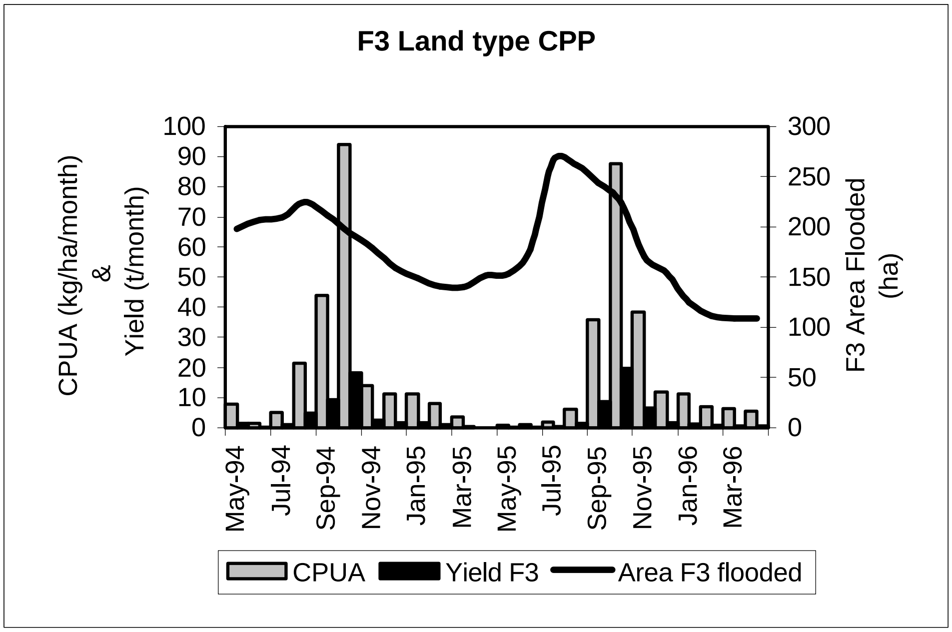
Date	CPUA (kg/ha/month)	CPUA (kg/ha/month)	CPUA (kg/	AVERAGE CPUA (kg/ha/month)	Flooded (ha)	YIELD (kg)
-93	1		4	2		289
Jun-	0	3		3	213	
Jul 93		3	2		290	881
-93	26		7	15		4477
Sep-	24	44		84	304	
Oct 93		46	47		284	18326
-93	49		42	47		10232
Dec-	9	28		25	182	
Jan 94		12	48		143	2953
-94	14		104	43		5805
Mar-	7	6		6	134	
Apr 94		1	n.a		161	773
Annual Yield						75 508

Table 6 3 land type in the CPP area during the season 1993/94.

The total catch from F3 land type during 1993/94 was estimated at 75 508 kg, with a

ded F3 land type for 1994-
presented in Figure

Figure 16 -
1996 in the CPP project area.



The annual and seasonal variations in floodplain fisheries catches became clearly visible through the habitat floodplain fisheries monitoring program, and it proved to be a viable tool for estimation of floodplain catch. Some statistical techniques could be applied, as the number of samples from the different strata were sufficient. Details on the catch over the eight years fisheries was monitored are presented in Chapter 5.

3.9 PRESENT STATUS AND RECOMMENDATION FOR FUTURE DEVELOPMENTS OF HABITAT RELATED FISHERIES MONITORING

In the previous chapters the methodology used by CPP to estimate the floodplain fisheries catch over the period 1992-2000 was presented. This method had to be used, as in 1992 the use of GIS and hydrological modelling in floodplain fisheries was new. The major challenge was to find an easy way to estimate the monthly area that gets flooded, and this was solved with the presented method.

3.10 Radar images

However, over the years, developments in GIS and remote sensing were tremendous. One of the major breakthroughs is the development of radar satellite images that can look through the clouds. The major advantage is that nowadays the real-time extent of flooding during the monsoon can be determined directly from radar images, which in principle is much easier than estimating this through measured water levels and GIS techniques. The question is whether there are differences in the reliability of the two methods.

An example of the extent of flooding estimated with classified radar satellite images and with GIS-water levels was presented in Figure 14, with radar. The flooded area was 5 000 ha, while the model estimated the total flooded area at 6 000 ha.

For the monsoon season of 1998, the monthly inundated areas for
land types were estimated by application of classified radar images, and these were further used for estimation of the monthly catch for the months of August and
Table and compared with the estimates
as obtained through GIS water levels

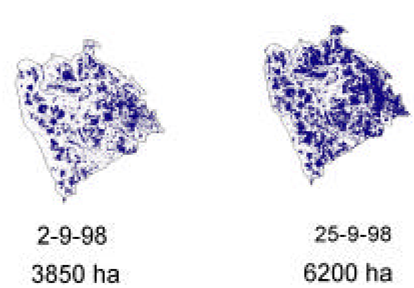
	Aug 98	-98
Area F1 GIS		3268
Area F1 radar		776
Area F2 GIS		2535
Area F2 radar		947
Area F3 GIS		305
Area F3 radar		173
Fish catch GIS		277
Fish catch Radar		97

Table 7
using GIS and water levels or radar satellite images for August and September 1998.

The estimates of the catch by using
method. A major reason, already mentioned before is that radar images can not detect the shallow flooded areas. A second reason is that radar images give the
average flooded area over the
month as calculated by using GIS and water levels. The flooded area can be highly

accurate when more images are available for each month. This problem is illustrated
Figure 17
which show this large monthly variation.

Figure : Comparison of radar images of 2 and 29 September 1998 covering



3.11 Direct application of annual yields

A very simple but statistically rough way is to apply the annual yields from the obtained sites/land types directly to the **total areas of the different land types**. This method requires a **proper land type map, a topographic map or a DEM of the fixed sample sites and regular measured water levels within the sampled areas**. The topographic map and the water levels enables to calculate the monthly CPUA and annual yield per site after which they can be raised to the total annual yield for the total area. For CPP the estimation of the annual total catch for F3 land as estimated with this direct method is presented in Table 7 and compared with estimation through the GIS method.

Year	Average yield F3 direct method (kg/ha/yr.)	Annual catch direct method (kg/yr.)	Average yield GIS method (kg/ha/yr.)	Annual catch GIS method (kg/yr.)	Difference (%)
92/93	102	31807	116	36352	-14%
93/94	318	99418	241	75508	24%
94/95	143	44608	137	42872	4%
95/96	141	44103	136	42681	3%
96/97	169	52906	155	48491	8%
97/98	278	86899	179	56002	36%
98/99	326	101885	311	97239	5%

Table 8: Comparison of direct catch estimation and catch estimation by using GIS and water levels for the whole project area.

The method seems rather simple and could be of interest at a national level; however, the major hindrance is statistical. Very important is the fact that the selected sites have to be representative for **Catch and Effort** patterns as well as for **Hydrological Patterns,** which is extremely difficult. Furthermore, extreme values within the sampling data set gain more importance as variations in the small sampling sites are larger, and these extremes are directly raised towards the total catch for the whole area.

3.12 The application of GIS-FISH or habitat related monitoring programs on a national level.

The Department of Fisheries through the Bangladesh Fisheries Resources Survey System (FRSS) collects statistical data on floodplain fisheries. In every district one FRSS survey officer collects data on:

River fisheries through Catch and Effort data recording.
Beel fisheries through Catch and Effort data recording.
Floodplain fisheries through a household based survey.
Shrimp and fish culture through sampling of production statistics.

Floodplain fisheries is monitored through a household-based survey whereby during the monsoon in each district, 10 people are interviewed from 100 pre-selected households and asked about the quantity of fish the caught during the previous month. Considering the sample size and the “recall” basis of the floodplain fisheries part of FRSS, some questions can be raised on the reliability of the data. FRSS has been discussed over the years and a number of recommendations were formulated.

Habitat Floodplain Fisheries Monitoring could be a way to improve the FRSS floodplain fisheries data. The use of radar images and habitat related CPUA data ach district could be a new way of estimating floodplain fisheries statistics in Bangladesh. Whereby the CPUA data for the specific sites are

district are provided by organisations having access to the radar images.
Within the frame of the development of the National Fisheries Data Base, it is strongly recommended to estimate floodplain fisheries of Tangail district by using the mages for the year 1998 and compare the results with FRSS data.

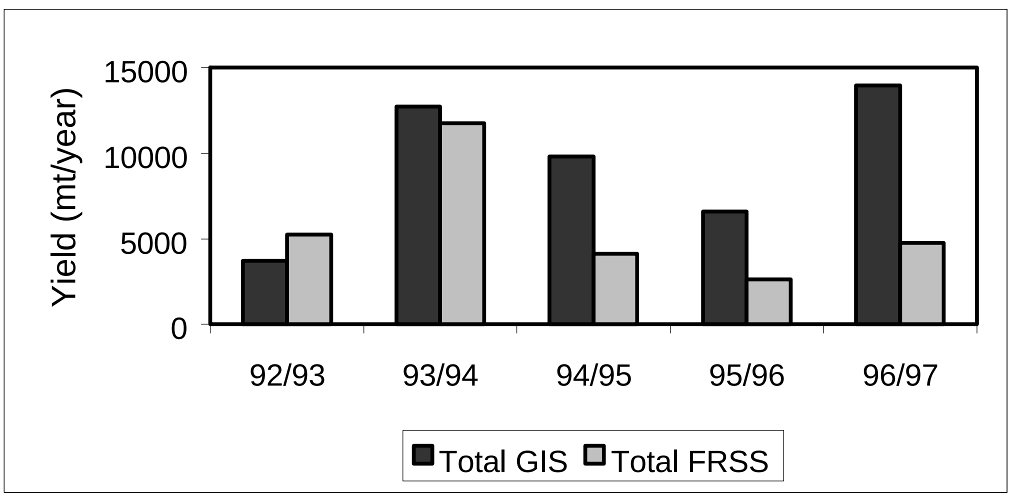
As an example of using the direct method on a national level, the data of CPP were

compared with the official statistics of FRSS. (18). In most cases the GIS

data but it is strongly recommended to study the methodology further, as it could improve the

18: The official catch estimates of floodplain and Beels of Tangail

method using the CPP data for Tangail District.



4 FISHERIES IN CPP DURING 1992-2000

4.1 Total fish catch

The annual total fish catch obtained during the period May 1992 to May 2000 is presented in Table 9 and Figure 19.

Year	Yields (mt/year)					
	F3	F2	F1	Lohajang	Khals	Total
92/93	36	42	5	1	2	85
93/94	76	176	33	3	29	316
94/95	43	158	15	n.a	n.a	216
95/96	43	92	12	n.a	n.a	147
96/97	48	223	39	4	9	323
97/98	56	292	38	1	9	397
98/99	97	596	119	8	25	845
99/2000	46	57	8	4	0	108

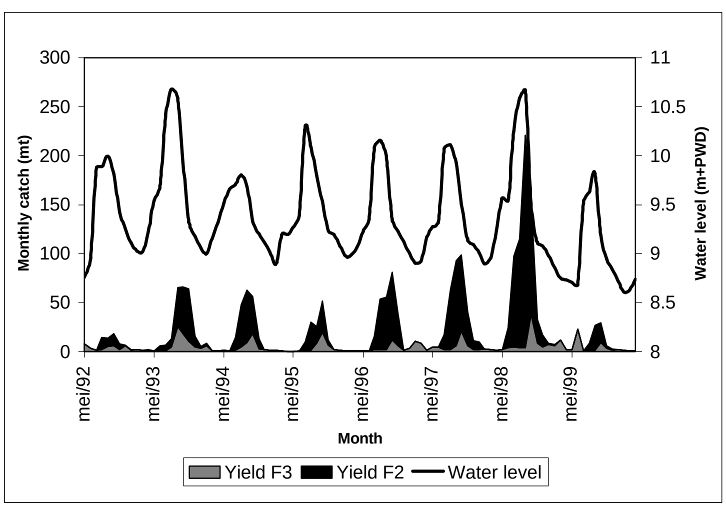
Table 9: Annual fish catch in the CPP project area (1992-1999) and its distribution among the different land types/habitats

On average annually 303 Mt of fish is caught in the CPP project area, but the catch varies with the extend of flooding and a lowest catch of 85 Mt was observed in 1992 and a bumper catch of 845 Mt was observed in 1998 and the differences are caused by the extend of flooding (see further chapters).

There is no significant trend in fish catch in the CPP project area.

Further, it becomes clear that the F2 land is the major contributor to the annual catch from a production point of view they are much more important then the permanent water bodies or F3 land. In relation to flood control, this is important, as the major changes through water management will take place at the F2 and F1 Land types.

Figure 19: The monthly total fish catch on the CPP area as estimated for F3 and F2 landtypes and the average monthly water level as registered at Ghotokbari Beel



In Table 10 the annual yield per ha, calculated with the total area of the different habitats in CPP are presented[5]. In F3 land about 165 kg of fish per ha is caught, the yields for F2, khals and the Lohajang River are respectively 83 kg/ha/year; 10 kg/ha/year, 102 kg/km/year and 157 kg/km/year. The presented yields are minimum estimates as higher yields are obtained from the individual sampling sites.

Season	F3	F2	Lohajang river	Khals
92/93	116	16	33	16
93/94	241	67	101	315
94/95	137	60	0	0
95/96	136	35	0	0
96/97	155	85	136	98
97/98	179	112	42	93
98/99	311	228	296	266
99/2000	46	57	4	0
Average	165	83	102	157

Table 10: Average annual yields of the different habitats in CPP

Comparing the different annual fish catches during the period 1992-2000 can be done, but it always must be kept in mind that 98/99 was an extreme year, with an extreme high flood and it resulted in very high fish catches. This phenomenon is visualised in Figure 20 where the deviation from the average annual catches (average equals 100%) for the different years is plotted. The yields obtained in 98/99 were 200-250% higher than the average, and 92/93 was an extreme dry year with a yield of 20-80% of the average.

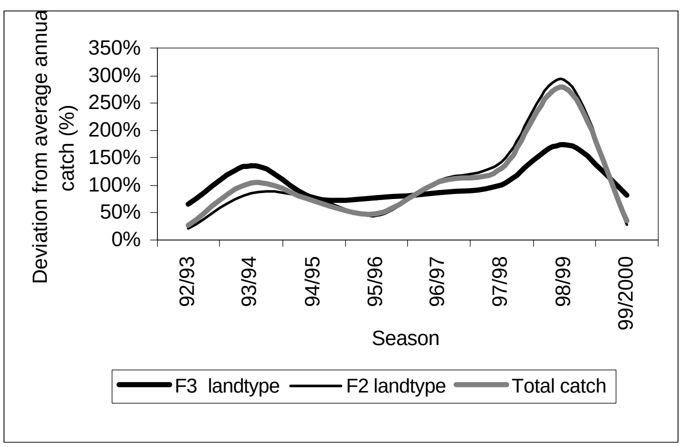


Figure 20: Annual deviation from the mean catch (1992-200) for F3, F2 land types and total catch.

It demonstrates the difficulty of floodplain fisheries monitoring, where **"long term"** data sets are essential to get an idea of occurring changes.

[5] In the final report of CPP slightly higher values were presented as the complete data of 1999/2000 were not yet incorporated and it some individual sites are producing higher estimates.

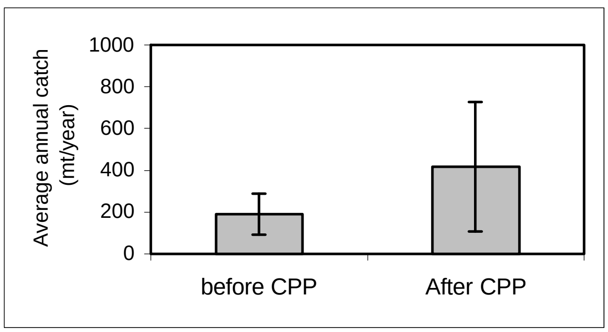
If you started a fisheries development programme with a baseline survey in 1997/98 and implemented actions in 1998/99 and monitored correctly then the success of the programme was tremendous.

However if the programme started one year later with a base line survey in 1998/99 and actions in 1999/2000, then the conclusions and evaluation of the project would have been completely different.

4.2 The impact of CPP on fisheries

Everybody including the consultants to the project expected a decline in fish catch due to the interventions of CPP on fisheries. However this was not the case **no significant difference** (Figure 21) in fish catch could be found before (1992-1995) or after CPP (1996-2000).

Figure 21: Average annual fish catch (± std) before and after CPP interventions



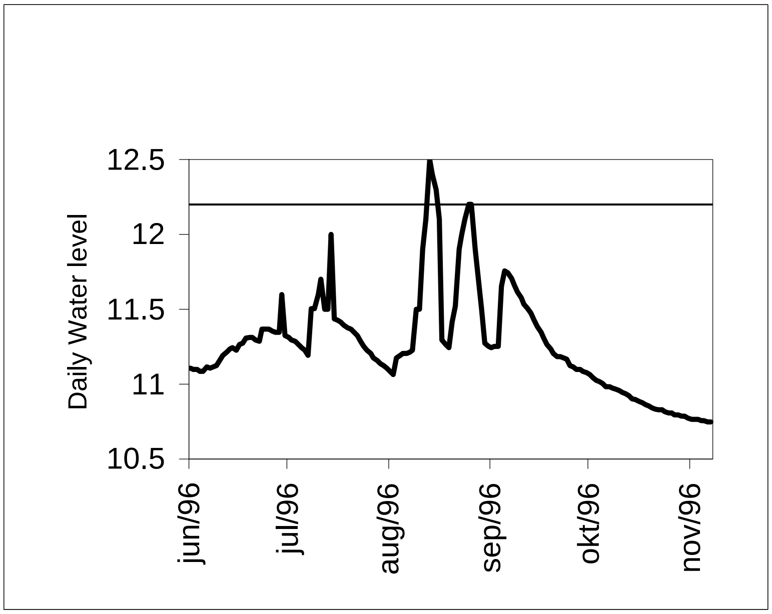
The major reason is that there is no significant difference in the extent of monthly flooding or catch rates before or after the interventions. This as CPP applied *"Controlled flooding"* i.e. only peak water levels around the danger level are controlled (Figure 22). Closing the gates in September 96 for a few days changes the extend of flooding but the extend is so small in comparison to the overall allowed flooding that it can not be detected.

Within this respect there is a fundamental difference between agriculture and fisheries which should be kept in mind if controlled flooding is concerned

Farmers are working with "flood risks" a few days of extreme water levels can destroy the entire seasonal crop. Taking away the risks of a 4 days extreme flood level will change the type of crop used by them.

The monthly flooded areas determine fish production and as indicated before, taking away some of the peak levels does not have a detectable impact.

Figure 22: Daily water levels and Controlled flooding



4.3 The human aspects of fisheries in the CPP area.

The fishermen in CPP can be classified in the following groups:

4.3.1 Professional fishermen

Their main occupation is fishing throughout the year. Most of the professional fishermen live together in certain villages in the CPP project area. The total number of professional fishing households in the CPP area was 355 at the start of CPP and this reduced to about 300 in 1998.

4.3.2 Occasional fishermen

In the social stratified society of Bangladesh, fishing was considered a taboo for Muslims. Nevertheless, the last decades the number of Muslims with fishing as a major occupation increased. This often in spite of intense social pressure from their co-religionists who regarded the involvement of anyone from their village in fishing as impinging on the status of the community. Because of this social stigma, people who have overcome the social barrier fish occasionally but relatively intensively during the period when fish is easily available (FAP 17, 1995). The number of occasional fishermen operating in the CPP project area could not be established due to the above-mentioned social stigma.

4.3.3 Subsistence fishermen

Subsistence fishermen, fish mainly for their own consumption. They use a simple gear and often it is the children or the elders who catch fish. The total number of households carrying out subsistence fishing in the CPP area was estimated at 17,290 (68% of the rural population, Household survey CPP, 1992).

4.3.4 Catch distribution

In Table 8 the distribution of the catch and the distribution of the total fishing effort among the different types of fishermen for F3 and F2 land types is presented.

YEAR	Occasional	Professional	Subsistence
1992	24%	45%	32%
1993	36%	19%	45%
1994	54%	18%	28%
1995	49%	17%	34%
1996	30%	35%	35%
1997	56%	19%	25%
1998	30%	23%	47%
1999	31%	37%	31%
2000	68%	9%	23%

Table 8: Distribution of the annual yield obtained from F3 and F2 Land types among the different type of fishermen in the CPP project area

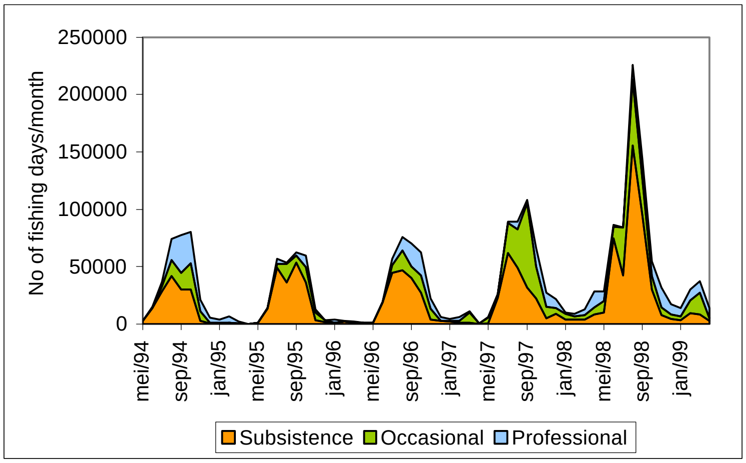
On average 42% of the catch is caught by occasional fishermen, 25% is caught by professional fishermen and 33% or about 100 mt/year is caught by subsistence fishermen.

Fishing is an important economic activity in the CPP project area, as it generates employment and income. On average fishing in F3 and F2 land types generates 450,000 fishing days per year, with an average generated income of 630,000 US$. However, the annual variation for these figures are very high, 275,000-698,000 fishing days/year and 385,000-1,095,000 US$/year (Table 11) and is related again to the extend of flooding (Figure 23).

Year	Number of fishing days per year				US dollars generated per year			
	Prof	Occ	Sub	Total	Prof	Occ	Sub	Total
94/95	121774	65360	151172	338307	170484	91504	211641	473629
95/96	27994	49148	198137	275278	39191	68807	277392	385390
96/97	87190	71014	187479	345683	122066	99420	262470	483956
97/98	76607	202994	221032	500632	107249	284191	309444	700885
98/99	129418	209892	442853	782163	181185	293849	619995	1095029

Table 11: Total no of fishing days and income generated by different types of fishermen in the CPP project area during the period 1994-1999

Figure 23: No of fishing days per month for the different groups of fishermen



The significance of subsistence fishing becomes clearer if looked upon the distribution over the different social strata and related to their annual income which is done in Table 12.

HH type	No HH	Annual catch	Value annual catch (Tk)	Value catch as % of annual income	Fishing days	Labour day equivalents
Large farmer	475	0.0	0	0.00%	0	0
Medium farmer	1 362	4.3	300	0.57%	7	6
Small farmer	4 589	8.7	608	1.96%	13	12
Land less & Marginal farmers	22 399	8.3	580	3.05%	13	12

Table 12: Key parameters of the catch of non-professional fishermen in the CPP project area in relation to their land holdings

From this we have to conclude that subsistence fisheries is of importance for the rural poor. The rural poor catch a significant portion of the total catch but this quantity is also caught by a huge number of people. Therefore we come to the same conclusions as FAP 17 (1994) the significance of fishing within the annual income of the rural poor in the project area should not be over-stressed, it is one of many sources, which becomes relatively more important during the flood season when all three of their main sources (agriculture labour, non-agriculture labour and self-employment) are at their annual low.

The professional fishermen in the project area several times complained about their fish catches. From 1992, the daily income obtained from fisheries was monitored in the catch assessment survey. The results are presented in Figure 24 the daily income of the professional fishermen fluctuates around 50 Tk/day with some peaks 60-120 Tk/day during high floods in October. From the data, it can not be concluded that the average daily income of the professional fishermen became less. It can be argued that during the same period everything became more expensive and that we have to correct for inflation. This is complicated and it is easier to look at the daily catch of the fishermen (Figure 25Figure 25).

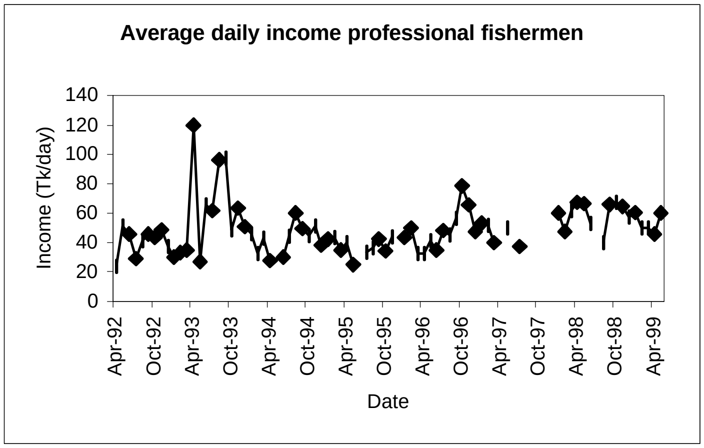
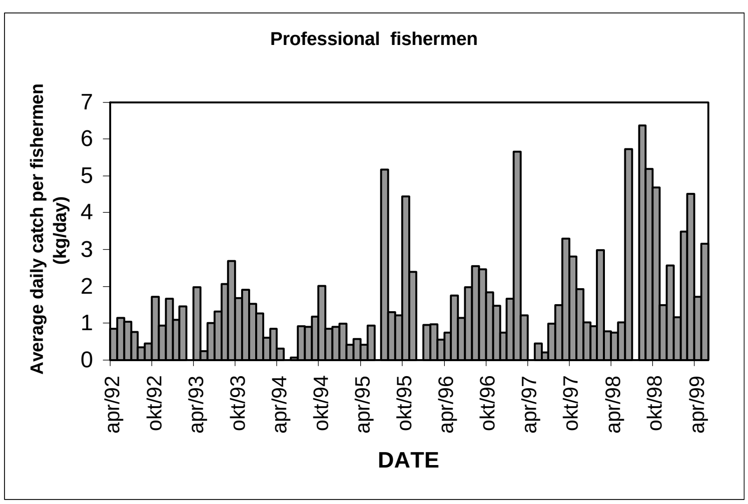


Figure 24: Average daily income obtained from fishing by professional fishermen in the CPP project area during the period 1992-1999

From the results it can only be concluded that for the professional fishermen the last two years (1997 and 1998) were bumper years with high daily catches due to the high floods (Figure 25). But there were also years when the fishermen were experiencing an extremely bad year which catches more than 50% below average. But this is all due to "nature", " the extend of flooding" and it is quite normal that the fishermen blame CPP for this if asked about their situation during this difficult period.

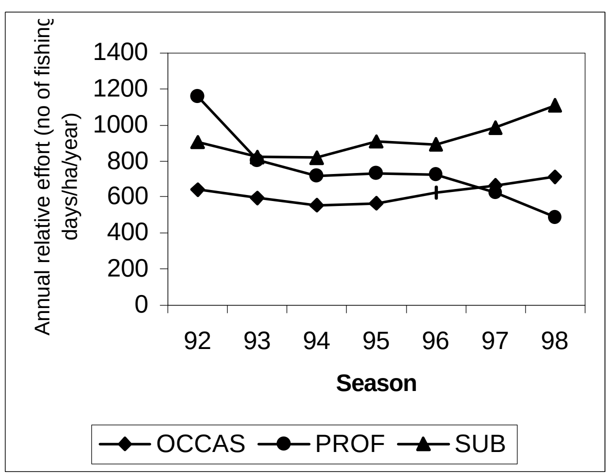
Figure 25: Average daily catch by professional fishermen in the CPP project area during the period 1992-1999



On the other hand, the professional fishermen are facing in their daily existence the following problems:

- One of the off-spins of the third fisheries project, which was carried out in Bangladesh in the early 90s, was that stocking of *beels* and floodplains with small fish, or transforming a *beel* into a large fish pond, got huge publicity. Owners of *beels* or influential people understood that this activity is very lucrative and now a number of *beels* in the CPP area were brought under this so called culture based fisheries system. Indirectly CPP had an influence on this process as the project area became more secure, and the people are less afraid that they will lose their fish because of flooding. One of side effects of culture based fisheries is that common access to the *beel* becomes restricted, in most cases the owners protect their stocked fish with armed guards or *mastan* and for the fishermen their fishing grounds became less. This was the major reason why CPP did not want to include culture-based fisheries in the mitigation measures (CPP 1993)
- Jugini beel, the only *khas beel* in the CPP project area, which used to be leased out to professional fishermen was taken over by the *mastan* in 1992/93, they were the first to introduce culture based fisheries in CPP
- The number of occasional fishermen, competing with the professional fishermen increased rapidly and the professional fishermen got pushed out from the floodplains and beels as becomes clear if we look at annual relative effort (no of fishermen/ha) for the different groups of fishermen (Figure 26).
- A further sign that they are in a difficult position is the reduction of the mesh sizes of their gears, which reduced significantly ($P < 0.05$) from 19-20 mm in 1992 to 12-14 mm in 2000.

Figure 26: Annual relative fishing effort for the different groups of fishermen over the period 1992-1998.



4.4 The Value of low lying beels and fisheries

During the last decade importance of beels as wetlands and as an important natural resource has been recognised in Bangladesh. In an early phase the CPP project developed the so called “Beel concept” (CPP, 1992) which aimed at the protection of the recruitment of the Beel resident fish species through adapted water management and the Centre of Natural Resources Studies (CNRS) developed at that time the so called “Beel sanctuary” concept with closed fishing seasons and rehabilitation of fish migration routes.

Both concept are widely known and accepted among fisheries biologist and environmentalist in Bangladesh but are unfortunately not yet a common good for planners and developers. A large number of them still consider the low lying beels as a not “used” area, i.e. not used for agriculture, having no or a limited economic value and so the best way would be to convert them into paddy land.

However the results of CPP indicate that on **pure economic terms only** fisheries from the beels have a higher financial return then any crop suitable to be grown in a drained of Beel. In Table 13 key financial parameters[6] of the different agriculture crops and fish catch are presented for the different dry and wet land types and the data indicate that the net profit of a fish crop of the beels equals the net profit of T. Aman local variety grown on F1 land.

If we add the **”non-use values”** of the beels such as bio-diversity, open common resource, shifting of open common resource to a limited resource, poverty alleviation, etc it becomes clear **that the most proper economic and ecological development option for the low lying beels is to maintain fisheries.**

Land type	Agriculture cropping pattern During the Kharif[7] season	Financial output[8] Agriculture (Tk/year)	Land type	Fish catch (kg/ha/year)	Financial output (Tk/year)
F0-dry	T. Aman HYV	20500			
F1-dry	T. Aman local	**11900**	F1–wet	8	550
F2-dry	DW Aman transplanted	8500	F2-wet	63	5400
F3-dry	DW Aman Broad casted	9700	F3-wet	165	**10700**

Table 13: Key financial parameters for agriculture and fish crops in the different land types

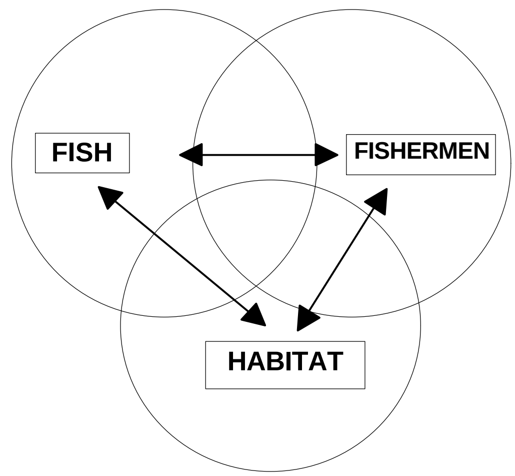
[6] All data obtained from the different monitoring programmes of CPP and are generated from large data sets
[7] Monsoon season
[8] Financial output = net profit

5 TOOLS FOR FISHERIES ANALYSIS AND MANAGEMENT

5.1 Introduction

The Floodplain Fisheries System consists in principle of three components: **Fish-Habitat-Fishermen** (Figure 27). CPP concentrated monitoring and analysis of data on the relation "fishermen-fish" in contrast with a number of other fisheries programs in Bangladesh, which concentrate more on the relation 'Fish-Habitat".

Figure 27: Principal components of floodplain fisheries systems



For the development of a fisheries management strategy, fisheries scientists and policy makers want to know what the present status of their fish stock is and what the impact of fishing on their fish stocks will be. Within the last century a number of tools, fish stock assessment programs, have been developed which can visualise the interactive processes between fishing and fish stocks. Fish stock assessment programs and their models can be grouped into the following categories, both applied by the CPP project.:

Holistic models. They use a limited number of parameters and consider the fish stock as a homogeneous biomass.

Analytical models. They are based on a detailed description of the stock and take into account the length or age structure of the stock, mortality rates, growth rates etc.

5.1.1 Holistic models

The best-known holistic model is "the surplus production models".

"Surplus production models" such as the Schaefer or Fox models use Catch per unit of effort in relation to the fishing effort as basic input. The models are based on the **assumption that the biomass of fish in the water is proportional to the catch per unit of effort.** Surplus production models use long-term data series as obtained from fisheries statistics, such as the BFRSS, but can only be used if a substantial change of the fishing effort has taken place over time. Surplus production models have been applied in Bangladesh for the estimation of the MSY of shrimp in the Bay of Bengal (MES, 1999).

5.1.2 Analytical models

Analytical models are based on a detailed description of the stock and require relatively more data and data of higher quality then holistic models. But it is believed that they produce more reliable predictions. Analytical models look at the structure of a certain fish stock and make an analysis with the following basic concepts;

If there are “too few old fish” the stock is over-fished and the fishing pressure on the stock should be reduced
If there are “many old fish” the stock is under-fished and more fish could be caught in order to maximise the yield.

Analytical models have been used extensively in the Western Hemisphere, but their use in tropical waters was hampered due to the fact that most of the models were “aged-based”. Age reading of fish is rather easy in the colder waters of the Western Hemisphere but is difficult or impossible in the tropical waters. The development of “length based” models and the growth of the computer industry since the early ‘80s made these tools available for tropical fisheries.

The fisheries monitoring program of CPP collected extensive data on catch and effort over the entire period 1992-2000, which were analysed using the basics of holistic or surplus production models.

Furthermore, extensive length based stock assessment data for the major species over the period 1992-1995 were collected; a complete set (1992-2000) was collected for Puti (*Puntius sophore*). These data were analysed using analytical or length based stock assessment tools.

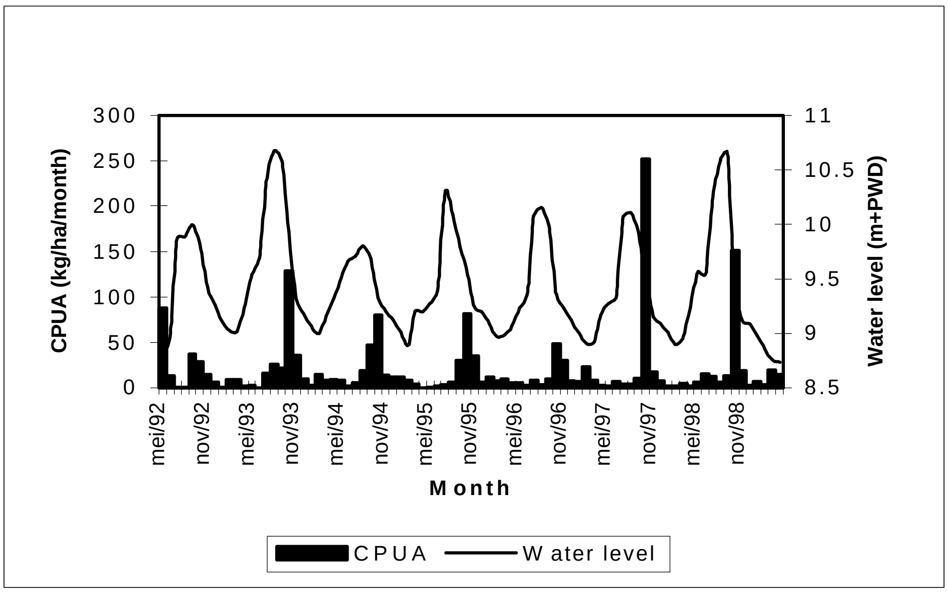
In the next chapters the results of a Catch and Effort analysis is presented and the overall consequences of the results for floodplain fisheries in Bangladesh is discussed. Followed by a chapter, which presents the results of the length based stock assessment and highlights the dynamics behind the different processes.

6 CATCH AND EFFORT AND ITS RELATION WITH FLOODS

6.1 The flood pulse

It is known that the growth of floodplain fish is fast and strongly related to flood season (Bayley, 1988, Dudley 1972). Furthermore, the growth can vary significantly between years and has been correlated with flooding intensity and duration (Dudley, 1972, Kapetsky 1974, Welcomme, 1985), and it can be expected that this phenomenon is an important factor for floodplain fish catches in Bangladesh.
Indeed, fisheries, and catch rates are highly seasonal and are related to the flood and water level as indicated by results of the monitoring of fisheries at Ghotokbari Beel, an F3 land type, during the last 7 years (Figure 28).

Figure 28: Seasonal variation in fish catches and water level at Ghotokbari Beel



The highest catches were always obtained during the receding of floodwater in the month of October, and in most years a small peak appeared in May, when the water level in the Beel was at its lowest level.

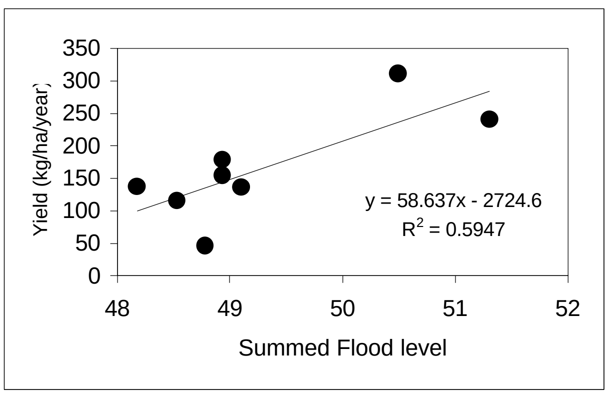
Secondly, it seems that the fish yields are related to the extent of flooding, i.e. in dry years such as 92/93 and 94/95, the yields were low if compared with yields obtained during the wet years 97/98 and 98/99 (Table 14).

Year	Hydrology	Yield (kg/ha/year)
92/93	Dry	116
93/94	Normal	241
94/95	Dry	137
95/96	Normal	136
96/97	Normal	155
97/98	Wet	179
98/99	Extremely wet	311
99/2000	Dry	46

Table 14: Annual Fish Yields (kg/ha/year) of F3 land type in relation to hydrology

In Figure 29 this phenomenon, which is called the ***"flood pulse",*** is quantified (*P< 0.05*) for CPP by plotting the summed average weekly water level[9] from July till October against the annual average yield of all F3 land types.

Figure 29: The relation between the flood index and the average annual yield (kg/ha/year) of all F3 land types during 1992-2000



This ***"flood pulse"*** concept was formulated by Junk *et. al.* (1989) as follows:

"The pulsing of the river discharge, the flood pulse, is a major force controlling biota in river-floodplains. Lateral exchange between floodplain and river channel and nutrient recycling within the floodplain have more direct impact on biota than the nutrient spiralling as proposed in a River Continuum Concept. In unaltered large river systems with floodplains in the temperate, subtropical or tropical belt, the overwhelming bulk of river animal biomass derives directly or indirectly from production within the floodplains, and not from downstream transport of organic matter produced elsewhere in the river basin"

The "flood pulse" concept was formulated as a **biological process**, related to flood level and the quantity of nutrients entering the system. However fish catch is not a biological process, it is in principle related to the number of fishermen (fishing effort)

[9] Further this will be used as the Flood Index

and their individual catch (Catch per Unit of Effort) and "**human aspects"** could be of importance.
In order get a clearer picture on this the catch and effort, data obtained over the years in CPP were analysed and related to hydrology.

6.2 Seasonal and annual variation in Catch and Effort

The fishing effort[10] and the Catch per Unit of Effort (CPUE) in combination with the average water level as observed at Garinda and Ghotokbari Beel from 1992 to 1999 is presented in Figure 30 and Figure 31.

Figure 30: Average daily fishing effort and water level as observed at Garinda and Ghotokbari Beel.

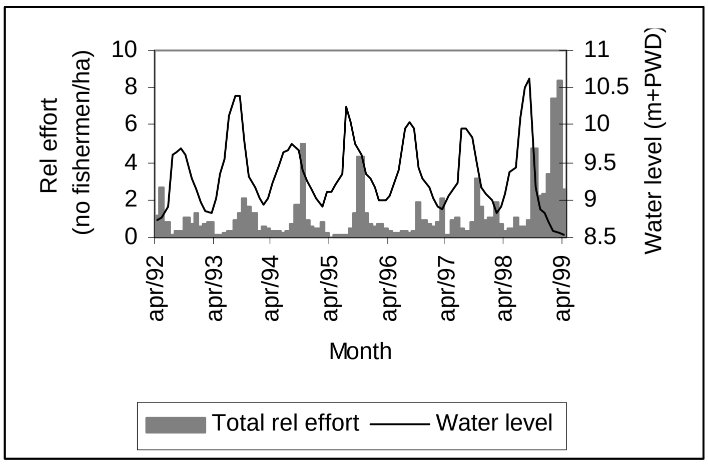
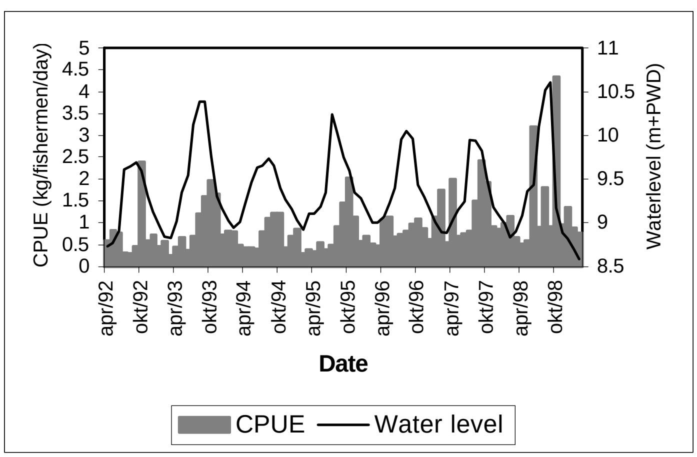


Figure 31: Average daily CPUE and Water level as observed at Garinda and Ghotokbari Beel



With exemption of 1999 the seasonal variation of fishing effort and the CPUE follows a similar pattern as observed for the monthly Yield and the monthly CPUA (Figure 28), with peaks in October at high water levels and low values during the dry season.

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[10] As unit of fishing effort CPP used "fisherman", i.e. a fisherman operating a certain gear, irrespective of the number of gears he uses. Further, a seine net is considered to be operated by one fisherman.

As indicated before in (Figure 29) the annual yield is significantly related to the extend of flooding (the flood pulse).

Mathematically, the catch or yield (Y) is expressed as:

$$Y = CPUE * f$$

Whereby
Y = monthly yield per ha.
CPUE = average monthly Catch per Unit of Effort.
f = average monthly fishing effort.

The question was whether the flood pulse is related to human factors, such as fishing effort, or to more natural factors, such as water level or CPUE. The impact of the different parameters can be tested with an analysis of variance (sum of squares) in a multi-linear regression analysis of the form:

$$\text{Log(Yield)} = \alpha + \beta_1\text{Log(CPUE)} + \beta_2\text{Log(f)} + \beta_3\text{Log(WL)}$$

Where α is a constant and $\beta1$, $\beta2$, and $\beta3$ are the regression coefficients of the different parameters.

A logarithmic transformation of the data was necessary as they were not normally distributed (Kolmogorov-Smirnov, $P<0.05$). After transformation of the data requirements for an analysis of variance: that the variance should be constant and the residuals should be normally distributed, were met. Multi-regression analysis was carried out *"stepwise"* whereby parameters were entered and accepted with a significance level of $P<0.05$ or rejected with a significance level of $P>0.05$.

Results of the ANOVA for the data of Ghotokbari[11] are presented in Table 15 and comparison of the Sum of Squares between the different models (Factor SS) indicated that **74% of the seasonal and inter-annual variance in observed yields can be explained by changes in fishing effort,** 15% can be explained by changes in CPUE and only 11% of the variance is explained by changes in water level[12].

[11] For the combined data of Ghotokbari and Garinda, more of the variance can be explained by CPUE.
[12] Within the range of observed levels of the different parameters.

Model	Sum of Squares		Df	Mean Square	F	*P*
Log(f)	Factor	*25912*	1	25.912	130.680	0.000
α	Error	18044	91	0.198		
	Total	43956	92			
Log(f)	Factor	*31034*	2	15.517	108.081	0.000
Log(CPUE)	Error	12921	90	0.144		
α	Total	43956	92			
Log(f)	Factor	*35140*	3	11.713	118.259	0.000
Log(CPUE)	Error	8816	89	0.099		
Log(WL) α	Total	43956	92			

Table 15: Results of the analysis of variance for different parameters influencing the yield of floodplain fisheries

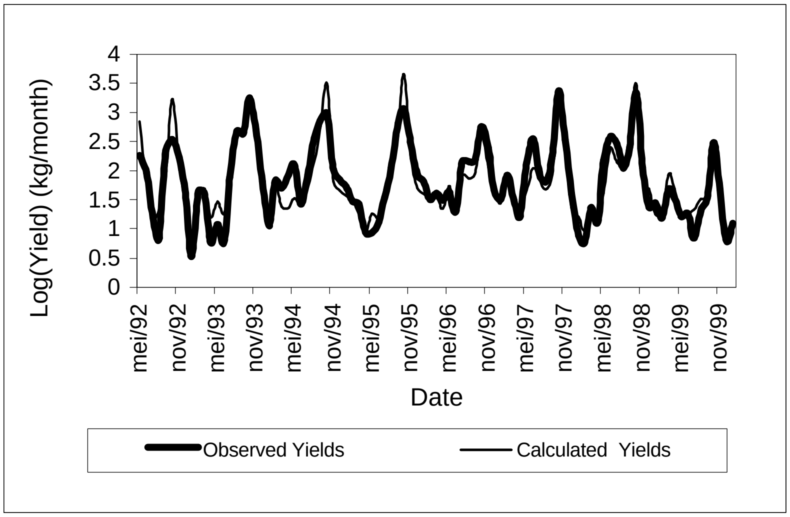
All parameters added significantly to the multi regression line (P<0.001), which can be described by:

$$^{10}\text{Log}(\text{Yield}) = -10.26 + 1{,}64*{}^{10}\text{Log}(\text{CPUE}) + 2.73*{}^{10}\text{Log}(f) + 10.91*{}^{10}\text{Log}(\text{WL})$$

In Figure 32 the observed yields and yields calculated with this multi regression line is presented. As expected with the significance levels of *P<0.005,* the fit follows the observed values very well.

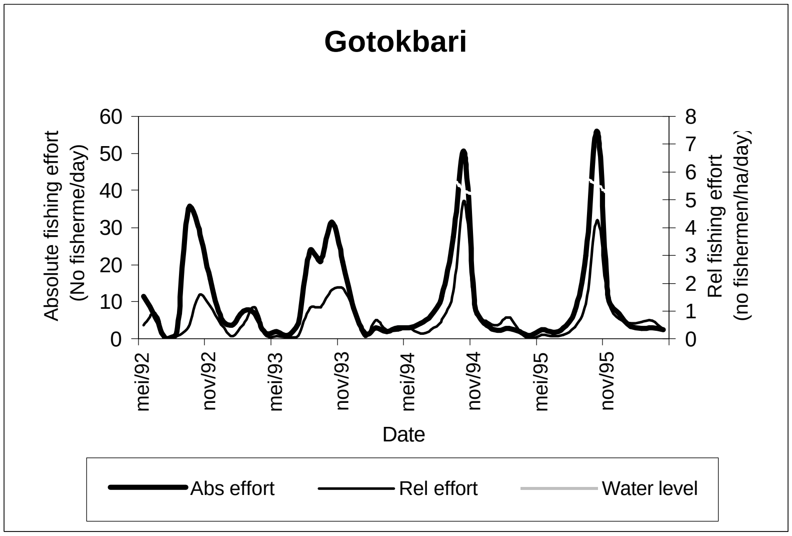
It can be concluded that changes in fishing effort is a major contributor to the observed changes in yields, followed by changes in CPUE; and that differences in water level is a minor contributor to the observed changes.

Figure 32: Observed yields and calculated yields.



Comparison of the fitted data with the observed data if looked upon more closely reveals that the largest deviations are found during the dry season (January-April). This could be expected considering the different seasonal events related to flooding; i.e*. "the rising of the water"* from July till October, the *"falling of the water"* from October till within the dry season and the fact that effort is expressed in "*no of fishermen per ha".* This is visualised in Figure 33; during the rising of the water, the absolute number of fishermen increases rapidly, but at the same time, the flooded area increases, and consequently the relative effort (No of fishermen/ha) increases at a much lower rate. During the receding of the flood in October. first there is an increase; and from November, the absolute as well as the relative number of fishermen is declining at a more or less similar rate. During the dry season the water level decreases and consequently the water area reduces gradually, the absolute effort remains more or less constant, with a small peak effort in April at very low water levels which means that the relative effort increases during this period. .

Figure 33: Comparison of the absolute and relative fishing effort in relation to observed water levels at Ghotokbari Beel.



The different events can be summarised as:

- A real increase in absolute as well as relative effort during the flood period
- An artificial increase in relative effort during the dry season due to reduction of the size of the water body

Within the regression analysis these two are conflicting, as we can have high relative fishing efforts during the flood period at high water levels and during the dry season with low water levels, reducing the impact of water level in the analysis. For a correct analysis the phenomena should be separated in the analysis. Therefore the absolute effort was used in a second analysis. Results of the ANOVA, whereby the different periods are separated into the following categories:

Raising water: June, July, August & September

Falling water: October, November, December & January

Dry season: February, March & April

Is summarised in Table 16.

Type of Regression	% of Variance explained by the different parameters		
	Effort	CPUE	Water level
Raising water with rel. effort	81.0*	13.5*	5.5*
Raising water with abs. effort	93.5*	6.2*	0.3
Falling water with rel. effort	92.7*	7.3*	0.6
Falling water with abs. effort	93.8*	5.9*	0.3
Dry season with rel. effort	48.8*	36.2*	15*

Dry season with abs. effort	72.6*	27.2*	0.2

Table 16: Percentage of variance in yields explained by variance fishing effort, CPUE and water level ($^{*}P < 0.05$).

Surprisingly, the major component remains fishing effort, followed by CPUE; and in most cases, the water level does not contribute significantly to the regression. In conclusion: **the major driving force in floodplain fisheries in CPP and most likely also in the rest of Bangladesh is the fishing effort or the number of fishermen.** During the high floods, more people start fishing because more fish can be caught in one day. Another reason, large numbers of people go fishing during the flood could be that they have no income or employment opportunity.

The fact that fishing effort is a major contributor to the catch is important as most of the fisheries programs in Bangladesh and discussions about the reduction of the natural fisheries resources have focused until the present mainly on habitat restoration/preservation and maintaining flood levels, i.e. biological or technical processes.

AN OFTEN HEARD STORY

When I was young there was plenty of fish in the Beel

When I went fishing with my father we caught plenty of Boal in one day

Remember when you were young it was 1965, with 65 million people in Bangladesh. Now we are with 120 million, with half of them fishing

The conclusion has consequences for fisheries management of inland waters in Bangladesh, and **management that does not include fishing effort is doomed to fail**. In general it can be stated that the impact of over-exploitation is underestimated in Bangladesh. This can be explained with events that were observed at Garinda and Gothokbari Beel in the CPP project area and the strong reduction of the catch of Indian carp all over Bangladesh.

6.3 Garinda and Ghotokbari Beel

Garinda and Ghotokbari Beel were monitored from 1992 and in both Beels the catch followed the seasonal patterns, with peak catches during the receding of the flood water in October and a high annual catch in years with high floods. However, in 1999, the catch in Garinda Beel completely collapsed, while the catch in Ghotokbari Beel continued as normal.

In Garinda Beel since 1996, Beel dependent fish species such as *Puti, Baim, and Kolisha* are gradually replaced by small prawns (*Icha* and *Chingri*), while the percentage of Catfish/Snakeheads remains more or less constant over this period (Figure 34). In Ghotokbari Beel, the species composition remained more or less stable during the same period (Figure 35).

Figure 34: Species composition Garinda Beel, 1992-1999

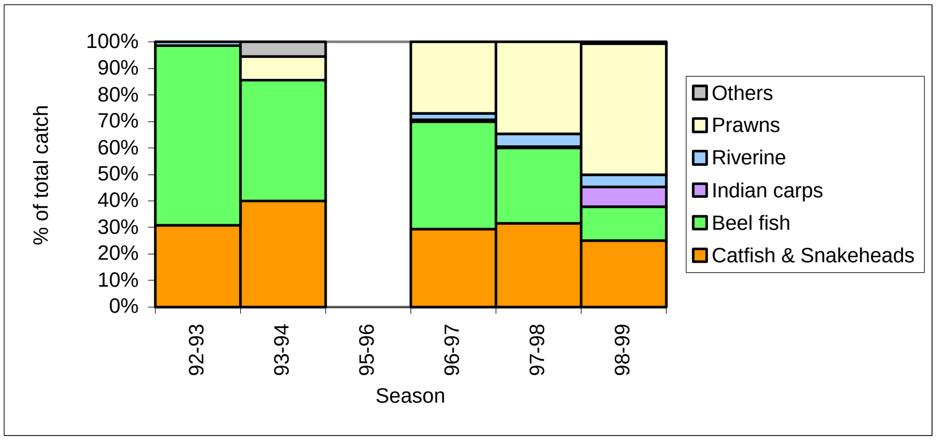
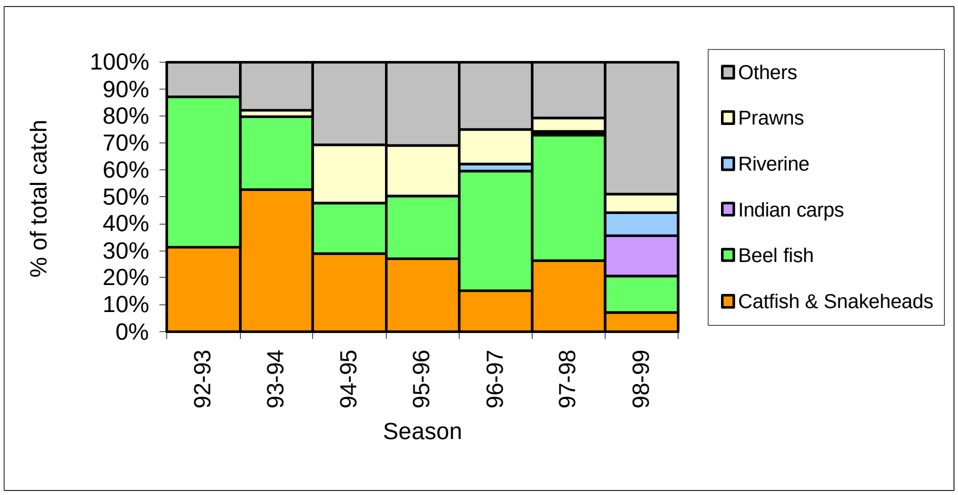


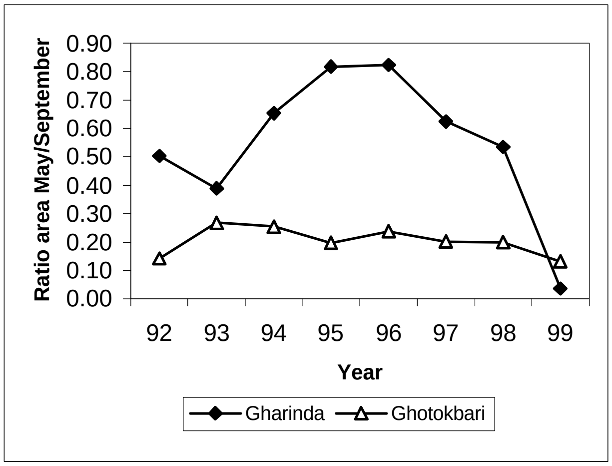
Figure 35: Species composition Ghotokbari Beel, 1992-1999



A strong reduction of the dry season water level and over-exploitation were responsible for the collapse of fisheries in Garinda Beel.

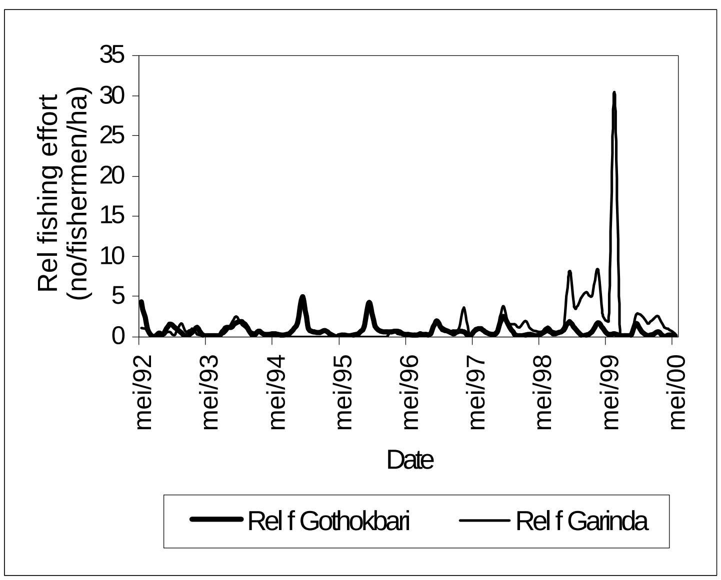
The water area covering a Beel during April-May is the recruitment area for the fish. If this reduces to almost zero, recruitment will be zero, and no fish will be found even if the area gets flooded soon after. This phenomenon has been observed at Beel Dakatia just after implementation of the emergency dredging by BWDB (KJDRP, 1995). This process gradually occurred at Garinda Beel, as is indicated by the gradually reducing ratio between the water area in May and the water area in September of the same year (Figure 36). For Ghotokbari Beel this ratio did not change over the years.

Figure 36: The ratio between the water area in May and of September for Garinda and Ghotokbari Beel, 1992-99



As a consequence of the reduced dry season, water coverage the fishing effort in Garinda Beel increased dramatically in May 1999 (Figure 37), finishing off the remaining fish.

Figure 37: Fishing effort as observed at Garinda and Ghotokbari Beel



It was concluded that the collapse of fisheries and bio diversity in Garinda Beel was caused by a gradual reduction in water level followed by a rapid increase in fishing effort.

6.4 The disappearing Indian carp

It is generally believed in Bangladesh that Indian carp disappeared from the catch due to the construction of Flood Control Drainage and irrigation schemes over the last decades. In the early '80s the estimated floodplain was 6,300,723 ha, and according to Siddiqui (1986), and about 2.5 million ha has been embanked in the last decades. This has certainly had an impact on fish production and recruitment of Indian carp. During the Flood Action Plan this picture was highlighted, and this overshadowed other factors involved. It can be questioned if the construction of FCD/I schemes is the only major reason for the decline because of the following two reasons.

The first reason is that since 1984 the Indian carp hatchling density in the Jamuna River did not seem to have changed as the CPUE of the savar net[13] did not change over the years (see chapter). This would mean that there is still sufficient recruitment of Indian carp going on upstream in the river system, and that the major spawning areas of Indian carp are still there.

A second reason is experience with other floodplain and tropical fisheries ecosystems over the world, which indicate that in over-exploited floodplains with high fishing pressure, the large, slow-growing species and the species that start to reproduce after 2-3 years are replaced by quick-growing and fast-reproducing species. This is exactly what we see happening in Bangladesh: carp, reproducing at a length of 30-50 cm, are disappearing, and miscellaneous fish species such as Puti and Baim, reproducing at a length of 8-9, cm are taking over.

Most likely the momentum has been lost for the Indian carp, but escaping attention is a similar fate awaiting the miscellaneous Beel resident species, and the first signs are there. In and outside the CPP area, a high percentage of small prawns are found in the catch of a number of Beels. This and more aspects of fisheries bio diversity will be discussed in chapter 8.

Furthermore, in the CPP, the average mesh size of the gears used reduced from 15 mm in 1992 to 8 mm in 2000 (Figure 38), which will worsen the situation even further.

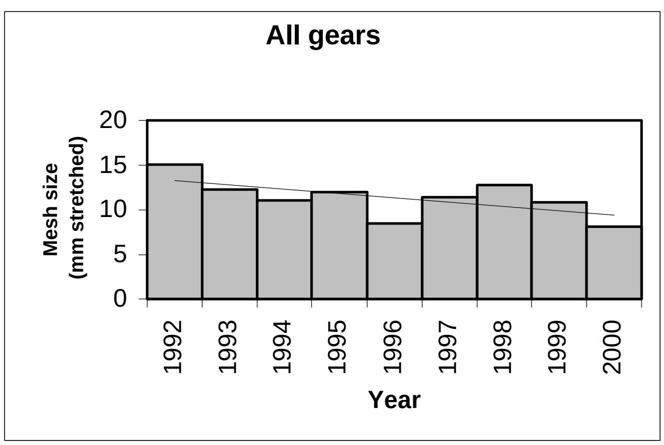


Figure 38: Average mesh size of gears used in the CPP area over the period 1992-2000

[13] Special nets for catching hatchlings

7 MECHANISMS BEHIND THE FLOOD PULSE AS HIGHLIGHTED THROUGH CATCH AND EFFORT AND LENGTH BASED STOCK ASSESSMENT DATA.

7.1 Introduction

In chapter 4.1 it was concluded that the major driving force in floodplain fisheries in CPP and most likely also in the rest of Bangladesh is the fishing effort or the number of fishermen. But the question remained whether the number of fishermen during high flood increases, because:

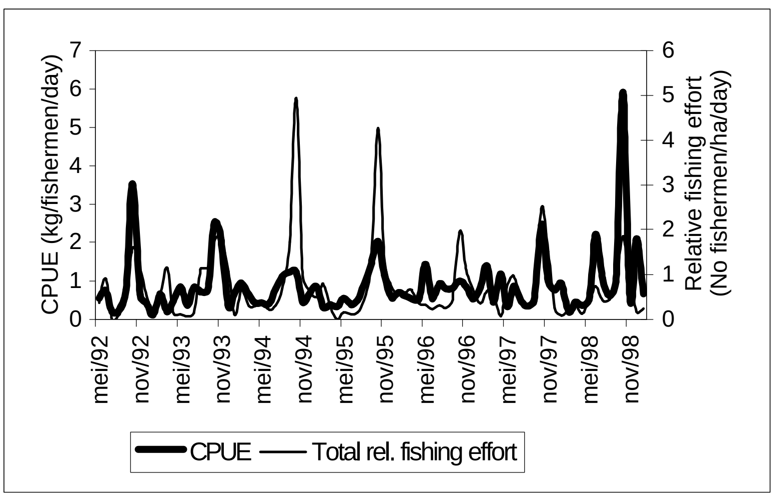
- more fish can be caught in one day, or the fish can be caught more easily.
- large numbers of people go fishing because they have no other source of income during the flood.

From a fisheries management point of view, both options are completely different in character; therefore, in this chapter, these aspects are treated in more detail.

7.2 Catch and effort

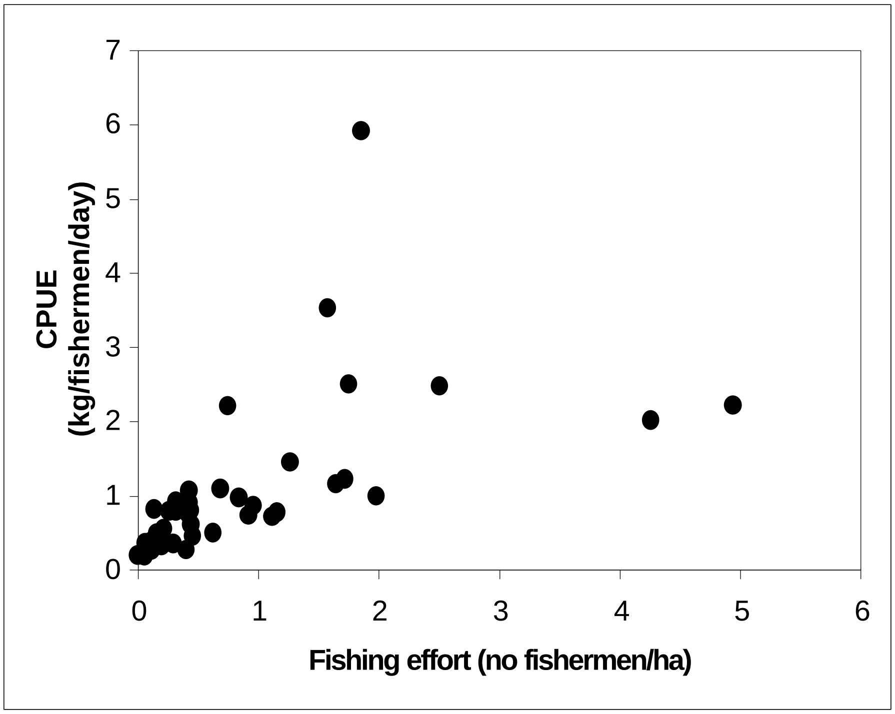
Looking more closely at the relative fishing effort and the CPUE over the different years indicated a pattern with peaks for both fishing effort and CPUE during the flood season (Figure 39).

Figure 39: Annual and seasonal variation of relative fishing effort and CPUE as observed at Ghotokbari Beel.



A highly significant ($P < 0.000$) positive relation between the relative fishing effort and the daily catch per fishermen (CPUE) becomes visible if they are plotted for the flood seasons of 1992-1999 (Figure 40).

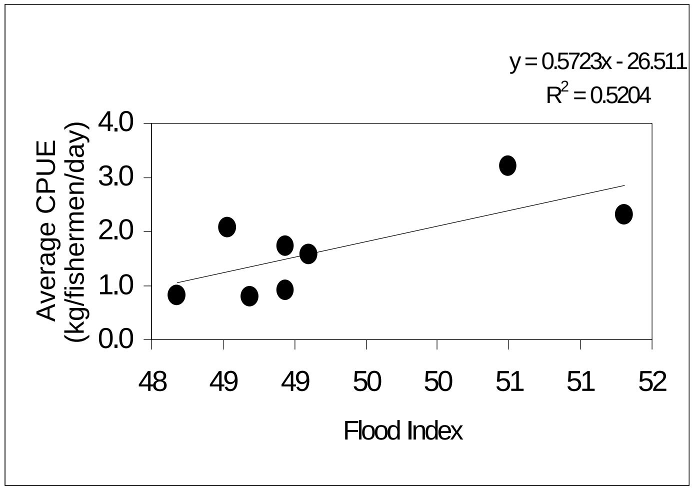
Figure 40: The relation between the relative fishing effort (no fishermen/ha/day) and the CPUE (kg/fishermen/day) as observed at Ghotokbari Beel during the floods (July-October) of 1992-1999.



A positive relation between CPUE and fishing effort at first instant is strange, as it is seems to be in conflict with the basics of **"Surplus production models**" such as the Schaefer and Fox models. They are based on the assumption that the biomass of fish in the water is proportional to the CPUE, and that the biomass and consequently also the CPUE will decrease if the fishing effort increases, i.e. a negative relation between fishing effort and CPUE would be expected.

If further looked upon on annual bases, there is a significant relation ($P< 0.05$) between the flood index and the average CPUE as observed during the flood months October-November (Figure 41)

Figure 41: Relation between the Flood Index and the average CPUE during the flood over the period 1002-2000.



In our case we have an ***"Inverse Schaefer or Fox curve"*** and if the assumptions of Surplus Production Models were applied it would mean that **the fish biomass during the flood season** increases which attract large number of fishermen towards floodplain fisheries. This increase in biomass in this case should be related to increased fish growth or an increased number of fish in years of high floods.

It is known that the growth of floodplain fish is fast and strongly related to flood season (Bayley, 1988, Dudley 1972). Furthermore, the growth can vary significantly between years and has been correlated with flooding intensity and duration (Dudley, 1972, Kapetsky 1974, Welcomme, 1985). For Bangladesh, the average length of the major species caught during the 95/96 flood year (relatively wet) was significantly higher if compared to the relatively dry 96/97 year (Halls *et al*, in press).

The average length of the different species as caught with "non-selective" gears such as scoop nets, seines, etc for the different years in the whole of the CPP area during the month October-November is presented in Table 17.

year	Average length Oct/Nov (cm)						
	Puti	Shing	Taki	Koi	Gutum	Baim	Kolisha
92	6.11	13.79	8.90	12.55	6.75	11.64	5.86
93	7.70	17.29	11.93	13.09	8.39	12.18	8.50
94	7.10	17.41	11.02	12.68	8.18	12.71	7.89
95	7.69	17.37	10.12	12.40	8.45	11.28	7.34
96	6.51	15.58	13.28	11.62	8.11	11.83	7.11
97	7.08	17.89	12.49	12.12	8.54	13.36	7.52
98	7.55	19.54	14.18	13.69	9.32	12.61	7.55

Table 17: Average length in Oct/Nov for the major species caught by non-selective gears in the CPP project area.

For most species the average length in 1992 was significant lower if compared with the other years, and 1998 was significantly higher. If looked upon for all the different years, only Kolisha gives a significant relation (P< 0.05, Figure 42) While for Puti and Gutum P falls between 0.1 and 0.5.

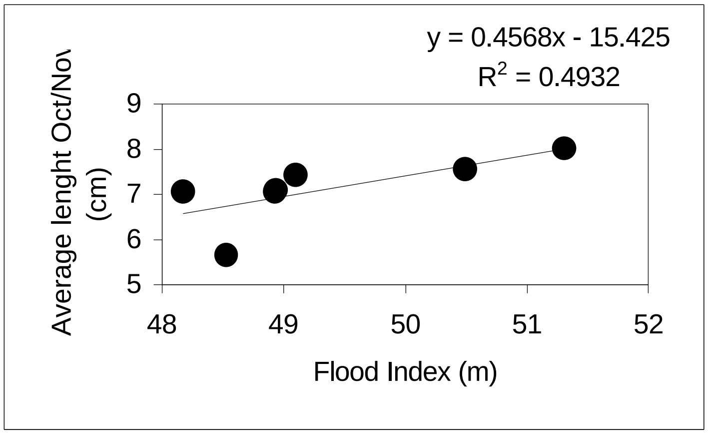


Figure 42: The relation between the flood index and the average length of Kolisha in Oct/Nov.

Indeed it seems that the length of fish is higher in years with high flooding; however a major bottleneck in this analysis is that the average length is calculated over all caught year classes or cohorts and the contribution of each cohort to the average length is not known. The method used by Halls (in press) which separates the different cohorts is a more correct one and in principle **analysis of length frequency data or applying a length based fish stock assessment** is more appropriate if growth is concerned.

7.3 Introduction and basic principles of analytical length based stock assessment models

Since 1992 for the major species, length frequencies data were collected in the CPP project area. In the next chapters the results of a length based stock assessment program for *Puntius sophore* will be presented. *Puntius sophore* was the only species monitored continuously over all years. For all other species the length based stock assessment program was abandoned in 1995 and for them the results will be only summarised.

The frame of the analysis is to see if flood or water level has an impact on growth or on mortality rates, and what the consequences for fisheries or water management will be.

Length based stock assessment programs are based on following a cohort, a group of fish of approximately the same age over time. Changes in the distribution pattern and their numbers over time reflects what happened with the cohort and can be analytically related to growth, mortality, fishing effort, etc. Within length based fish stock assessments there are two basic principles or steps to follow:

Growth rates, length frequencies obtained over a certain period, can be used to determine the growth rate. However, determination of growth can be done only from fish obtained from “non selective” gears.
Mortality rates, once the growth rate is determined, and length frequencies of fish obtained from different gears can be used to determine the impact of each gear on the fish population through its mortality rate.

7.4 Growth

7.4.1 Analyses

Length frequency data were collected every month from a number of different gears at all sites since May 1992. For the analysis the data of non-selective gears were combined for bi-monthly periods. The latter was necessary to maintain reasonable sample sizes.

Growth of fish species is mostly described with the Von Bertalanffy Growth Function. (VBGF).

$$Lt = L\infty * \left(1 - e^{-k*(t-to)}\right)$$

Where:

L∞	L infinitive or the asymptotic length -- that is, the mean length the fish of a given stock would reach if they were to grow indefinitely
K	growth rate parameter or the rate at which L∞ is approached
T0	tzero or the “age of the fish at zero length” if they had always grown in a manner described by the equation.

Preliminary analysis of the data indicated that the growth of most species had a strong seasonal variation, which is not well described by the ordinary von Bertalanffy growth curve; therefore the seasonal version of the von Bertalanffy growth function (Somers, 1988) was used, which has the following form:

$$Lt = L\infty * \left(1 - e^{-k*(t-to)-(CK/2p)*[\sin 2p\,(t-ts)-\sin 2p\,(to-ts)]}\right)$$

Where L∞, K, t0 and Lt are defined as above, while the new parameters C and ts refer to the intensity of the (sinusoid) growth oscillations of the growth curve and the onset of the first oscillation relative to t=0[14]

The parameters of the VBGF were estimated from the aggregated data using the Electronic Length Frequency Analysis method (ELEFAN, Pauly and David, 1981) in the FISAT software package (FAO-ICLARM, 1996).

ELEFAN works with the following assumptions (FAO-ICLARM, 1997):

- samples used are representative of the population;
- all length differences can be attributed to differences in age;

[14] For Elefan users, WP=ts+0.5

- growth is similar from one year to the next, i.e. there are no factors inducing any strong changes in growth over years;
- The seasonal oscillating version of VBGF provides an appropriate description of the growth of fish.

The third assumption that growth is similar from one year to the next is in our case not true, as we expect different growth rates due to differences in flooding. Therefore parameters were estimated independently for each year whereby for all years the "winter point" was kept constant at 1 (January).

ELEFAN and the VBGF have the disadvantage that they try to find the optimum combination of L_∞ and K for each data set, which makes direct comparison of L_∞ and K for the different years complicated. This can be overcome by using the "***Phi-constant"*** of Pauly and Munro (1984), which is based on the finding that double logarithmic plots of the coefficient K *vs* the asymptotic Weight tends to be linear with a slope of 2/3. If converted to asymptotic length phi-prime can be used to compare growth performance and is described as follows:

$$\phi' = Log(K) + 2Log(L_\infty)$$

7.4.2 Results

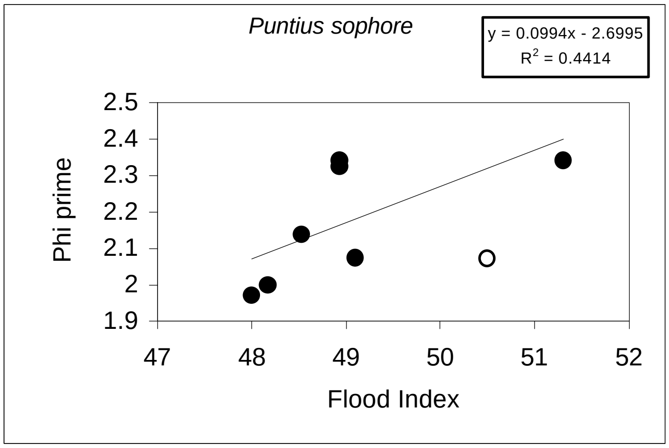
The parameters for the von Bertalanffy Growth function and the corresponding phi-prime estimated for *Puntius sophore* over the years is presented in Table 18.

Year	L_∞ (cm)	K ($year^{-1}$)	C	WP	Phi-prime
92/93	13.1	0.8	0.3	1	2.14
93/94	13.0	1.3	0.8	1	2.34
94/95	12.9	0.6	1.0	1	2.00
95/96	13.0	0.7	0.8	1	2.07
96/97	13.0	1.3	0.6	1	2.32
97/98	13.0	1.3	0.9	1	2.34
98/99	13.0	0.7	0.7	1	2.07
99/2000	13.1	0.6	0.6	1	1.97

Table 18: Growth parameters for *Puntius sophore* in the CPP project area

With L∞ of 13 cm and a K of 0.61, *Puntius sophore* is a fast-growing species reaching its asymptotic length almost within one year. Further, there is a strong trend indicating a higher growth (K, $0.05<P<0.1$) in years with high flood, and there is a significant ($P<0.05$) relation between the growth performance (Φ-prime) and the flood Index if 1998 is excluded[15] from the data set (Figure 43).

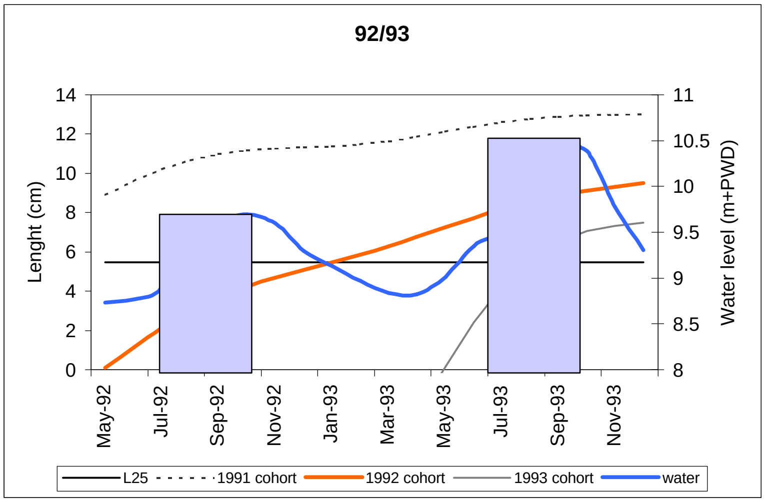
Figure 43: The relation between the growth performance of *Puntius sophore* and the flood index as observed in the CPP project area during 1999-2000.



The relation between growth and catch or the "flood pulse" becomes more clear if the individual growth of each cohort is plotted over time for the different years and looked upon in relation to L_{25}, the length at which 25% of the fish will be vulnerable to be captured. For *Puntius sophore* the L_{25} was estimated with a converted catch curve (Pauly, 1984) and had a mean value of 5.2-5.5 cm. The plots for the individual cohorts are presented in Figure 44, Figure 45, Figure 46, Figure 47 and Figure 48.

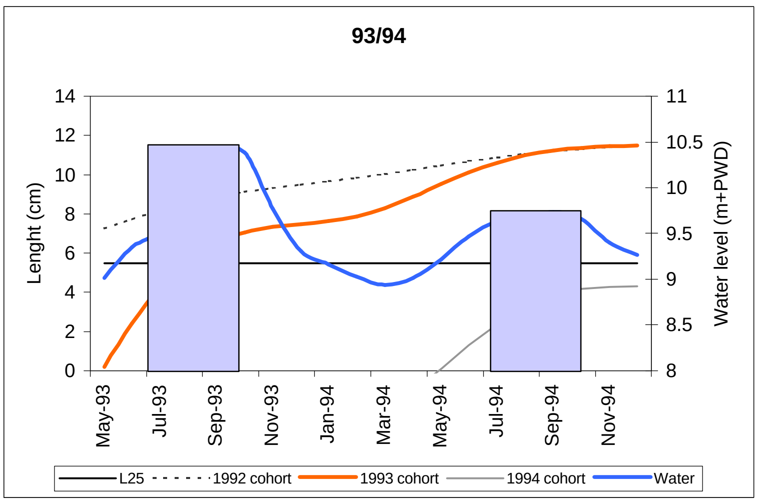
[15] 1998 was an extreme and dangerous flood year, which disrupted all normal activities in the CPP area.

Figure 44: Growth of *P. sophore* during 92/93



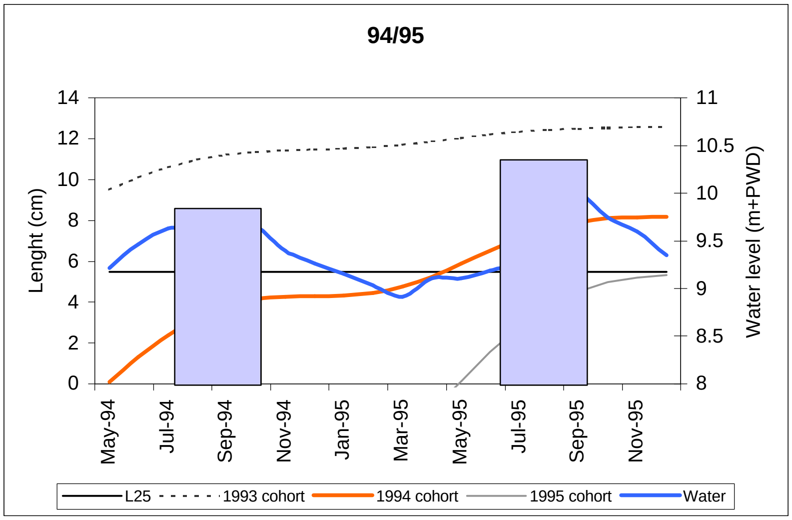
1992 was a dry year resulting in a slow growth of Puti and the 1992 cohort are entering the catch somewhere in January 1993, when its length exceeds L_{25} (solid black line).

Figure 45: Growth of *P. sophore* during 93/94



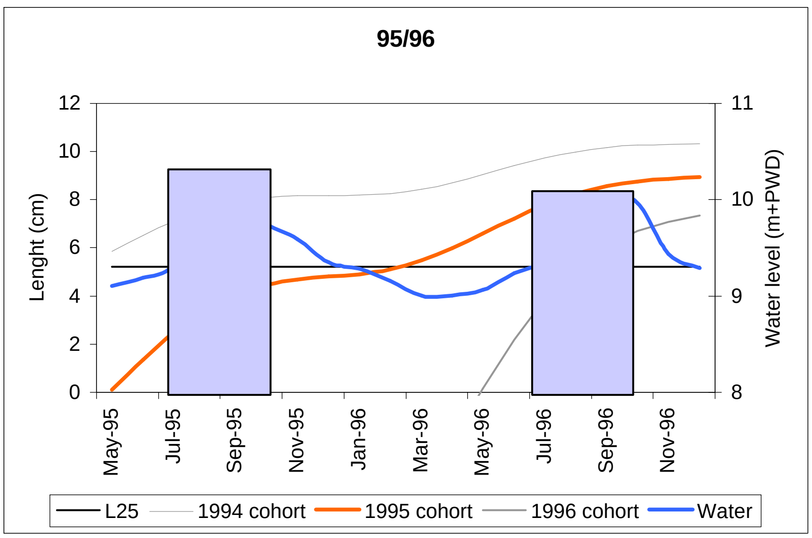
In contrast, 1993 was a wet year, resulting in a fast growth of Puti; and the 1993 cohort enters the catch already during the flood of 1993. The catch during the 1993 flood thus consists of survivors of the '92 cohort and the newborn of the 1993 cohort.

Figure 46: Growth of *P. sophore* during 94/95



The flood of 1994 was relatively dry and Puti was growing slowly; consequently, the catch during the flood of 1994 comprised mainly of survivors of the 1993 cohort.

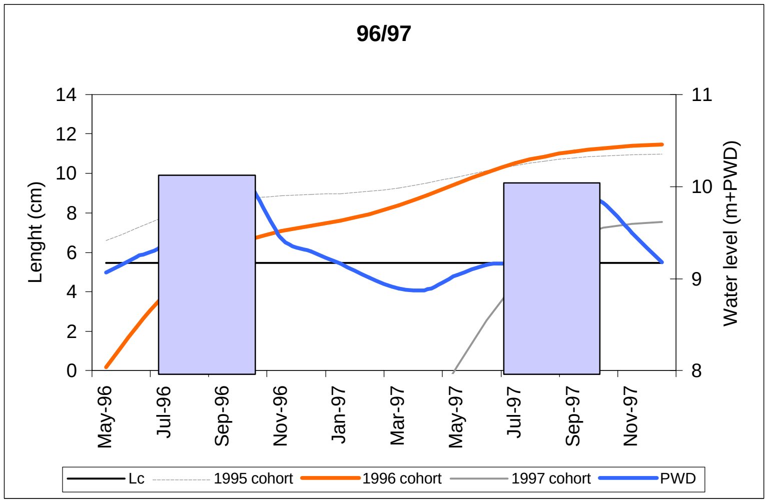
Figure 47: Growth of *P. sophore* during 1995/96



1995 was a year with a normal but short flood period. The growth of Puti was slow and the 1995 cohort entered the catch after the flood was over, and consequently the catch during the flood of 1995 mainly consists of survivors of the 1994 cohort.

1996 was a normal flood year with high growth for Puti. Consequently the catch during the 1996 flood period consist of survivals of the 1995 cohort and the new 1996 cohort.

Figure 48: Growth of *P. sophore* during 1996/97



1997 was a wet year and Puti grew fast. The 1997 cohort already entered the catch during the flood of 1997, and the catch comprised of two cohorts, the survivors of the 1996 cohort and the newborn of 1997.

7.4.3 Conclusions and consequences for Puntius sophore

The examples of *P. sophore* highlight two phenomena that are important for flood plain fisheries and the flood pulse:

A fast growth results in newborns entering into the fisheries several months after they are born. In such a situation, the catch during the flood season is composed of two cohorts, the new cohort and the survivors of the previous cohort. This could be the mechanism behind the inverse "Schaefer curve", as in this case large number of fish are available for the fisheries, and the CPUE increases if compared with years when only one cohort from the previous year is available.

However, what is happening with the previous year's cohort during the dry season? Its survival is then of utmost importance in terms of numbers and weight.

Furthermore, as *P. sophore* is a short-living species, its recruitment can be a critical factor. Low survival rates caused by high fishing pressure during the dry season could reduce the needed "spawning parent stock" to an absolute minimum, resulting in low catches in the preceding year, even if the hydrological conditions are optimal (high flood).

Both phenomena can only be checked by looking at the mortality rates of the different cohorts over time. This can be done with the data from the Length Based Stock Assessment program and will be discussed separately in chapter 7.8.

7.4.4 Other species

Analysis of the data[16] on the other species: Shing, Baim, Taki, Kolisha and Gutum indicated a strong relation (*P<0.05*) between growth and flood for Taki, Shing and Kolisha (Figure 49, Figure 50 and Figure 51). For the other two other species, Gutum and Baim, this relation was not significant.

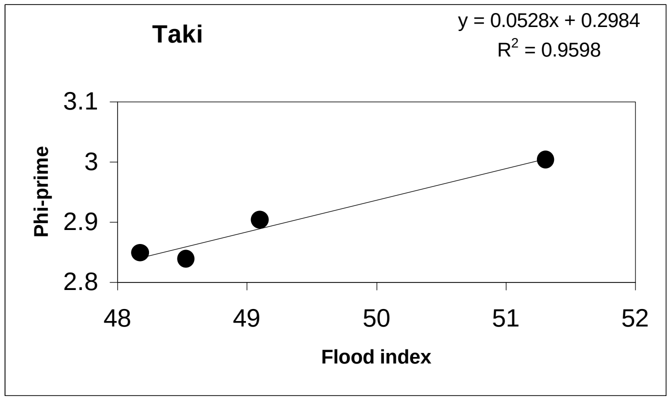


Figure 49: The relation between the growth performance index (Phi-prime) and the flood index for *Ophiocephalus punctatus.*

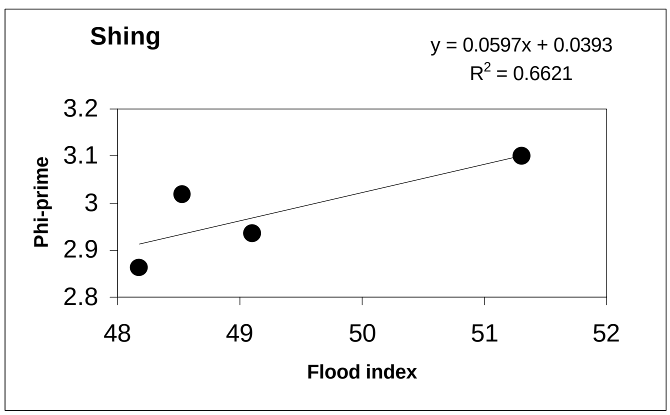


Figure 50: The relation between the growth performance index (Phi-prime) and the flood index for *Heteropneustes fossilis.*

[16] For these species data were only collected from 1992-1996.

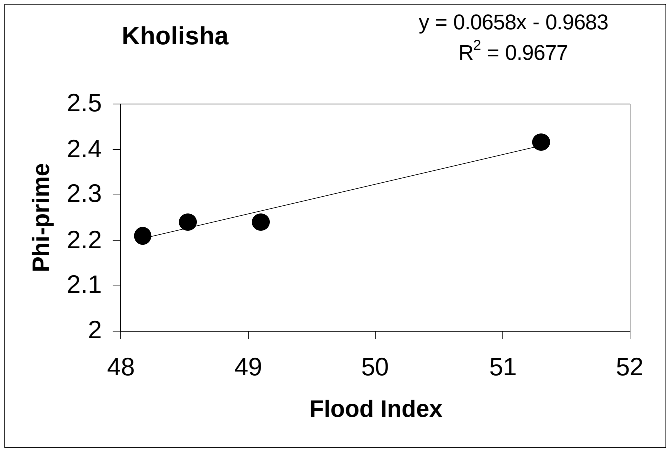


Figure 51: The relation between the growth performance index (Phi-prime) and the flood index for *Colisa fasciatus.*

In Figure 52, Figure 53 and Figure 54 the growth of the individual cohorts for Taki, Shing and Kolisha over the four years in relation to the observed flood and the L25% is presented.

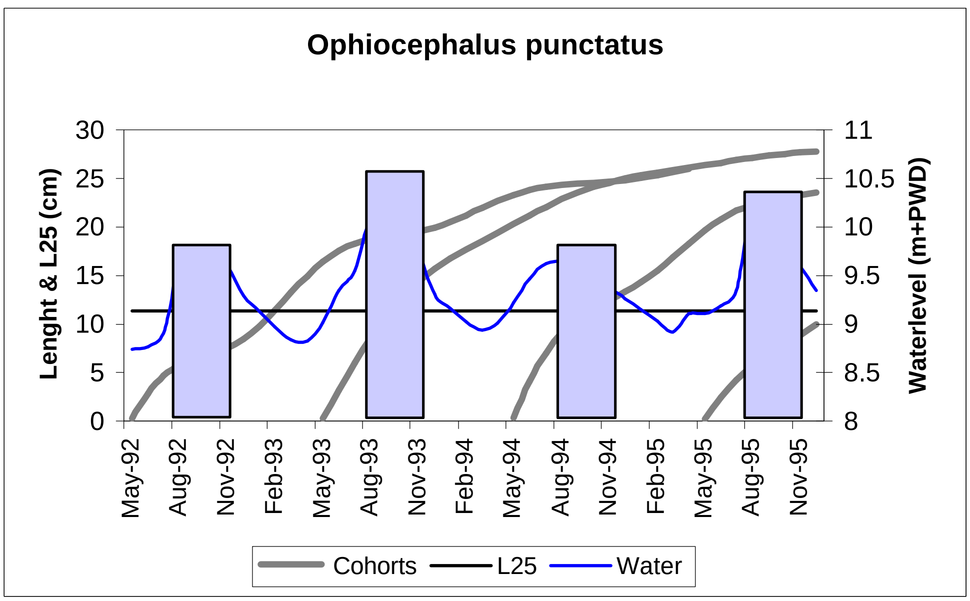


Figure 52: The growth of individual cohorts of Taki in relation to flooding.

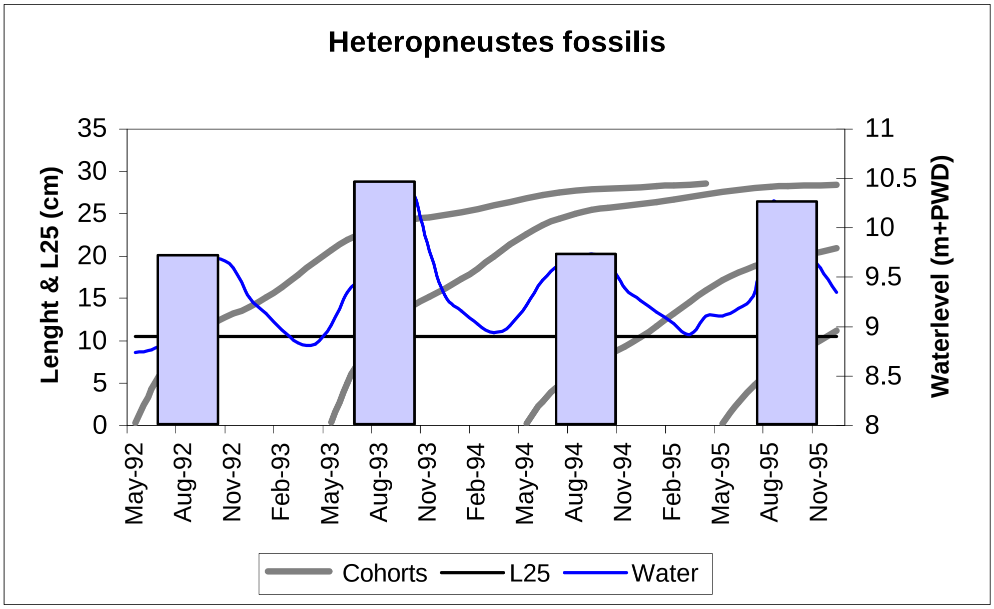


Figure 53: The growth of individual cohorts of Shing in relation to flooding.

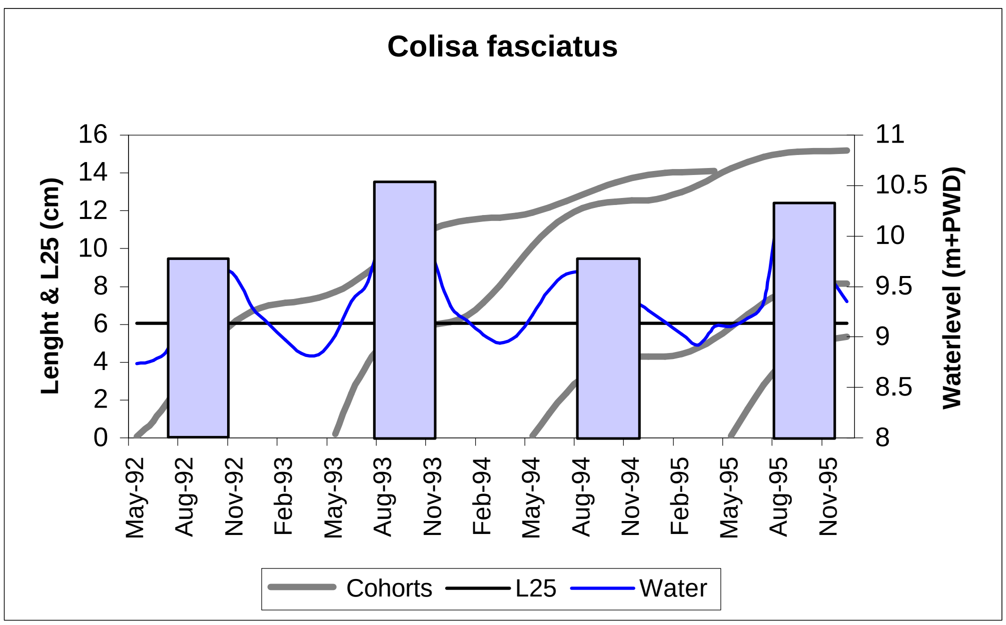


Figure 54: The growth of individual cohorts of Kolisha in relation to flooding.

7.5 Mortality rates.

7.5.1 Basic principles and results

Most fish stock assessment models are based on the mathematical exponential decay model that can be described as:

$$Nt = No * e^{-(F+M)*t}$$

No = Initial number of fish
Nt = Number of fish at time t
F = Fishing mortality
M = Natural mortality
T = Time interval

Once the mortality rates are estimated the models can be used to predict what will happen if the fishing pressure increases, if it is assumed that the fishing effort is proportionally related to the fish mortality (F).

The basics theory of the models will only be summarised in the next chapters, as it is well presented in two excellent handbooks on this subject: ***"An introduction to tropical fish stock assessment"*** by Sparre and Venema (1992) and ***"FAO-ICLARM Stock Assessment Tools, Reference Manual"*** by Gayanilo *et al*., 1997. In some paragraphs, explanations are integrally taken from them as they could not be formulated better.

The total instantaneous mortality rate (Z) is estimated by the method of linearised catch curve analysis based on non-aggregated length frequency data obtained from non-selective gears (Pauly 1984, Sparre and Venema, 1992) and with incorporation of the method of Pauly (1990) for seasonal growth

The instantaneous natural mortality, M (yr^{-1}), was at first instantly estimated using Pauly's empirical formula (Pauly 1980). This equation relates M to $L\infty$ (cm), K (yr^{-1}) and the average water temperature (t, ^{o}C) according to the following formula:

$$Ln(M) = -0.0152 - 0.279 ln(L\infty) + 0.6543 ln(K) + 0.463 ln(t)$$

The average water temperature was 26.4 ^{o}C and the fish mortality F (yr^{-1}) is estimated from the difference between the total and natural mortality rate (F=Z-M).

The mortality rates as estimated each year for (yr^{-1}) are presented in Table 19

Year	Z (seasonal)	M-Pauly	F	E=(F/Z)	Fishing effort (no fishing days at F3)	Yield Puti (t/year)
92/93	3.71	1.89	1.82	0.49	52897	11
93/94	5.32	2.61	2.71	0.51	68918	47
94/95	4.21	1.57	2.64	0.63	64622	20
95/96	4.42	1.74	2.68	0.61	60884	20
96/97	4.36	2.61	1.75	0.40	51137	67
97/98	4.82	2.61	2.21	0.46	60089	74
98/99	2.88	1.74	1.14	0.40	114596	76
99/00	2.70	1.57	1.13	0.42	41402	n.a[17].

Table 19: First estimates of instantaneous mortality rates, fishing effort and annual catch of *Puntius sophore* in the CPP area whereby natural mortality is estimated with Pauly's empirical formula .

[17] This season is not yet over.

The estimates for Z ranged between 2.7 $year^{-1}$ and 5.3 $year^{-1}$ with an average of 4 $year^{-1,}$ which is equivalent to an average survival rate of only 1.6% $year^{-1}$. The mortality rates are high, but comparable with Z=3.2 $year^{-1}$ found for *Puntius sophore* in the Pabna Irrigation and Rural Development Project (Halls et al., in press).

The natural mortality rate as calculated with Pauly's empirical formula ranged from 1.57 $year^{-1}$ to 2.68 $year^{-1,}$ which is rather high. Through its formula M is related to L∞ and K, which means that natural mortality (M) would be related to the flood pulse with higher natural mortalities in years with a high flood. Biologically, this is not expected and therefore it can be questioned if Pauly's formula can be applied to floodplain fisheries. This question is further supported by the fact that there was no significant relation between the fish mortality (F) and the annual catch of *Puntius sophore* if natural mortality as estimated through Pauly's formula is used for the estimation of F. This is strange, as this is the basis for analytical fish stock assessment models.

Therefore it was decided to estimate M directly from the data set by plotting the fishing effort against total mortality, Z (Figure 55).

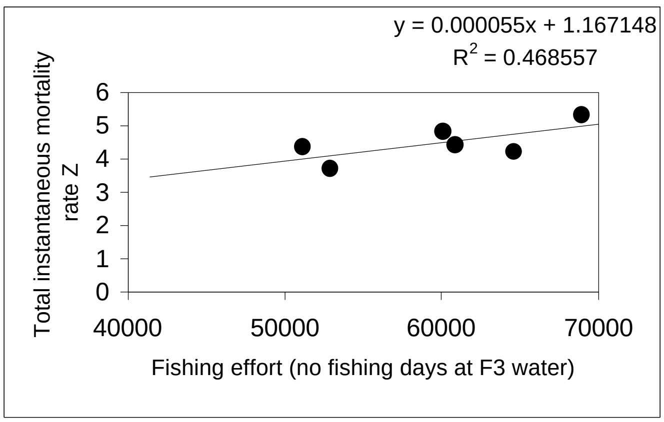


Figure 55: The relation between fishing effort and total mortality of *Puntius sophore* (P<0.05).

The relation indicates a constant natural mortality of 1.168 $year^{-1}$, the mortality at a fishing effort of zero. This estimate of natural mortality is further used and new estimates for the different mortality and exploitation parameters are presented in Table 20.

Year	Z	M	F	E	effort	Yield puti
92/93	3.71	1.168	2.54	0.69	52897	11
93/94	5.32	1.168	4.15	0.78	68918	47
94/95	4.21	1.168	3.04	0.72	64622	20
95/96	4.42	1.168	3.25	0.74	60884	20
96/97	4.36	1.168	3.19	0.73	51137	67
97/98	4.82	1.168	3.65	0.76	60089	74

Table 20: Final estimates of instantaneous mortality rates, fishing effort and annual catch of *Puntius sophore* in the CPP area.

With these estimates the relation between the fishing effort and the annual catch of *P sophore* becomes clear[18] (Figure 56). The catch of Puti increases if F increases, and should start to decline[19] once the fishing pressure becomes too high, and this could be indicated by the last point on the right.

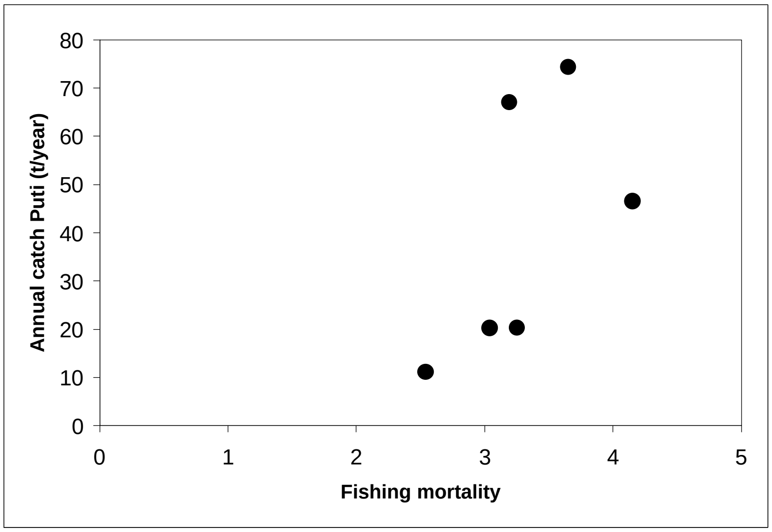


Figure 56: Relation between fishing mortality and the catch of *Puntius sophore.*

[18] Again the 1998/99 data have been excluded as the estimates of Linf and K are doubtful.
[19] Such a relation between F and catch was modelled and has a parabolic function (Dr. Halls, MRAG, pers.com)

In our case we are further interested in whether the increased fishing effort that was observed in the Catch Assessment Survey during years of high flood also is reflected in the Stock Assessment Survey through the fishing mortality rate; therefore F and the Exploitation rate E are plotted against the flood index in Figure 57 and Figure 58.

Figure 57: The fishing mortality ($year^{-1}$) of *P. sophore* in relation to the flood index (*P<0.05*)

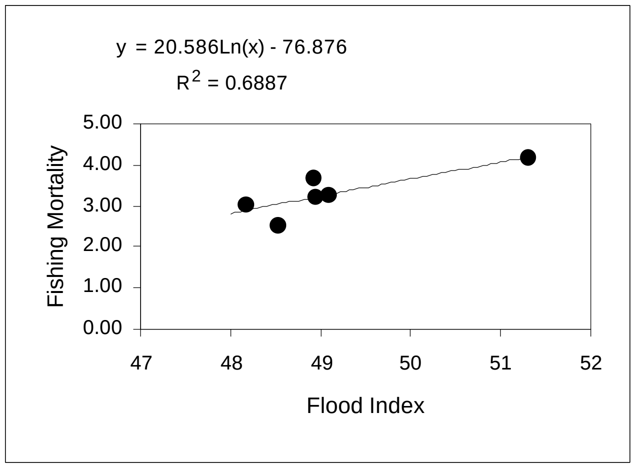
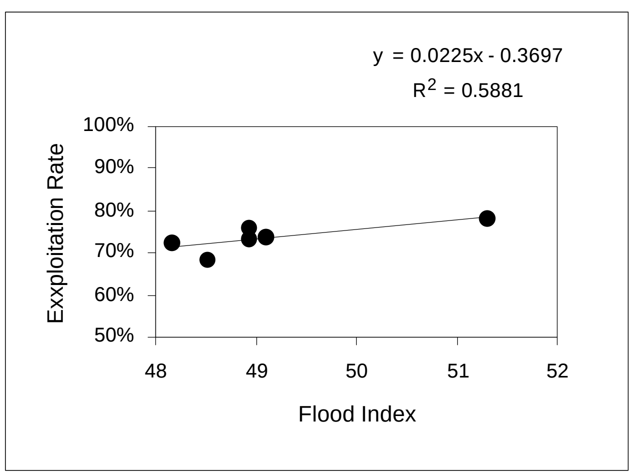


Figure 58: The exploitation rate (E=F/Z) for *P. sophore* in relation to the flood index (*0.05<P<0.1*)



The fishing mortality and the exploitation rate increases in years with high floods, and it can be concluded that the Stock Assessment Program confirms the findings from the Catch Assessment, i.e.

Increased fishing effort is the major driving force behind increased yields in years of high floods indirectly guided by a higher growth rate of the fish and/or lower employment opportunities for the rural poor during the years of high flood.

Knowing the overall mortality and exploitation rates is a first step in fish stock assessment, as it provides first insight in the level of mortality and exploitation. However, we want to know more;

- We want to know if we harvest our stocks on a sustainable way and a first step is to look at Yield per Recruits
- Secondly much more information and insight is gained if it is known when during the life span of a cohort the highest mortality takes place, or for floodplain fisheries what will be the impact of fishing in the dry or wet season on the overall production. The principal tool for this is Cohort or Virtual Population Analysis (VPA)

7.6 Relative Yield per Recruit analysis

Beverton and Holt (1957) developed a yield per recruit model describing the state of stock and the expected yield in a situation in which a given fishing pattern has been operating for a long time, i.e. under steady state conditions. Since the Beverton and Holt model expresses yields on a *per recruit basis,* the yields are relative, i.e. relative to the recruitment. If, say, a recruitment of 1 million fish gives a yield of 100, then 200 million recruits would yield 20,000. Therefore the results of the model are expressed in units of yield per recruit per time, e.g. grams per recruit per year (Gayanilo *et al*., 1997). The **absolute value** of the Y/R has no direct relation to fisheries management and **have no meaning.**

The mathematical basis of the Beverton Holt model is the exponential decay model combined with the von Bertalanffy growth curves. The derivation of the mathematical expression is well described by Sparre and Venema (1992) and Gayanilo et al., (1997) and the ‘Length based” form can be described as:

$$Y/R = F * \left[\left(\frac{L\infty - Lc}{L\infty - Lr} \right)^{M/K} \right] * W\infty * \left[\frac{1}{Z} - \frac{3U}{Z+K} + \frac{3U^2}{Z+2K} - \frac{U^3}{Z+3K} \right]$$

Where

F	= fishing mortality
L∞	= L infinitive
K	= growth parameter
Lc	= Length at first capture
Lr	= Length at recruitment[20]
M	= Natural mortality
W∞	= W infinitive
Z	= Total mortality
U	= 1-Lc/Lr

The basic model allows us to calculate Y/R with varying inputs of different parameters, such as F and Lc, and then assess which effect the various input values have on the yield per recruit of the species under investigation for fisheries management. The two parameters F and Lc are of importance as they can be controlled because:

- the fishing mortality, F, is proportional to fishing effort
- the length at first capture is a function of gear selectivity or mesh size

With the available data a average yield per recruit curve was made for *Puti (Puntius sophore)*. An average curve was made due to the fact that most parameters are related to the flood pulse and the major objective is to know the status of the system irrespective of the flloodlevel. For this in the Y/R analysis as input parameters the averages of L∞. K, F, Z and Lc were used.

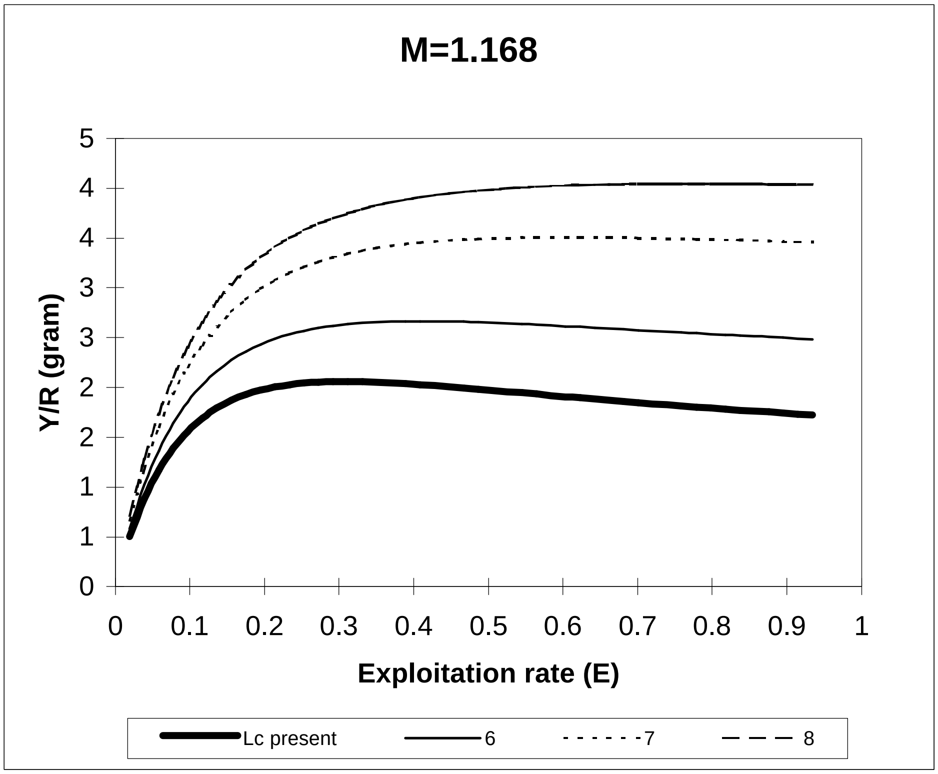
Parameter	
Loo	13.1
Lr	1
Lc present	6.7
Lc/Loo	0.38
F present	3.31
K	0.94
M	1.168
a	0.0184

[20] Do not confuse this with “Length of first recruitment”.

b	2.503

Table 21: Input parameters for a relative Yield per Recruit analysis for *Puntius sophore*

Figure 59: Relative Yield per Recruit Analysis of *Puntius sophore* with M=1.168



The model indicates that a maximum sustainable yield would be obtained at exploitation levels of 10-20%. However with an natural mortality of 1.168 year^{-1} an exploitation rate of 75% was found, which would be far above the optimal exploitation rate. Increasing the mesh sizes in such a way that the L50% becomes 8 cm in stead of the present 5 cm would improve the yields.

Unfortunately no consequences could be drawn from the results of this model for the present status of stocks and fisheries of Puti in the CPP project area as;

However the model was used to indicate the direction for further modelling of floodplain fisheries, modelling which encompasses changes in fishing effort as well as changes in the hydrology of the system or reduction of the flood pulse. In the next chapter this is explained more in detail with the Y/R curve as an example of how this could be done.

7.7 Stock assessment models for dynamic floodplain fisheries systems

Knowing the basic parameters from a stock assessment program is meaningless if they are not further used for predictions and evaluation of management options. As discussed in Chapter 4, the major components of floodplain fisheries are ***"Fish-Fisherman-Habitat",*** and any predictive model must encompass the three aspects.

From the previous chapters it can be concluded that the main characteristics of flood plain fisheries in CPP are:

Yields are strongly depending on fishing effort
Growth is strongly related to the flood index

Both characteristics should be used for Dynamic Floodplain Fisheries Modelling, and as an example of how this could be done an adapted Beverton and Holt Yield per Recruit model is presented in the next chapter.

7.7.1 An adapted Beverton and Holt Yield per Recruit model for floodplain fisheries.

The basic mathematics of the Y/R curve were presented in the previous chapter and the major input parameters are:

- the Fishing fish mortality, F, which is proportional to fishing effort
- the length at first capture is a function of gear selectivity or mesh size

For an ***"adapted floodplain fisheries Beverton and Holt model"*** a third variable can be added - the growth constant, K – because:

- K is related to the extent of flooding and will reduce if flooding is controlled or reduced.

For *Puntius Sophore* the Y/R was calculated with the adapted model whereby F and K were the new variables and Lc was kept constant The following inputs were used:

$L\infty$ was kept constant at 13.1 cm

K was varied in accordance with the flood index and was derived from the relation between phi-prime and the flood index which provided the formula: $Log(K)=0.0994*Flood\ Index-2*Log(L\infty)-2.69$. A minimum value of K=0.3 was maintained as it is not realistic that the growth completely stops at low floods.

Lc was kept constant at 6.68 cm and is the average Lc for all years, as calculated with linearised catch curve method (Sparre and Venema, 1992) for non-aggregated length frequency data

Lr is assumed to be 1 cm

M 1.168 $year^{-1}$

$W\infty$ $= 0.0184(L\infty)^{2.93}$

The results of the model are presented in the form of a three-dimensional graph in Figure 60 and in the form of isoplets in Figure 61.

Figure 60: The relation between Y/R, Exploitation rate and flood index

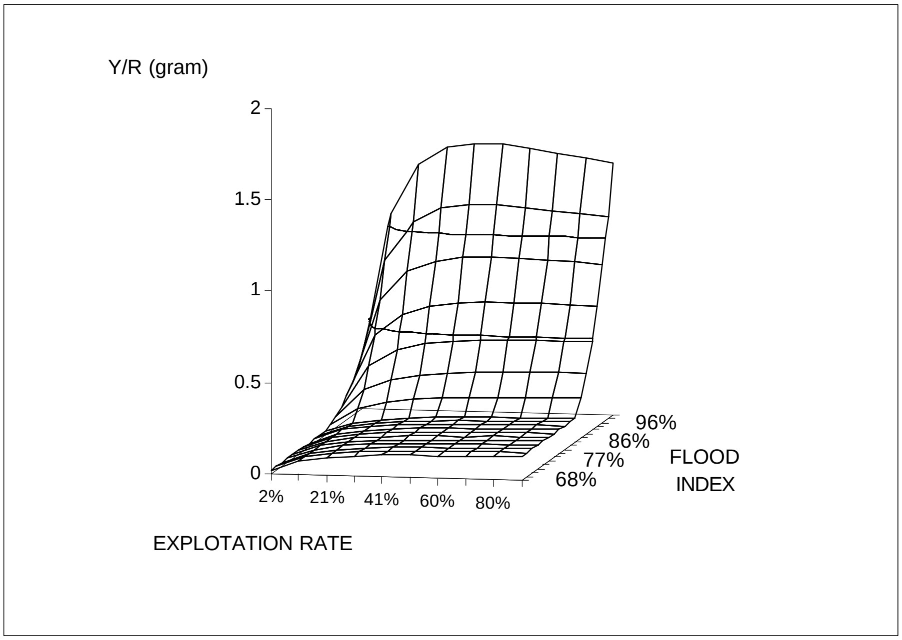
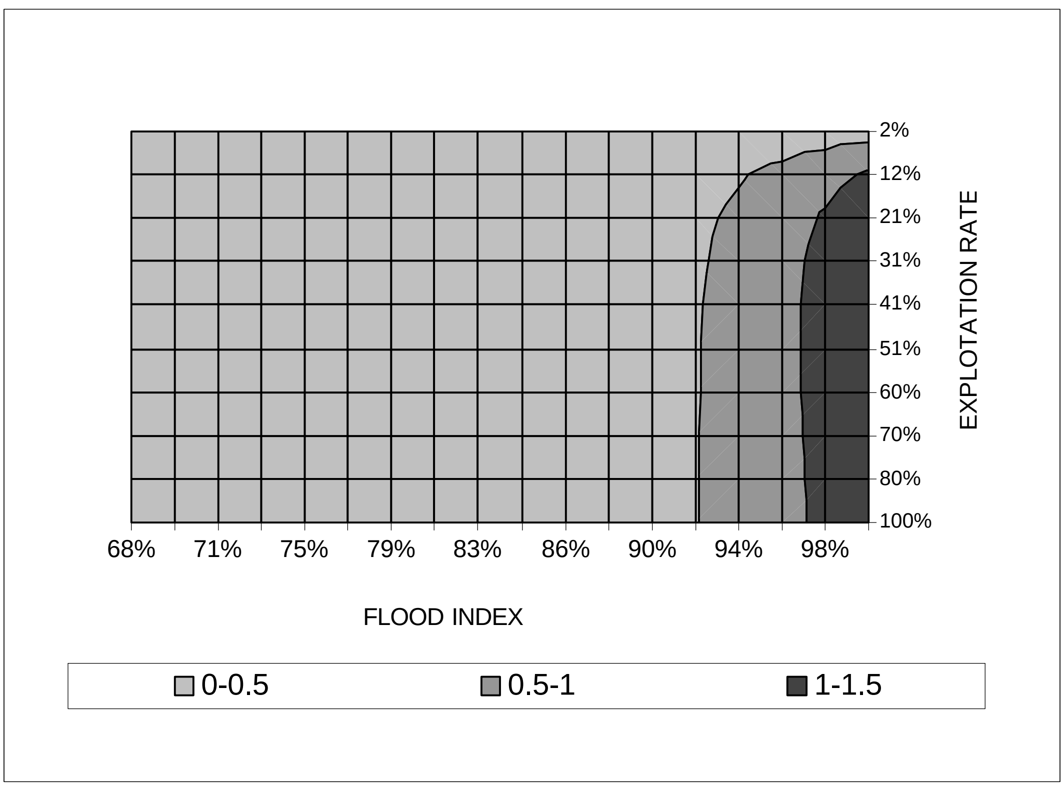


Figure 61: isoplets diagram of the relation between Y/R, exploitation rate and flood index



In the model, the exploitation rate is presented on the X-axis; the flood index is presented on the Y-axis, and the resulting Yield/Recruit on the Z-axis. The present exploitation rate is 75%; increasing this effort will result in a further decline of the Yield per Recruit. The Flood Index in an uncontrolled situation set at 100%, reducing the extent of flooding through water management, will result in a rapid decline of the yield per recruit. The isoplets present the same data but are easier to use again on the X and Y-axis the exploitation rate and floodindex, areas with the same colours present combinations of E and FI resulting in the same Y/R values.

The model should be looked upon as an theoretical example of how interactions between ***'Fishermen-Habitat-Fish"*** can be analysed and modelled.

The preliminary results of the model indicate the following characteristics:

- A strong sensitivity of the model for changes in flooding, which is caused by the strong reduction of the growth of *P. sophore.*
- A strong sensitivity for changes in natural mortality.

In principle the Y/R is a "steady state" model, describing the state of the stock and yield in a situation when the fishing pattern has been the same for a long period and they are not very suitable for the dynamic floodplain fisheries.

More appropriate would be to apply the principles to the "Non-steady state" Thompson and Bell models. The basic input of Thompson and Bell models are the results of a cohort or Virtual Population Analysis (Sparre and Venema, 2000). Unfortunately after a preliminary analysis it had to be concluded that the available methods for length based Virtual Population Analysis can not be applied in to the dynamic floodplain fisheries systems and this will be explained in the next chapter.

7.8 Virtual Population Analysis

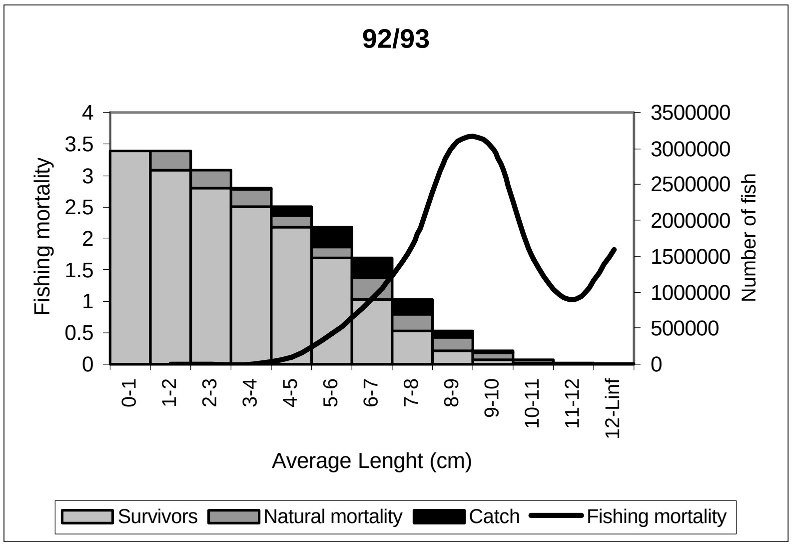
Virtual Population Analysis or VPA can provide detailed information on mortality rates and population dynamics of a cohort over time. Virtual Population Analysis is basically an analysis of the catches of commercial fisheries, obtained through fisheries statistics. This is combined with detailed information on the contribution of each cohort to the catch, which is usually obtained through sampling programs. The idea behind the method is to analyse "that what can be seen", the catch, in order to calculate "the population that must have been in the water to produce this catch" (Sparre and Venema, 1992).

The total landings from a cohort in its lifetime are the first estimate of the number of recruits from that cohort. It is, however, an underestimate because some fish must have died from natural causes. Given an estimate of the natural mortality (M), we can do a backwards calculation and find out how many fish belonging to the cohort were alive year by year and ultimately, how many recruits there were. At the same time we learn the values of the fishing mortality (F), because we have calculated the numbers alive and know from the beginning how many were caught in any particular year. VPA therefore looks at a population in an historic perspective. Once the history is known it becomes easier to predict future catches (Sparre and Venema, 1992).

For the CPP project a simple adapted VPA was carried out in a spreadsheet on the length frequency data of *Puntius sophore*. The regular VPA method (Sparre and Venema, 1992) was adapted in such a way that **"Delta T"** was calculated by taking into consideration the oscillating growth. The combined length frequency data of all gears were used, so the representative fishing effort will be "a fisherman". All length frequency data were raised on monthly bases with the total catch of *P. sophore* as calculated from the Catch Assessment Survey and the GIS analysis.

The results of the VPA for 1992/93 and 1993/94 are presented in Figure 62.

Figure 62: Results of a standard VPA for the year 1992/93.



The results of the VPA indicate that in 1992/93 the fishing mortality starts at 5-6 cm and the highest mortality occurs at 8-9 cm.

From a management point of view these results have limited value, as we want to know when the highest fishing mortality takes place, the dry season or the wet season. For this we have to follow one cohort over time and carry out a VPA over this time period.

Considering this question, unfortunately, the answer is that a simple/standard VPA cannot be used as the characteristics of the data set, i.e. the strongly different oscillating growth rates of the different cohorts violates the basic principles of a VPA,

"The constant parameter system which assumes that working with data from different cohort within one year resembles those of a cohort during its life span"

In our case a data set of one year has two or more cohorts, each with a different growth rate, i.e. in 1993/94 the fish caught at a length of 7-9 cm are the slow-growing fish born in May 1992, while the fish caught at a length of 4-5 cm are the fast-growing fish born in May 1993.

There is an alternative approach to the VPA: "Slicing with pseudo cohorts" which specially deals with data sets with oscillating growth (Sparre and Venema 1992).

But this method uses one fixed oscillating growth rate over different years and is therefore also not suitable for slicing of our yearly cohorts.

In principle the problem can be overcome by separating in the whole data set the different yearly cohorts by slicing with an overlay of the different annual growth curves and calculating a separate VPA for each cohort. We are developing this method at the moment but the description of it is beyond the scope of this book. However, for the moment an alternative approach using the existing “slicing technique” can already provide some preliminary insight in mortality rates throughout the season and an example is presented below.

For each year, two monthly pseudo cohorts, the pseudo cohorts with the highest recruitment in the period May-July were sliced in FISAT and a VPA was made with as major input the growth parameters of that year. The method provided for each pseudo cohort:

Monthly fish mortality;
Catch numbers;
Survivors;
Biomass and average length.

For the final VPA for each year, the average of the fish mortality and length was calculated, while for catch numbers, population and biomass the sum of these data from both pseudo cohorts was used.

For the cohorts 1992, 1993 and 1994, the results are presented in Figure 63.

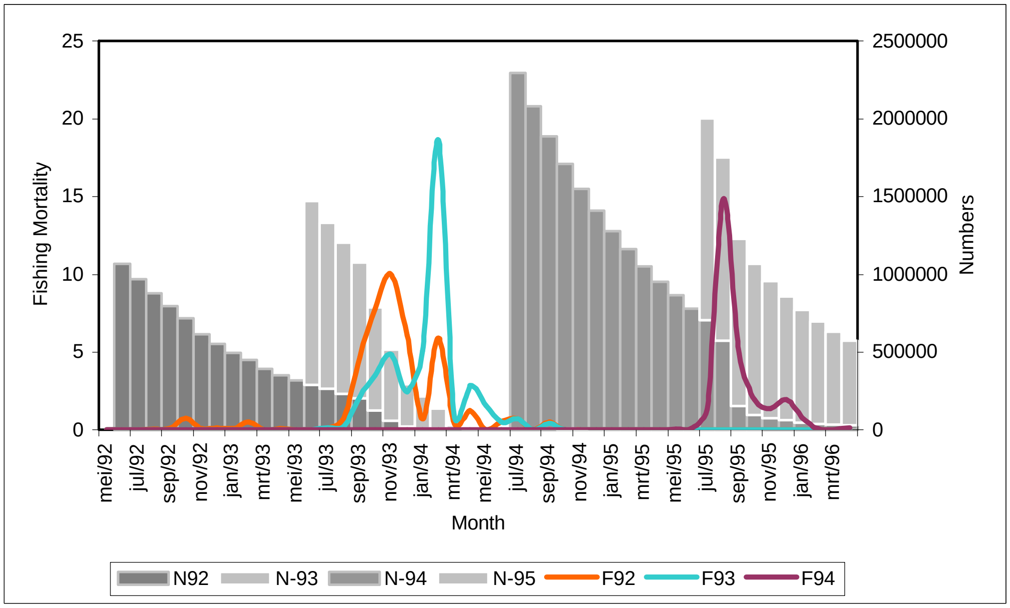
The 1992 cohort with its slow growth is mainly caught during the flood of 1993, when they are over one year old.

The fast-growing 1993 cohort is already caught during the flood of 1993 and the remaining fish are caught during the dry season of 1994, when they are just one year old.

The slow-growing 1994 cohort shows a picture similar to that of the 1992 cohort; they are mainly caught during the flood of 1995, when they are over one year old.

The combination of two cohorts in the catches of 1993/94 explains why the average yield was relatively high in this year if compared with 94/95 and 95/96, when the catch encompassed only one cohort.

Figure 63: Numbers and fish mortality of the 1992, ‘93 and ‘94 cohorts of *Puntius sophore* in the CPP project area.



7.8.1 Conclusions on mortality

It can be concluded that the Stock Assessment Program confirms the findings from the Catch Assessment, i.e. increased fishing effort is a major driving force behind increased yields in years of high floods, as fishing mortality and exploitation rates are going up in years with high floods

From the VPA the following general preliminary conclusions can be drawn:

A dry year followed by a wet year will result in a high catch during the wet year and makes the “flood pulse” even more complex.

High fishing mortalities are taking place during the flood season and it seems that fast growing cohorts, born in a year with high flooding, are more vulnerable to fishing during the dry season during the first year of their lifespan.

The absolute figures of recruitment and parent stock numbers as calculated with the VPA for the month Mai/June do not show a relationship, and the VPA should be improved by slicing with the real growth rates for each cohort.

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8 A RAPID FISH BIO DIVERSITY APPRAISAL FOR FLOODPLAIN ECOSYSTEMS

In Chapter 5, changes of species composition due to reduced spawning area and increased fishing effort was discussed. There are, however, some other examples from Bangladesh and from floodplains in other countries. These examples allow us to define a broad indicator for fish bio diversity related to fisheries and water management.

In general it can be stated that in over-exploited floodplains, with a high fishing pressure, the large, slow-growing species and the species that start to reproduce after 2-3 years are replaced by quick-growing and fast-reproducing species. This could be one of the reasons why the Indian carp disappeared from the floodplain catches in the last decades.

The results of the fisheries monitoring program at the Chandpur Irrigation Project indicated that a complete “cut-off” of a floodplain system from annual flooding results in a species shift towards Catfish (*Shing*), Snakeheads (*Taki*) and small Prawns (*Chingri* and *Icha*).

The results of Garinda Beel in the CPP area and Beel Dakatia in the Khulna Jessore Drainage Irrigation Project area indicated that even if the floodplain is not “cut off” from annual flooding, a similar shift takes place if the spawning area becomes too small. The remaining species will be Catfish, Snakeheads, Prawns and riverine species entering the floodplain with the annual flood.

In relation to floodplain fisheries and water management, the following successive phases in fish bio diversity can be recognised:

Phase I: a healthy flood plain system with no over-exploitation. This situation existed some twenty years ago and maybe still exists in the large floodplains in the north of the country and in Sylhet

Phase II: an over-exploited floodplain, due to the high fishing effort and small mesh-sizes used. The Indian carp stocks and other large fish come under pressure; they disappear as they reproduce only after several years and are gradually replaced by fast-growing, small but quick-reproducing fish, the “miscellaneous” species.

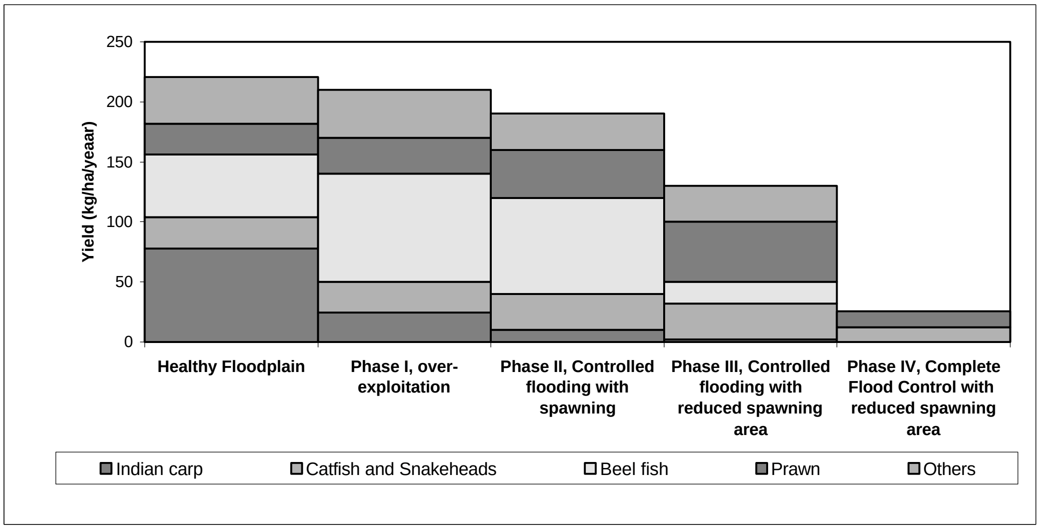
Phase III: controlled flooding and improved drainage is carried out, the total *beel* area reduces somewhat but *beel* resident species are still abundant

Phase IV: controlled flooding and drainage is further improved, large quantities of groundwater are extracted for *Borro* irrigation, and the area dries out. Spawning area in the pre-monsoon is seriously reduced. *Beel* resident species such *as Puti, Baim,* and *Gutum* are under pressure and will disappear. Some riverine fish are still available because annual flooding still continues and small prawns become the bulk of the biomass.

Phase V: Complete flood control. Catfish, small prawns and Snakeheads are the only survivors.

The different phases are visualised in Figure 64.

Figure 64: Species composition and yields of floodplain fisheries (F3 land types) in relation to intensifying fisheries and flood control.



The mentioned species can be used as indicators for bio diversity and health of a floodplain system. The method could be considered as a **Rapid Fish Bio diversity Appraisal,** whereby the dominance of small prawns is used as a key indicator for the status of the system, and is most likely more practical and less time-consuming than trying to cover all species in a bio diversity index.

During the last months of the fisheries monitoring programme, CPP applied this method to all the perennial beels inside and outside the project area in order to see if the collapse of the catch and the dominance of prawns in Garinda beel is an exception or part of an overall trend.

It is realised that the results of this survey are very preliminary, and that conclusions cannot yet be drawn. However, the combination of the **“Rapid Fish Bio diversity Appraisal”** and **“GIS”** could be a powerful tool for assessment of the status of water bodies, therefore, as an example, the results are presented in the next paragraphs and could serve as a basis for further developments.

All perennial beels were visited three times during the period December 1999 – March 2000, the catch was recorded from the fishermen and separated into the following groups/species:

Prawns: *Macrobrachium spp*

Beel species: Koi, Puti, Kolisha, Baim

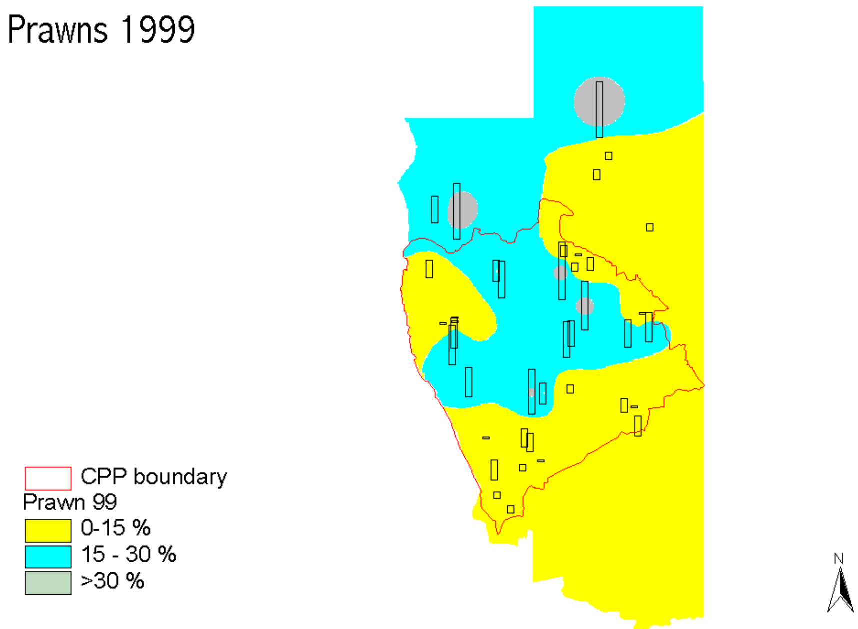
Carp: Catla, Rui, Mrigal

Catfish: Taki (Ophiocephalus punctatus) and Shing (Heteropneustes fossilis)

Others

The spatial distribution of the species composition inside and outside the CPP area was analysed in GIS by using “spatial analyst” and presented in Figure 65 and Figure 66.

Figure 65: Spatial distribution of prawns in the catch of perennial Beels inside and outside the CPP project area

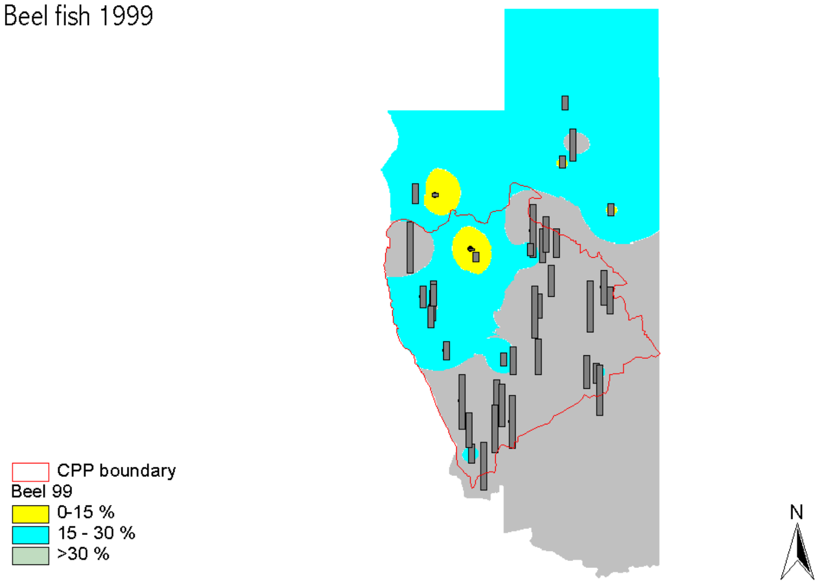


The proposed bio diversity index uses prawns as an indicator for loss of bio diversity or "health status" of the water body, whereby an increased percentage of prawns indicates deterioration. From the analysis (Figure 65) we see that there are two "hot spots" outside the CPP area, and two inside the CCP. Further, it becomes clear that the north-east and central part of CPP have medium density of shrimps and the north-west and southern part of CPP and the outside area east of CPP have low densities of prawns.

A part of the concept is that Beel resident species are replaced by prawn and Snakeheads/catfish once the status of the water body detoriates. The picture for Beel fish shows more ore less the inverse situation of prawns (Figure 66) with medium densities of "Beel fish" in the north outside CPP and central CPP and high densities in the southern part.

Figure 66: Spatial distribution of "Beel fish" in the catch of perennial Beels inside and outside the CPP project area.

Beel fish 1999



From the example it could be concluded that the Beels in the south and southeastern part seem to be undamaged. The Beels in the North and Central part of CPP and in the Northeast outside CPP seem to be deteriorating as the species composition changes from ‘Beel residents” toward a more ‘Prawn dominant” system. The difference could be caused by the fact that the southern part of CPP is more flooded and has a lower population density resulting in a lower fishing pressure. Another factor could be the construction of the railway and the by-pass road in the eastern part of the CPP project.

In general it can be concluded that the change in species composition as observed in Garinda beel over the last years is most likely part of a larger pattern inside and outside the CPP area. The Bio diversity Index and its use in a GIS environment illustrates clearly the patterns, but it is realised that it illustrates patterns after a change has taken place and once we are most likely too late to reverse the process. Definition of “clear criteria” -- i.e. the ranges for prawns to be accepted for a “healthy system" -- will be needed in order to detect changes at an early phase.

9 PREDICTIVE IMPACT MODELING WITH HYDROLOGICAL MODELS AND GIS

9.1 Introduction

One of the major questions during a number of studies related to flood control during the Flood Action Plan was ***"What will be the impact of the proposed interventions on fisheries",*** and this was also the Terms of Reference of the initial fisheries study of CPP.

Reduction of the floodplain will result in direct and indirect losses. The direct loss is a reduction in fishing area producing a certain quantity of fish per year. Indirect losses are the result of the reduction in spawning and nursing area, impacting the whole fish community. In the past, several methods were used for the impact of flood control on fisheries:

In the '80s, the average production of the floodplain was multiplied with the total floodplain area in order to estimate the floodplain fisheries production. Fisheries losses were estimated by multiplying the floodplain area lost with the average floodplain production.

Water depth and water quality data were used in the Morpho Edaphic Index in order predict/estimate fisheries production. However, this method proved to be unreliable.
In several FAP projects (FAP 12, FAP 5.2 & FAP 3) the methodology was improved and different habitats such as Beel, floodplain, khals and rivers were considered. The production levels in most cases were obtained from secondary data.
CPP 20 started to link habitat related fish production figures with hydrological models in order to predict the fisheries production for different water management scenarios in 1992 (CPP, 1992). Over the years this methodology was improved through: a rigorous, habitat-specific monitoring programme of FAP 17 (1992-1994) and CPP (1992-2000); development of hydrological models; and the incorporation of Geographical Information Systems for the determination of the different habitat areas.

Over the years the model improved and became more accurate, and more parameters were added, especially socio-economic ones. The model, little by little, evolved towards a decision support model or a preliminary stage of "blue accounting" (EGIS, 2000) for different water management options in CPP.

A multidisciplinary and integrated approach to planning for natural resource use, for which such models are essential, is getting more attention in Bangladesh. Therefore in the next chapters detailed information is provided on such a model made for CPP to explain the principles, and to provide the basis for further development and use of this method in Bangladesh.

To explain the principle and the inputs/outputs of the model, it was applied to a water management scenario whereby the water level in the Lohajang River during the monsoon is maintained at a level in the range of 11.0 –10.5 m +PWD.

9.2 The CPP model

The CPP model works with quantifiable parameters, i.e. kg, Tk, labour days, ha, etc., only, and consists of the following five modules:

A hydrological module, which translates target level into temporal and spatial flood patterns
A fisheries module, which calculates the fish catches for the different target levels
An agriculture module, which calculates the agricultural production for the different target levels
An economic module, which calculates the economic returns for the different target levels
A socio-economic module, which provides information on socio-economics and distribution of profits and losses.

The model works with the assumption of a constant fishing effort and does not take into account the impacts of over-fishing due to increased fishing effort or increased population growth. The rainfall and upstream hydrology of the season 1993/92 was chosen as major input for the model because pre-project data on fisheries and agriculture were available for this year and the hydrology approaches a "normal" year. The proceedings of each module are described in the next chapters.

9.2.1 Hydrological module

The hydrological module is the Mike 11 model of CPP. The gates of the main regulator are set in such a way that the preferred target water level in the Lohajang River is maintained throughout the monsoon. The model generates the average monthly water levels for 21 locations in the CPP area. For the dry season the water levels are reduced/increased at the same rate as was observed during the dry season of 93/94, whereby for each target option the average water levels as obtained from the model served as a starting point.

For each target option a specific gate setting is needed to maintain the preferred target water level. For each option the specific gate setting is used to create a land type map according to the MPO specifications as discussed in Chapter 3.4.2.

The generated water levels and the land type maps are used as input for the GIS module.

9.2.2 GIS module

Within the GIS module the generated water levels for each option are used to calculate the monthly inundated areas for the F3, F2, F1 and F0 land types in a way that is described in Chapter 3.4. The generated flooded area serves as an input for the Fisheries and the Agriculture modules.

9.2.3 Fisheries module

All options are compared with the situations of the season 93/94, which is considered as a pre-project baseline situation. The monthly CPUA for the different land types for this year are used to calculate the annual fish catch for the different water target level options and are presented in Table 22.

DATE	CPUA (kg/ha/month)		
	F3	F2	F1
May-93	1.83	0.53	0.10
Jun-93	3.47	3.11	0.62
Jul-93	3.03	2.35	0.47
Aug-93	15.02	3.20	0.64
Sep-93	84.01	15.49	3.09
Oct-93	64.52	20.16	4.03
Nov-93	46.51	29.70	5.94
Dec-93	25.39	8.08	1.61
Jan-94	20.64	2.24	0.44
Feb-94	42.68	3.14	0.62
Mar-94	6.41	0.00	0.00
Apr-94	4.80	0.00	0.00

Table 22: The monthly Catch Per Unit of Area used as input for the fisheries module.

For the distribution of the catch over the different types of fishermen -- Professional, Occasional and Subsistence -- the distribution as observed during 1993/94 is used:

Professional 25%
Occasional 42%
Subsistence 33 %

9.2.4 Agriculture module

Due to lowering of the water level in the Lohajang River, drainage will improve and the different land types will become dryer and even shift from one type to another; i.e. some of the F3 land will become F2, some of the F2 becomes F1 and some of the F1 becomes F0. During the monsoon each land type has its own cropping pattern or land use suitability. For the comparison of agriculture under the different target water level, only the monsoon crop, i.e. Aman, was used, as any water management scenario does not affect the dry season crop during the monsoon.

Cropping patterns, production and financial outputs for the different land types during the monsoon are presented in Table 23.

General classification	Land type	Cropping pattern	Hired labour requirements (days/ha/crop)	Financial output (Tk/year)
High or Tan Jomi	F0-dry	T. Aman HYV	168	20559
Medium or Pachot Jomi	F1-dry	T. Aman local	172	11955
Medium or Pachot Jomi	F2-dry	DW Aman transplanted	113	8484
Low or Dopa Jomi	F3-dry	DW Aman Broad casted	134	9712

Table 23: Cropping pattern, production and financial outputs of agriculture on the different land types during the monsoon.

A suitable land type for DW Aman broadcasted the generated areas for F3-dry is used because DW Aman is grown only at the edges of the Beel or the higher F3 land. This is also the case for the other crops where the F2-dry, F1-dry and F0-dry are used.

In the agriculture module the dry areas as estimated per land type for the month of September in the GIS module are considered to be the total area under agriculture. For each land type this area is multiplied with the production rate or financial output of the specific crop growing at that land type.

9.2.5 Economic module

In the economic module, the annual production of fish and rice[21] is translated into financial output. The financial output for agriculture was provided by the agriculture section of CPP and is presented in Table 23.
Details on the financial outputs used for fisheries are presented in Table 24, Table 25 and Table 26 and are based on CPP data.

[21] Rice crop for the monsoon only

OPERATIONAL COSTS PER UNIT OF GEAR	Cast	Seine	Liftnet	Scoops	Gill net	Traps	Lining
Investments Gear (Tk)	1500	30000	150	50	200	3000	200
Duration (years)	4	3	1	1	2	2	1
Investment others (Tk)		15000					
Duration others (Years)		6					
Investment per year (Tk)	375	4167	150	50	133	1500	200
Fishing Time (hours)	3	2.41	2.48	2.21	2	2	2.5
Annual fishing hours	93	8	84	196	58	26	26
Annual fishing days	9	1	8	20	6	3	3
GROSS PRODUCTION F3 WATER							
% of Production	22%	9%	10%	28%	15%	10%	6%
Annual yield per ha (181 kg/ha/yr.)	40	16	18	51	27	18	11
CPUE average kg/fishermen/day	1.29	5.16	0.54	0.57	0.94	1.37	1.03
No fishermen/ha/year to catch the total	31	3	34	89	29	13	11
Relative fishing effort	0.19	0.07	0.31	0.42	0.11	0.33	0.16
INPUTS							
Investments per ha/year	71	292	47	21	14	491	32
Real Labour days * 50 TK	463	38	419	982	289	132	132
Fish price Tk/kg	70						
OUTPUTS FINANCIAL							
Gross Product Value per gear per ha (Tk)	2787	1140	1267	3548	1901	1267	760
Total Inputs per gear per ha financial (Tk)	71	292	47	21	14	491	32
Net Profit per gear per ha (Tk)	2716	849	1221	3527	1886	777	728
Total profit/ha Financial (Tk)	11703						
Profit/kg (Tk)	65						

Table 24: Details of financial analysis of fisheries at F3 land type

OPERATIONAL COSTS PER UNIT OF GEAR	Cast	Seine	Liftnet	Scoop	Gill net	Traps	Lining
Investments Gear (Tk)	1500	33000	150	50	200	3000	200
Duration (year)	4	3	1	1	2	2	1
Investment others (Tk)		15000					
Duration others (year)		6					
Investment per year (Tk)	375	4500	150	50	133	1500	200
Fishing Time (hours)	3.19	2	0.9	2.04	2	2	2.5
Annual fishing hours	49	3	11	105	32	10	14
Annual fishing days	5	0	1	11	3	1	1
GROSS PRODUCTION F2 WATER							
% of Production	22%	9%	10%	28%	15%	10%	6%
Annual yield per ha (82 kg/ha/yr.)	18	7	8	23	12	8	5
CPUE average kg/fishermen/day	1.18	5.65	0.69	0.45	0.77	1.70	0.89
No fishermen/ha/year to catch the total	15	1	12	51	16	5	6
Relative fishing effort	0.08	0.03	0.34	0.39	0.18	0.16	0.05
INPUTS							
Investments Tk/ha/year	29	153	51	19	25	239	10
Real Labour days * 50 TK	244	13	53	525	160	48	69
Fish price Tk/kg	70						
OUTPUTS FINANCIAL							
Gross Product Value per gear per ha (Tk)	1263	517	574	1607	861	574	344
Total Inputs per gear per ha financial (Tk)	29	153	51	19	25	239	10
Net Profit per gear per ha (Tk)	1234	364	523	1588	836	336	335
Total profit/ha Financial Tk)	5215						
Profit Tk/kg	64						

Table 25: Details of financial analysis of fisheries at F2 land type.

OPERATIONAL COSTS PER UNIT OF GEAR	Cast	Seine	Liftnet	Scoop	Gill net	Traps	Lining
Investments Gear (Tk)	1500	33000	150	50	200	3000	200
Duration (year)	4	3	1	1	2	2	1
Investment others (Tk)		15000					
Duration others (year)		6					
Investment per year (Tk)	375	4500	150	50	133	1500	200
Fishing Time (hours)	3.19	2	0.9	2.04	2	2	2.5
Annual fishing hours	6	0	1	13	4	1	2
Annual fishing days	0.59	0.03	0.13	1.28	0.39	0.12	0.17
GROSS PRODUCTION F1 WATER							
% of Production	22%	9%	10%	28%	15%	10%	6%
Annual yield per ha (82 kg/ha/yr.)	2	1	1	3	2	1	1
CPUE average kg/fishermen/day	1.18	5.65	0.69	0.45	0.77	1.70	0.89
No fishermen/ha/year to catch the total	2	0	1	6	2	1	1
Relative fishing effort	0.01	0.00	0.03	0.04	0.02	0.02	0.01
INPUTS							
Investments Tk/ha/year	3	14	5	2	2	24	1
Real Labour days * 50 TK	30	2	7	64	19	6	8
Fish price Tk/kg	70						
OUTPUTS FINANCIAL							
Gross Product Value per gear per ha (Tk)	154	63	70	196	105	70	42
Total Inputs per gear per ha financial (Tk)	3	14	5	2	2	24	1
Net Profit per gear per ha (Tk)	151	50	65	194	103	46	41
Total profit/ha Financial (Tk)	649						
Profit Tk/kg	65						

Table 26: Details of financial analysis of fisheries at F1 land type

9.2.6 Socio economic module

The socio-economic module takes into account how the benefits and losses of the different options are distributed over the different social strata in the rural area of CPP. It considers the following social strata:

Landless
Marginal farmers
Small farmers
Medium farmers
Large farmers

The combined results of the Household survey and the Agriculture Monitoring Plot survey allowed researchers to estimate the land ownership of the Net Cropped Area and the Beels[22] in the CPP area, which is presented in Table 27.

[22] Beels should be included as the model works with shifting land types i.e. F3-wet (beel) shifts to F3 dry (DW aman)

Farmer	No HH	% of Rural HH	% of NCA	Area (ha)
Landless	19890	69%	0%	0
Marginal	2509	9%	11%	1080
Small	4589	16%	44%	4341
Medium	1362	5%	26%	2539
Large	475	2%	20%	1991
Total	28825	100%	100%	9952

Table 27: Distributions of the Net Cropped Area (fishing area included) over the rural population in the CPP project area.

In Table 28 the distribution of the catch over the rural population in CPP is presented. The data are a combination of the Household survey of CPP (1992) and the FAP 17 data for the North Central Region, and it was assumed that all professional fishermen belong to the "landless" category.

HH type	Occasional	Subsistence	Professional
Large farmers	0%	0%	0%
Medium farmers	2%	3%	0%
Small farmers	12%	21%	0%
Landless & Marginal farmers	86%	76%	100%
Total	100%	100%	100%

Table 28: Distribution of the catch over the rural population in the CPP project area.

The data in the two tables allows us to parcel the agriculture benefits and the fisheries losses for the different target water level options over the different categories of the rural population in the CPP area. Within the analysis the professional fishermen and their catch and the rest of the rural population with its subsistence and occasional catch are treated separately.

In this module the following assumptions are used:

The distribution of the NCA over the social strata is the same[23] for the different land types (F3,F2, F1, and F0).
Exclusively the landless and marginal farmers carry out the hired labour needed for the different crops.

All calculations are on a Household basis with 5.5 persons in a household..
Annual income: large farmer, 80 000 Tk; medium farmer, 53 000 Tk; small farmer, 31 000 Tk; marginal farmer, 19 000 Tk; landless 15 000 Tk
Fish price 70 Tk/kg, Labour 50 Tk/day, 1 US$ = 50 Tk
The availability of protein for consumption is calculated with the ***subsistence catch only***. For the transformation of "Wet fish weight" to "Dry protein" a conversion factor of 0.174 is used and the daily requirement of protein was set at 43 g/capita/day.

[23] In reality this is not the case; medium and large farmers possess more F1 and F0 land (CPP Household survey, 1992).

9.3 *Results*

9.3.1 Shift in water and land

Due to the lowering of the water level in the Lohajang River, drainage is improved and the extent of flooding will be less -- i.e. the area becomes drier. In Figure 67 and Figure 68 for the two extreme options, without CPP and a 10.50 m + PWD target level, the inundated and dry area per land type throughout the year is presented and its is clear that especially the area of dry-F0 increases substantially with a reduction of the flooded areas of F2 and F1.

Figure 67: Monthly flooded and dry areas for the different land types without CPP

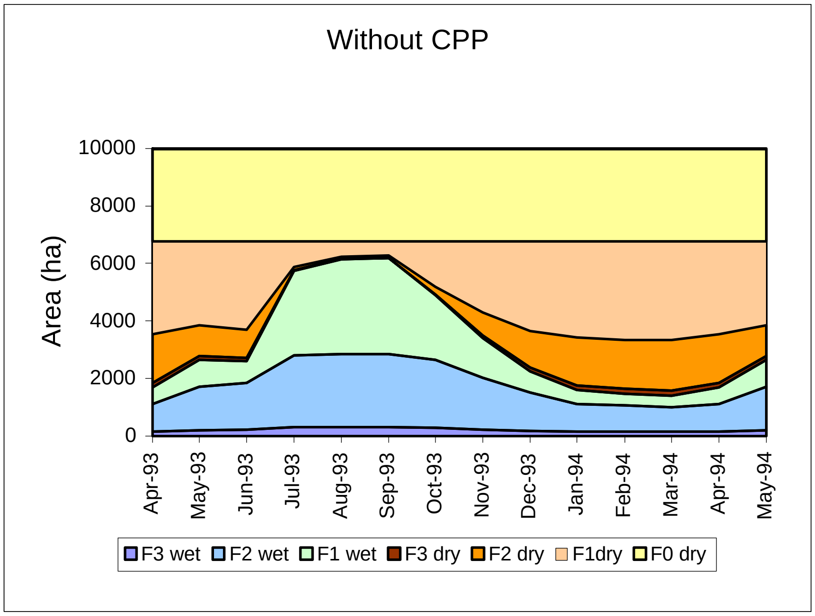
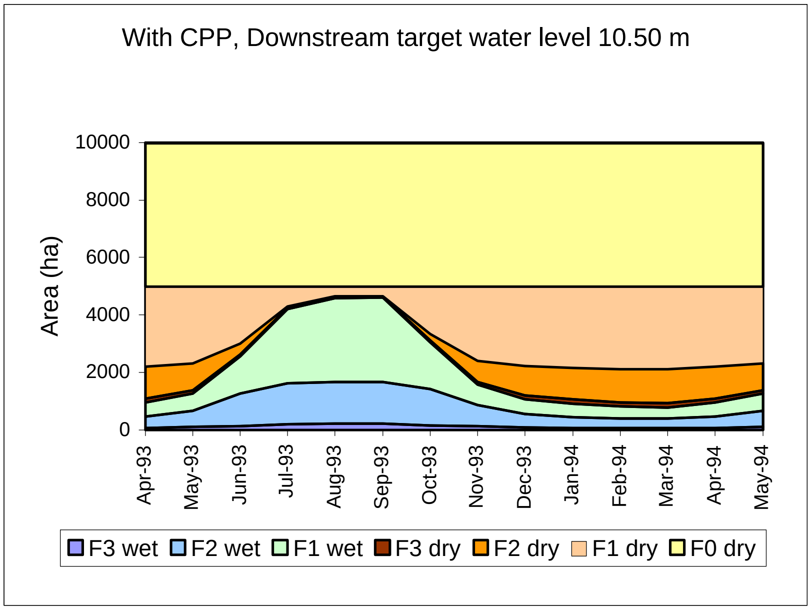


Figure 68: Monthly flooded and dry areas for the different land types with a level of 10.50 m + PWD in the Lohajang river.

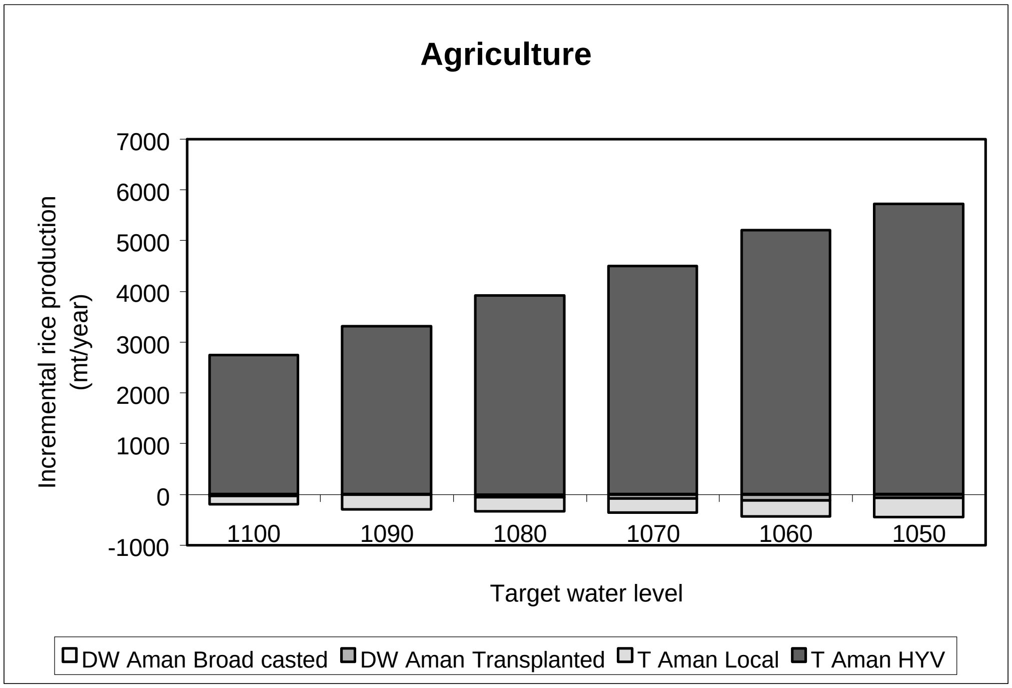


9.3.2 Production and Value

The reduction of dry F2 and F1 area and the increase in dry F0 area is also reflected in the rice production. By lowering the water level of the Lohajang River, the production of DW transplanted Aman and T Aman locally will decrease, while the production of DW Aman broadcasted will increase slightly. The benefits are found in the large incremental production of T Aman HYV (Figure 69). The total rice production[24] will increase by 5 300 mt/year, from 11 7000 mt/year for the pre-project phase to 17 100 for the 10.50 meter water level.

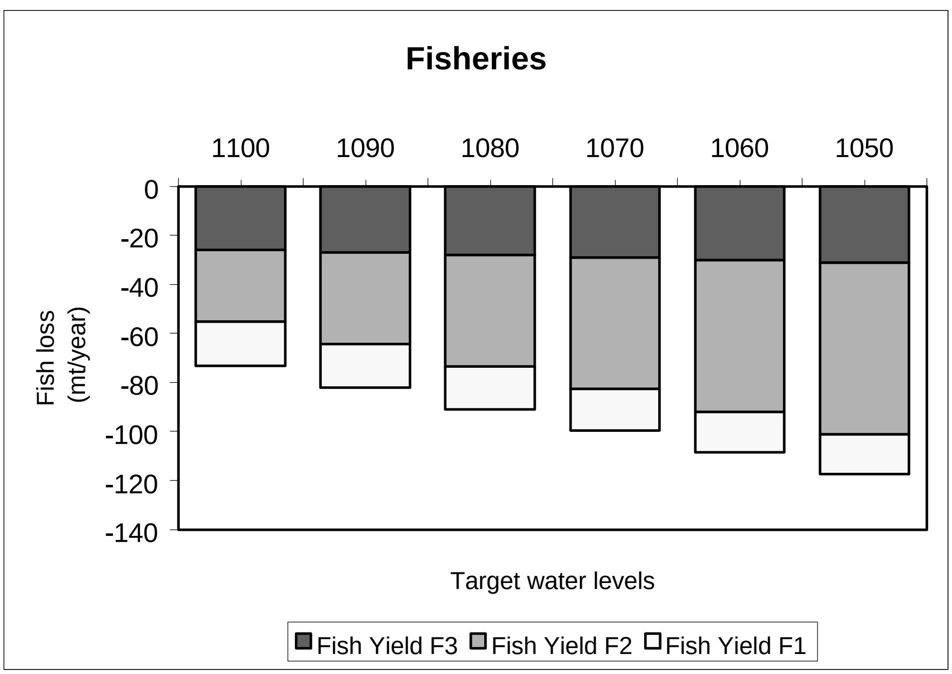
Figure 69: Incremental rice production at different target water levels of the Lohajang river.

[24] During the kharif/monsoon season



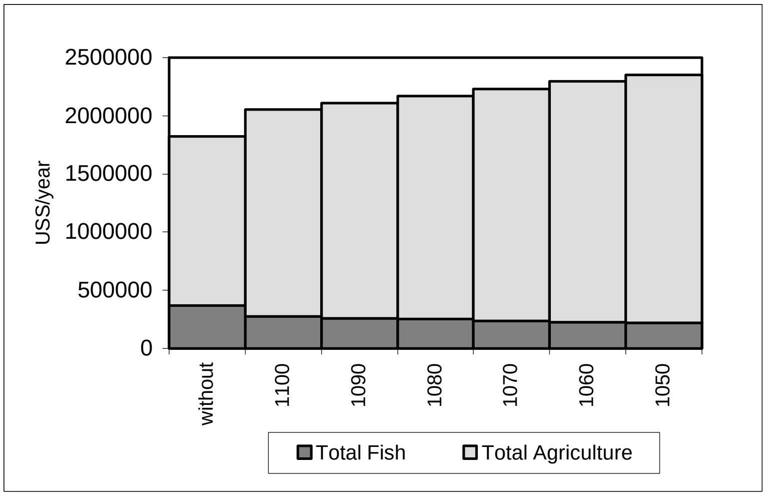
The consequence of a drier CPP area there will be reduction of the fish catch, especially from the F2 and F1 areas (Figure 70). The total fish catch will be reduced by 41%, from 285 mt/year for the pre-project situation to 168 mt/year for the 10.50 m target level.

Figure 70: Reduced fish catch in the CPP project area for the different water target levels



On financial terms the benefits obtained from agriculture outweighs the losses from fisheries and the value added increases with 0.5 million US/year from 1.8 million US/year for the without CPP situation to 2.3 million US/year for the 10.50 meter Target water level (Figure 71).

Figure 71: The total "value added" for agriculture and fisheries as estimated by the model for the different water management options of CPP.



9.3.3 Socio-economic aspects

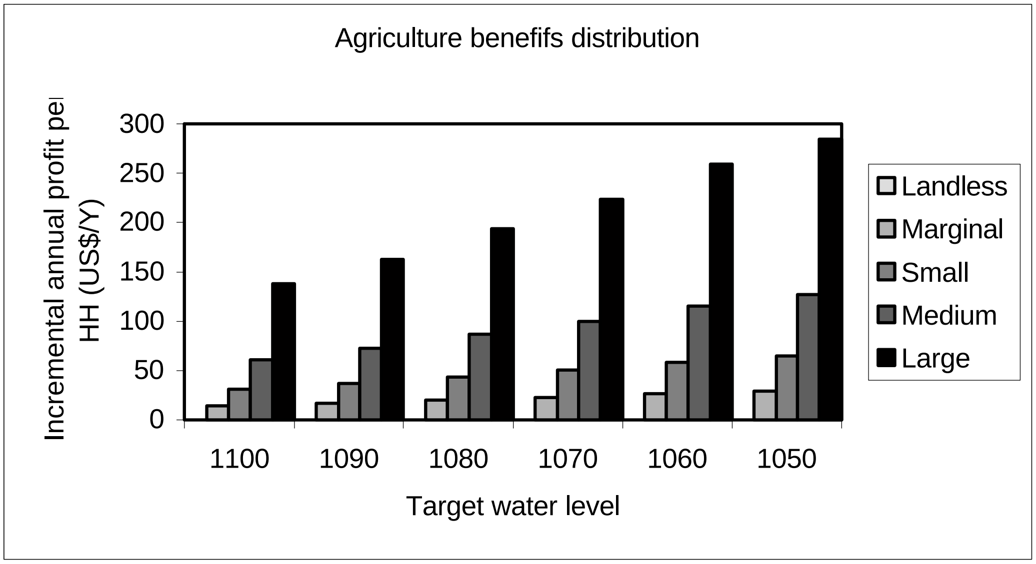
Increased financial outputs are not the only justification of an intervention; it is the overall policy and the outputs of an intervention in relation to this overall policy that justifies or rejects an intervention. If the overall policy is to increase rice production, then the results of the estimates would justify the implementation of the 10.50-meter Target level. However, if the overall policy includes poverty alleviation, it is essential to consider how much the rural poor are gaining from the intervention. This is done by looking at the distribution of the benefits/losses over the different social strata. The model looks at professional and subsistence fishing combined with occasional fishing separately.

Agriculture

The large farmers, because they own more land, get the highest incremental profit from the agricultural improvements, ranging from $140–285 US/household/year, for respectively the 11.00-meter and the 10.50-meter scenario. The marginal farmers, in comparison, receive incremental profits ranging from $14-29 US/household/year, and the landless who have no direct incremental profit at all (

Figure 72). In relation to the annual income also the large farmers will have the highest contribution as their income increases with 9-18%, this in comparison with the rate for marginal farmers which is in the range of 4-8% (Table 29)

Figure 72: Distribution of the direct incremental benefits of agriculture for the different water target levels over the different social strata in CPP.



Type	Water target levels					
	1100	1090	1080	1070	1060	1050
Landless	0%	0%	0%	0%	0%	0%
Marginal	4%	4%	5%	6%	7%	8%
Small	5%	6%	7%	8%	9%	10%
Medium	6%	7%	8%	9%	11%	12%
Large	9%	10%	12%	14%	16%	18%

Table 29: Distribution of the incremental agriculture benefits for the different target water levels in percentage of the average annual income of the different social strata in CPP.

Fisheries

If the total annual catch of Occasional and Subsistence catch in CPP is analysed in relation to the total number of rural households and their annual income from all economic activities (Table 30), we come to the same conclusions as FAP 17 (1995). Fishing is an economic activity, but the significance of fishing within the annual income should not be overstressed. It is one of many sources, which becomes relatively more important during the flood season when all three of their main sources (agriculture labour, non-agriculture labour and self-employment) are at their annual low (FAP 17, 1995).

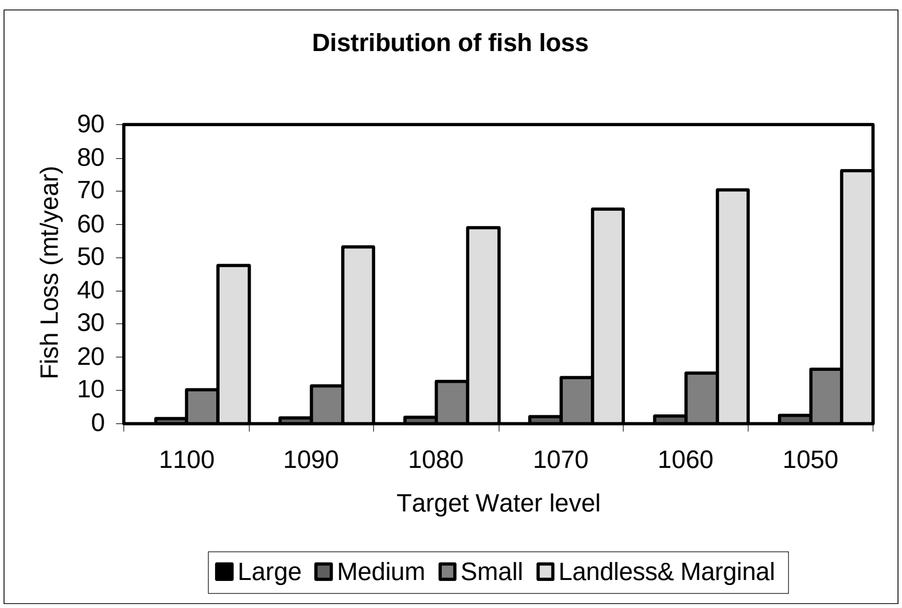
HH type	No HH	Annual catch	Value annual catch	Value catch as % of annual	% of required daily animal	Fishing days	Labour day equivalents

				income	protein intake[25]		
Large farmer	475	0.0	0	0.00%	0.00%	0	0
Medium farmer	1 362	4.3	300	0.57%	0.55%	7	6
Small farmer	4 589	8.7	608	1.96%	1.20%	13	12
Land less & Marginal farmers	22 399	8.3	580	3.05%	0.88%	13	12

Table 30: Key parameters of the catch of non-professional fishermen in the CPP project area in relation to their land holdings (source CPP 2000).

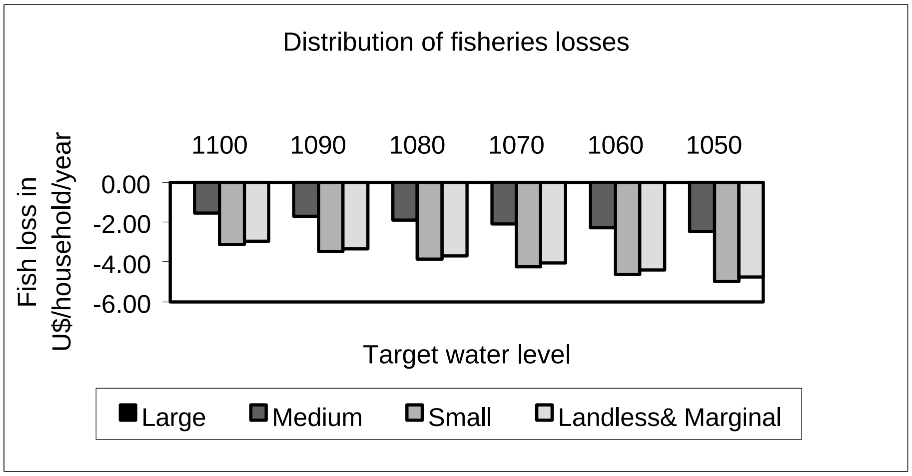
Reduction in the floodplain area will cause losses in fisheries, and for fisheries the picture is the inverse of agriculture: the large farmers have no losses as they do not fish, and the losses are mainly felt by the marginal farmers and landless, where 50-80 mt/year is lost (Figure 73). Due to the large number of landless and marginal farmers (23 000 HH) on an individual household basis the loss becomes only $3-6 US/household/year (Figure 74) In terms of income this is equivalent to 1-1.5% of their annual income per year (Table 31).

Figure 73: Distribution of total annual fisheries losses over the different social strata of the rural population of CPP.



[25] Calculated with subsistence catch only

Figure 74: Distribution of the fish losses for the different water target levels over the different social strata in CPP.



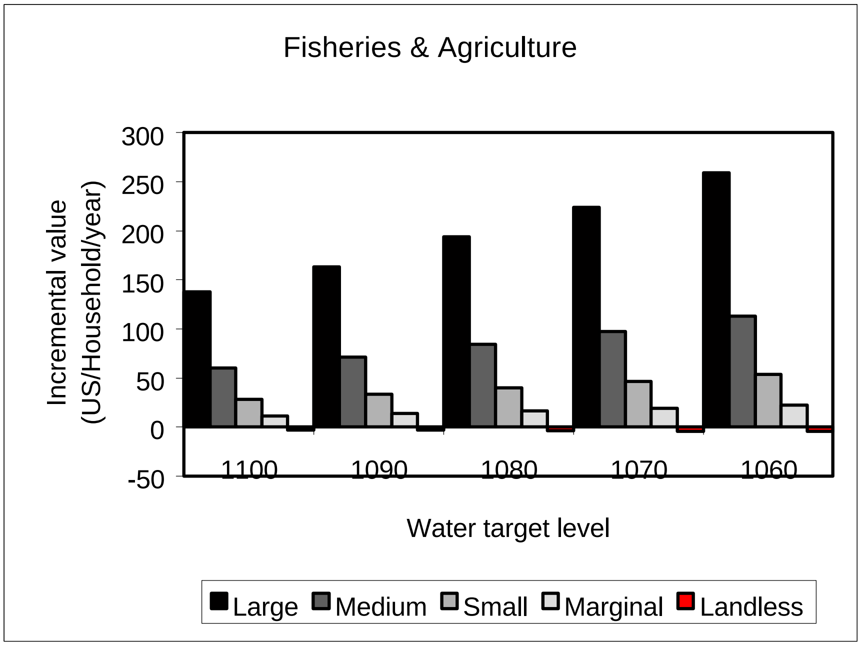
HH type	Water target level					
	1100	1090	1080	1070	1060	1050
Large	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Medium	-0.15%	-0.16%	-0.18%	-0.20%	-0.22%	-0.23%
Small	-0.50%	-0.56%	-0.62%	-0.68%	-0.74%	-0.80%
Landless & Marginal	-0.88%	-0.98%	-1.09%	-1.19%	-1.30%	-1.40%

Table 31: Distribution of the fish losses for the different target water levels in percentage of the average annual income of the different social strata in CPP.

The combined impact on agriculture and fisheries

Combining the agricultural benefits and the fisheries losses indicates that all households except the landless will have a direct net profit (Figure 75). The landless, however, will lose $3-6 US/Household/year. Considering the fact that they form the majority of the rural households (68%) and they are the poorest and most vulnerable group, this cannot be neglected.

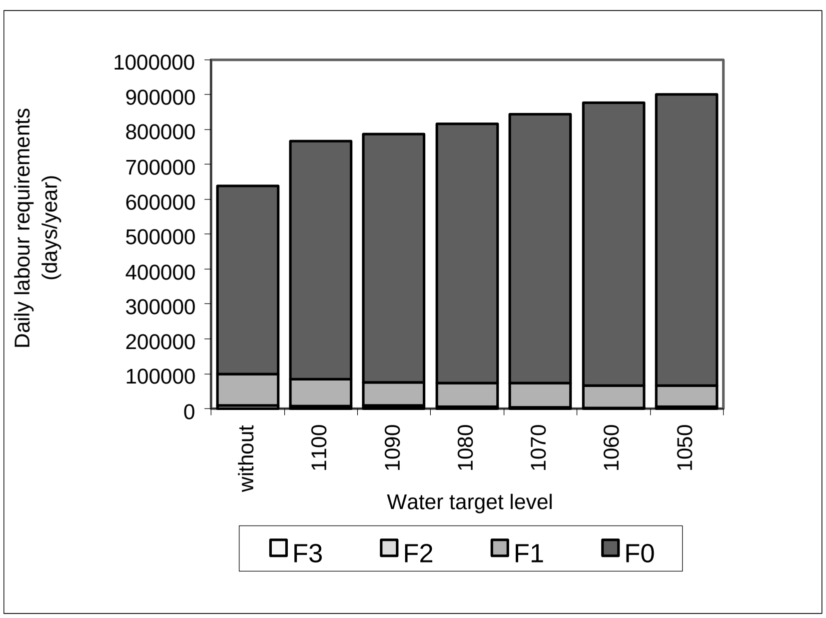
Figure 75: The distribution of the total profits of the different scenarios over the social strata of the rural population in the CPP area.



Income generation as a spin-off of agriculture developments

It is often stated that developments in agriculture will generate income-generating activities for the landless and marginal farmers through daily labour. Estimates on the actual daily labour requirements for the different crops are obtained from the Agriculture Monitoring Plots of CPP and were presented in Table 23. The differences in requirements seem to be small, but they become substantial if they are estimated for the whole of the CPP project area for the different scenarios (Figure 76).

Figure 76: Daily labour requirements for agriculture in the CPP area as estimated for the different water target levels.



Indeed it can be expected that on the long run the daily labour requirements will increase with 280 000 days/year with the 10.50 meter scenario (Table 32)

Target level	Total Incremental days	Days/HH/year	Tk/HH/Year
1100	127597	6	285
1090	148367	7	331
1080	177876	8	397
1070	206386	9	461
1060	237775	11	531
1050	262662	12	586

Table 32: Incremental daily labour requirements for the different target water levels and its income generation for landless and marginal farmers in the CPP area.

This would mean that 6-12 labour days per year would be generated for the landless and marginal farmers if they provide daily labour exclusively[26], and the overall impact of the different scenarios on the different groups in the rural area is presented in Table 33.

HH type	Target water level					
	1100	1090	1080	1070	1060	1050
Large	138	163	194	224	259	285
Medium	60	71	84	97	113	124
Small	28	33	40	46	54	59
Marginal	17	20	24	28	33	36
Landless	3	3	4	5	6	7

Table 33: Incremental annual income per household (US$/year) for the different social strata as estimated with the fisheries-agriculture model for the different target water levels

From the exercise it could be concluded that the small, medium and large farmers will profit from the interventions and they will be better off. The marginal farmers and landless will have a slight benefit or will not lose from the interventions.

Daily Animal protein intake

FAP 16 (1995) studied the fish consumption of the rural household in the CPP area and concluded that open-water fisheries are a major source of animal protein consumption of the rural poor in the CPP area. The results were based on a household consumption survey in a small number of villages in the CPP area. From all four areas studied the Tangail CPP area had the lowest average daily consumption of 11 grams of fish/capita/day, equivalent to 1.9 gram of fish protein per capita/day. The fish consumed is both caught and bought.
Unfortunately in 1992 the results could not be compared with the catch statistics of CPP as they were not available. Reliable catch statistics for CPP are now available and the role of subsistence fisheries in respect to animal protein consumption of the rural population can be analysed and has been incorporated in the model. The results are presented in Table 34 and Table 35.

[26] It can be expected that the urban poor are also involved

HH type	Water management scenario						
	Without	1100	1090	1080	1070	1060	1050
Large	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Medium	1.4	1.0	1.0	0.9	0.9	0.8	0.8
Small	3.0	2.2	2.1	2.0	1.9	1.8	1.7
Landless & Marginal	2.2	1.6	1.5	1.5	1.4	1.3	1.3

Table 34: Estimated daily per capita available fish for consumption from subsistence fishing for the different water management scenarios in CPP.

The present availability of fish from subsistence fishing for daily consumption is low and is in contrast with the general belief in Bangladesh that subsistence fishing is an important source of protein; but on the other hand, they are consistent with the findings of FAP 16 indicating that the average daily fish consumption in the CPP area was 50% below the values as observed in the other studied areas (FAP 16, 1995).

HH type	Water management scenario						
	Without	1100	1090	1080	1070	1060	1050
Large	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Medium	0.55%	0.41%	0.39%	0.37%	0.36%	0.34%	0.32%
Small	1.20%	0.89%	0.85%	0.82%	0.78%	0.74%	0.71%
Landless & Marginal	0.88%	0.65%	0.62%	0.60%	0.57%	0.54%	0.52%

Table 35: Daily animal protein provided by subsistence fishing in percentage of the total required daily animal protein intake (43 g/capita/day).

At present about 0.88% of the daily required protein intake of the landless and marginal farmers could be provided through subsistence fishing of these households, and this would decrease to 0.52 % if CPP implements its 10.50 meter scenarios.
The results could be the reflection of the importance of income for the rural poor,. They will only fish if there is no other alternative, and they will buy the fish if they have money. This would mean that subsistence fisheries becomes less important in areas where alternative income is more easily available, and this phenomena could be checked with the data on subsistence fishing and fish consumption of the Helen Keller Foundation in Bangladesh.

Professional fishermen

Key parameters of the catch and income of professional fishermen before CPP is presented in Table 36. With an annual income of about Tk 10 000 per year, they can be grouped among the poorest of the inhabitants of CPP and changes in fisheries due to interventions of CPP will hit them harder then the other poor, as their income is mainly provided through fishing.

Key parameters	
No of fishermen	355
Annual catch (mt/year)	54
Annual catch per HH (kg/HH/year)	153
Annual income (Tk/HH/year)	9931

Table 36: Key parameters of professional fishermen in the CPP area before the interventions of CPP.

The estimated impact of the different target water levels on the income of the professional fishermen is presented in Table 37. It can be concluded that the professional fishermen will always be impacted by CPP interventions, which is normal as CPP becomes drier due to the interventions. The extent depends on the extent of the conversion of flooded area into agricultural land, and losses range from 26% to 41% of annual income for respectively the 11.00 and the 10.50 meter scenario.

Parameter	Water management scenario						
	Without	1100	1090	1080	1070	1060	1050
Annual catch	54	40	39	37	35	34	32
Kg/HH/YEAR	153	114	109	104	99	95	90
Annual income	9931	7380	7075	6769	6464	6158	5853
Loss in income		26%	29%	32%	35%	38%	41%

Table 37: Estimated loss of income of professional fisheries for the different water management scenarios of CPP.

9.4 Conclusions and recommendations for future developments

The model can predict future trends in developments based on shifting of land types under a more or less steady state condition, i.e. no large changes in population structure, income generation activity, or what is more important fishing effort. In principle, any scenario can be predicted as long as the hydrological model can estimate shifting patterns in dry and flooded area.

The model could be further improved by adding:

- population growth rate;
- more details on cropping patterns and inputs, i.e. the use of fertilisers or pesticides per crop could be added to have an idea of pesticide loads, etc.;
- the bio diversity index
- Investment, Operation and Maintenance costs

Fine-tuning of the model towards real developments in fisheries can only be done if it is linked with the output of *"adapted dynamic fish stock assessment models"* where fishing effort and water management or its impact on the extent of flooding is related to fish production, species-wide, in a three-dimensional way.

10 HATCHLING MIGRATION AND WATER MANAGEMENT

10.1 Introduction

The Compartmentalisation Pilot Project in Tangail is a water management project that implemented "controlled flooding" in Bangladesh. The basic concept of controlled flooding is that high and dangerous flood levels are controlled but normal floods are allowed to enter the project area, as opposed to complete flood control, whereby an area is completely embanked and cut off from all floods. It is widely known that transforming floodplains into "protected and dry areas" through complete flood control has a negative impact on the spawning and nursing areas of a number of fish species. The impact of "controlled flooding", which still encompasses embankments and regulates the water flow from the river towards the floodplain, on this aspect was not known when CPP started in 1992. One of the aims of the project was to minimise this impact, and therefore CPP carried out a study on this subject that went through the following phases:

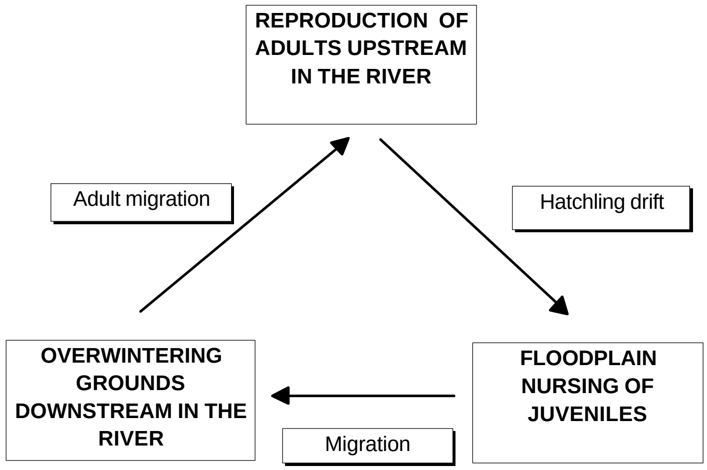
First, general characteristics of hatchling migration in the main river were studied.
The results were incorporated in the design and construction of the major regulator.
After construction of the regulator, it was tested to see if the concept worked in regard to hatchling migration.
The results of the latter were used to formulate new design or management criteria for the main regulator and for regulators in Bangladesh in general.

The results of the different components were presented before in a number of technical reports of CPP. But it was felt that the compilation of all the results in one report would give a better overview of the experiences gained on this subject by CPP. The results of the different studies as outlined above are presented in the first chapters of this report. In the last two chapters an overall picture of hatchling migration and densities in Bangladesh is presented. This could provide more insight into some basic processes of hatchling migration in the hope that it will be used to support implementation of different mitigation measures, such as "loop cuts", "fish passes" or "fish gates".

10.2 Riverine Fish migration in Bangladesh

On the basis of their behaviour, mainly related to migration and reproduction, the fish species of Bangladesh can be divided in two groups: “whitefish” and “Blackfish” (Sao-Leang and Dom Saveun, 1955). “Blackfish” species are able to tolerate the de-oxygenated water conditions of the dry season floodplain water bodies and may spend most of their lives in a single water body. These include species such as snakeheads, catfish and climbing perch *(Anabas testudineus*). “Whitefish” migrate upstream and laterally to the inundated floodplains adjacent to the river channel in the late dry season or early rainy season in order to spawn in the quiet nutrient-rich waters. The eggs and larvae of these species are drifting downstream and are entering the floodplain with the floodwater, where they feed on the developed plankton. At the end of the rainy season, the adults and young of the year escape/migrate to the main river channel in order to avoid the harsh conditions of the floodplain during the dry season. Whitefish or Riverine fish in Bangladesh consist mainly of Rui, Cattla, Mrigal, Pangash, etc., and they compose 5-10% of the total inland catch of Bangladesh (DoF, 1996)

Figure 77: Riverine fish migration in Bangladesh



Migration and spawning of the major carp in Bangladesh was first studied by Tsai and Ali in 1983-85. They found that the major carp in Bangladesh were comprised of three stocks: the Brahmaputra stock, Padma stock and the Upper Meghna stock. The Brahmaputra stock is the largest stock in Bangladesh, and its spawning grounds are located in the Southern tributaries of the Brahmaputra river in the Assam Hills and Letha Range, Assam, India (Alikhuni, 1957 and Jhingran, 1991). Upstream migration of adult major carps in the Jamuna/Brahmaputra River starts in March, coinciding with the gradual rise of water level. Spawning starts in May, with the onset of the Southwest monsoon, and continues till the end of July (Azadi, 1985, Shaha and Haque, 1976 and Tsai and Ali, 1985).

The long range of the migration of riverine fish and the return of the larvae makes them vulnerable. Large numbers of adults are caught before they reach the spawning places. The newborn larvae are searched for by predators and fishermen and encounter numerous water management structures such as sluices and regulators before they are back in the floodplains. Consequently their numbers decline significantly on their way down towards the floodplain as indicated by Tsai and Ali (1985), and this is further discussed in Chapter 0.

10.3 Hatchling migration in the CPP project area

In order to minimise the negative impacts of controlled flooding on hatchling migration, it must be known, **where**, **when** and **how** the larval fish are moving through the river. Almost no information was available on this and therefore CPP investigated the larval movement and larval distribution patterns in the Lohajang River during the monsoon of 1992, 1993 and 1994. Results of this study were presented in an earlier Technical Report of CPP (CPP. 1994) and in an International Scientific Journal (de Graaf *et al*., 1999) and are summarised in the next chapters.

10.3.1 Short Description of The Sampling Procedures

Nets made of mosquito netting (mesh size smaller as 0.5 mm) were placed in the Lohajang River. The opening of the net was made of iron rod and the net had a surface area of 0.125 m^2. At the side and at the middle of the river a net was placed

30 cm above the bottom of the river and a second net just below the surface. The flow rate of the water was determined with a floating object, and during 1993 the 'real' flow rate was measured three times a week with a flow meter. The nets were placed at daytime and at night time for 1 hour. The caught larvae were preserved in formalin and counted and identified in the laboratory. Results of the sampling programme were calculated/expressed in *hatchling density* or *the number of hatchlings per cubic meter of water (No/m^3)*

10.3.2 Results

Hatchling migration

The larvae were coming in waves (Figure 78, Figure 79 and Figure 80) and it seems that the peak of the waves is related to peak water levels of the Jamuna River. In all three studied years, carps were found within the first waves only and were absent after the first of September. Hilsa *spp. (Tenualosa)* and other non-identified species were found throughout the monsoon.

Figure 78: Hatchling migration in the Lohajang River 1992

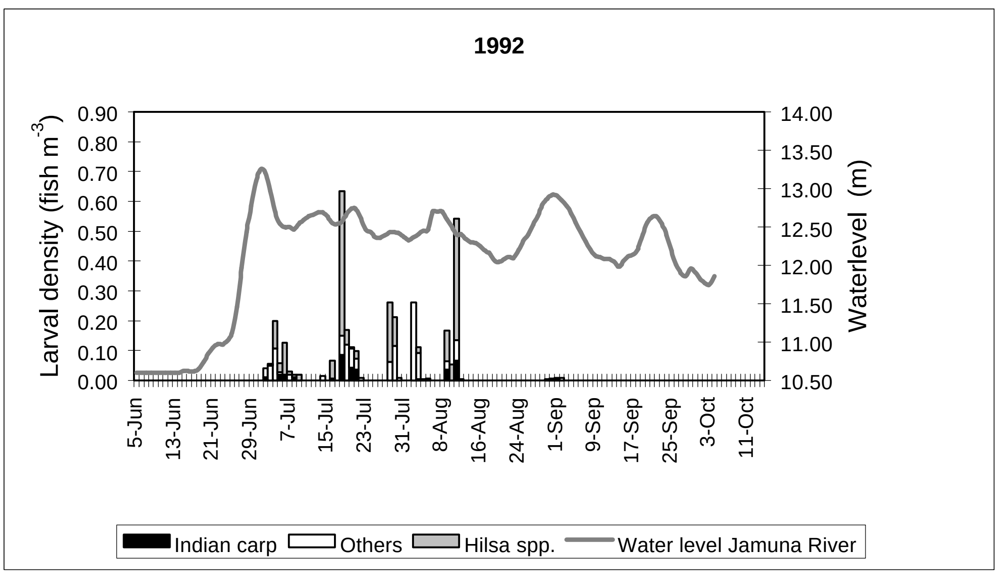


Figure 79: Hatchling migration in the Lohajang River 1993

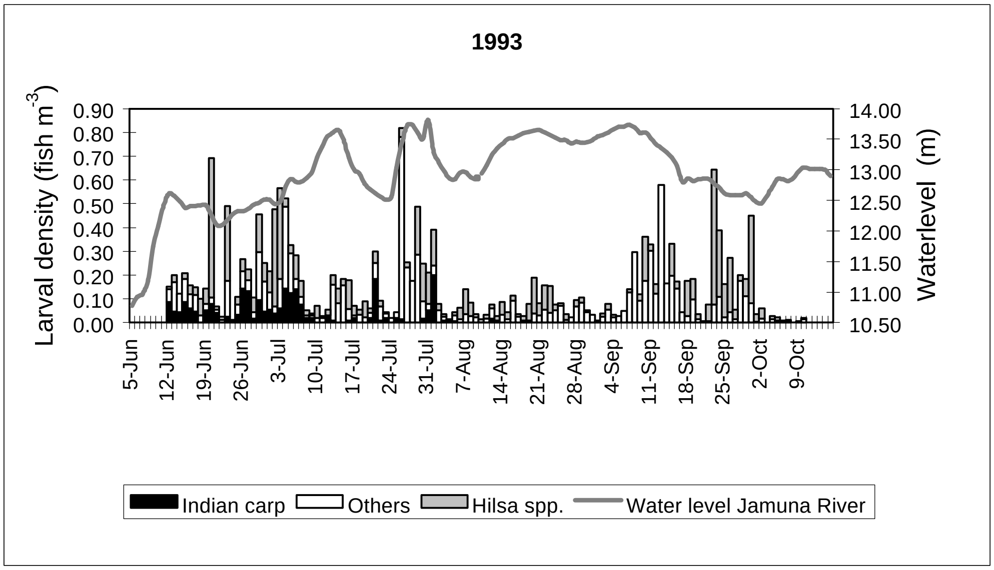
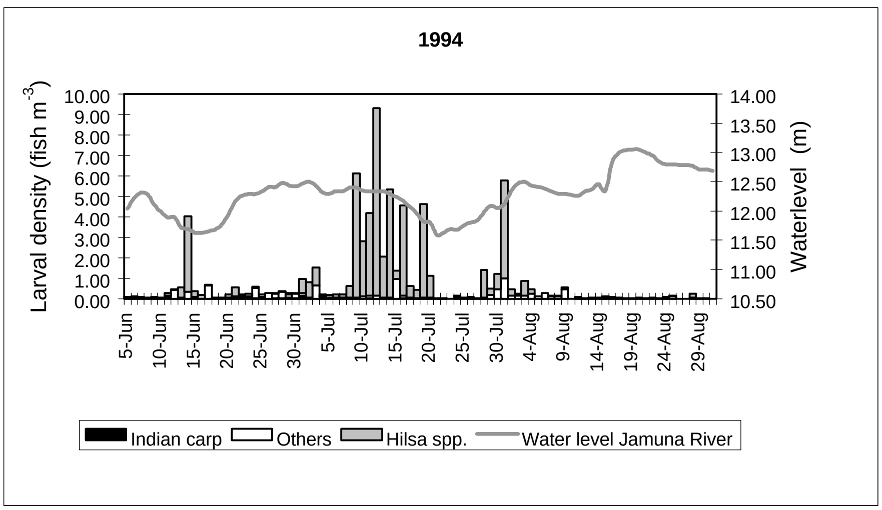


Figure 80: Hatchling migration in the Lohajang River 1994



In 1993, which was a year with normal flooding, significantly higher carp densities were found than during 1992 and 1994, which were relatively dry years. Flooding of upstream spawning areas is considered important for natural stocking of downstream floodplain areas. Protection of the spawning areas is therefore important to the perpetuation of Indian carp stocks. Larvae of Indian carp cannot move actively against currents > 0.1 m s^{-1} (Mitra, 1968) and consequently eggs and larvae are flushed from spawning grounds with receding flood waters and are transported passively downstream to the lower lying floodplains which serve as nursery area. The hatchling study indicated that spawning of Indian carp in the Brahmaputra River System took place during the first 8-10 weeks of the monsoon flood.

Significantly higher hatchling densities were found in the surface layer of the river near the embankment (

Figure 81) and no diurnal (night versus day) distribution patterns were found. The Turbidity of the river water is most likely the force behind the presence of vertical and horizontal distribution patterns and the absence of diurnal distribution patterns. Similar results were reported for fish larvae in the Amazon River. Pavlov (1995) found that larvae from the same taxonomic group drifted in different layers of the water column in different rivers. In a turbid river, e.g. the Amazon River, *Characiformes* larvae migrated through the mid-depth/surface, while in a clear-water river, e.g. the Nanay River, they migrated through the mid-depth layer. The Lohajang River is a turbid river and its Turbidity or sediment load may be a regulating force in vertical and horizontal distribution patterns of fish larvae.

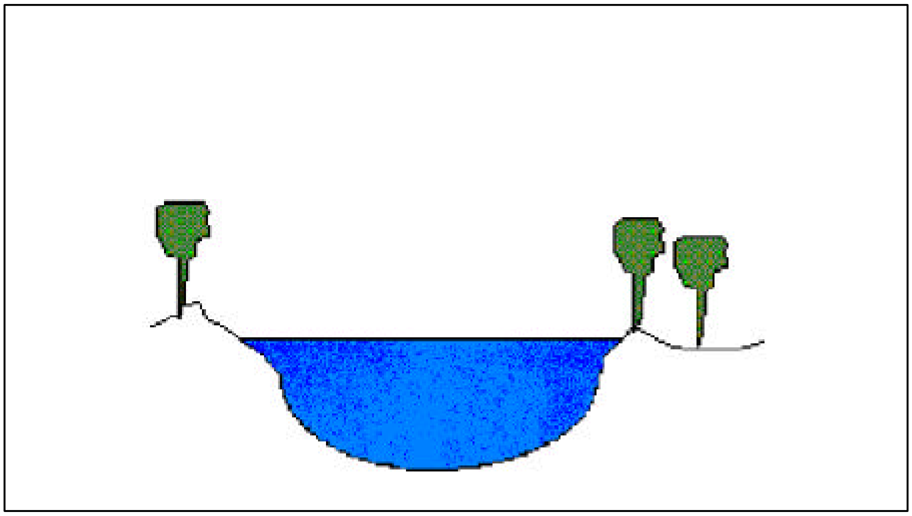


Figure 81: Distribution patterns of drifting hatchlings in the Lohajang River

Species composition of the drifting hatchlings

The majority of the larvae caught during 1994 consisted of a *Tenualosa spp* (Hilsa or Ilish), but the exact species name could not be identified. The following species were identified; *Labeo rohita, Catla catla, Cirrhinus mrigala, Crossocheilus latius*, *Glossogobius giurus, Rasbora daniconius*, *Macrognathus aculeatus, labeo calbasu, Salmostoma bacaila, Clarias battrachus, Lepidocephalus guntea, Puntius spp. Esomus danricus, Chanda spp.* and *Gagata viridescens*

The species composition (excluding *Tenualosa spp*.) as obtained weekly from the Lohajang River during the period of June 10 to August 31, 1994, is presented in Figure 82.

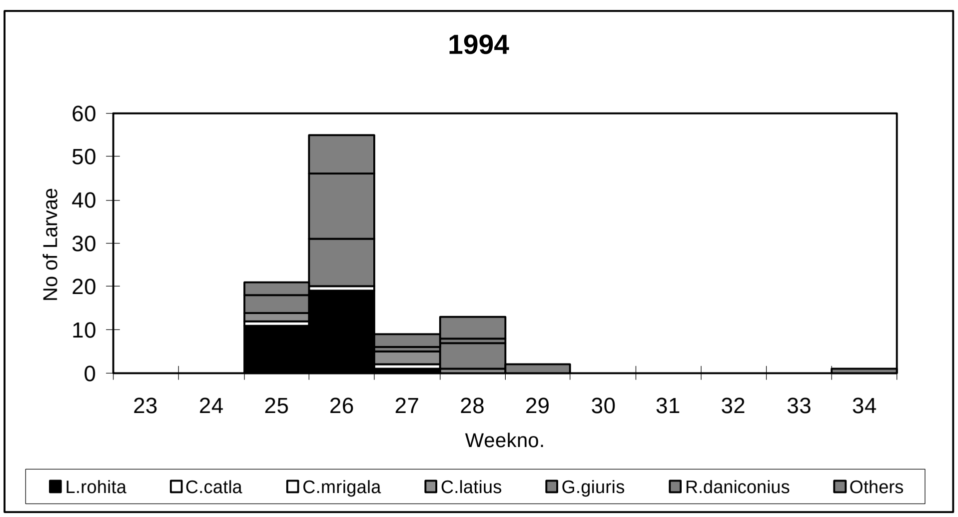


Figure 82: Species composition of migrating larvae in the Lohajang River during the monsoon of 1994.

The overall species composition during the sampling period is presented in Table 38.

Species	Percentage of total number (%)
L. rohita	30.4
C. mrigala	2.9
C. catla	0.9
C. latius	5.8
G. giuris	23.5
R. daniconius	19.6
Others	16.7

Table 38: Species composition of drifting fish larvae (*Tenualosa spp* excluded) in the Lohajang River during the monsoon of 1994.

The most important species in the larval drift (*Tenualosa spp* excluded) were *L. rohita*, *G. giuris* and *R. daniconius*. Among the major carps, *L. rohita* is the most dominant species as it contributes to 80-90% of the total number of major carp larvae. All major carps are entering the floodplain within the first 6-8 weeks of the flood.

10.4 The implication of the study results for water management and design of the main regulator.

There is sometimes confusion about fish passes and fish gates, especially as related to maximum flow rates. A fish pass as constructed by FAP 16 allows adult fish at the end of the winter to migrate, actively against the current, towards the spawning places. Currents should not exceed 0.7-1.0 m sec^{-1}; otherwise, the fish will not able to pass. Fish gates are regulators constructed in such a way that hatchlings drift smoothly with the current into the floodplain. Here not the current but the physical design and mode of operation is more important.

Within the CPP project area, outward migration of adult Indian carp at the beginning of the monsoon does not exist as under the natural conditions there is no permanent connection between the beels and the Brahmaputra River. This is because the Lohajang River dries up in October/November and the hydrological connection is only re-established in June of the following year. So the major design criteria for the regulator in the Lohajang was free and smooth passage of the drifting hatchlings towards the floodplain.

The results of the hatchling study showed that spawning of major carp in the Brahmaputra River only takes place during the first 8-10 weeks of the flood. In controlled flooding schemes, maximum recruitment of Indian carp is therefore obtained if the routes between the river and the floodplain are maintained open during this period, and it was recommended by the fisheries section that in the future, all gates of the regulator remain open during this period.

The implication for water management interventions of finding that fish larvae are drifting through the surface and near the embankments was that they should be let in as much as possible from these areas to maximise larval influx.

10.4.1 The design and construction of the major regulator

During the preparation of the construction works in CPP, the following functions and criteria for the main regulator were formulated (CPP, 1992). The function of the main inlet regulator is to provide security and protection for the Tangail compartment during high floods, and to maintain an appropriate water level in the Lohajang River, which would facilitate controlled flooding and drainage in the compartment. Moreover, the main inlet regulator should be controlled and operated, in such a way that it should not be detrimental to fish migration from the main rivers into the floodplain.

The mean inlet regulator in the Lohajang had a regional function. The head-loss from the discharge through the structure had to be not too high for a typical peak flow in the Lohajang, which was estimated at about 80 m^w sec^{-1}. An eight-vent structure with 1.5 m by 3.0 m vent sizes would give this discharge, with a head-loss over the structure of 0.7 m.

Functioning of the regulator was tested with a MIKE 11 hydrological model, and it showed that an increased number of vents did not yield in a substantial rise in the downstream water levels except for temporary peak discharges. With a smaller number of vents, the throttling effect became substantial, even at the normal discharge rate of 20-50 m^3 sec^{-1}.

The sill level of the structure was assessed at 9.5 m+PWD, which corresponded with the bottom level of the Lohajang River. The top level of the structure was based on a 1 in 50 years return period (13.47 m+PWD at Jugini) plus a margin for the corresponding ponding effect (0.5 m) and a freeboard for wave action. An outline of the preliminary design as made during this period is shown in Figure 83.

The available knowledge on fish-friendly structures and hatchling migration at that time, which was mainly the first year’s results of the hatchling migration study of CPP and a draft report of a desk study made on the subject for FAP 17 (FAP 17, 1993), was translated into the following practical basic preliminary design criteria.

Overshot flow was expected to be more “fish friendly” than undershot flow, the latter being harmful to fish larvae.
Turbulence from undershot gates would be more intensive in comparison with overshot gates. A combination of these two flow types in one structure called for a downstream extension of the piers up to a length where uniform sub-critical flow has been established.
Control of downstream water level by means of a combination of fully retracted and fully open gates could lead to problems of energy dissipation due to asymmetrical flow downstream.
Gradual downstream energy dissipation was considered less damaging to fish. This would require extensive downstream bed and bank protection.

Combining these findings and pending the outcome of further study, the following layout was proposed for the eight-vent main inlet in the Lohajang River in 1992.
The 6 ventral vents are undershot gates; the two outer vents, the “fish gates”, are run as free surface vents. The side vents would be the last to be closed in extreme water level situations, and it was proposed that flow in these vents would be controlled by “Two-part” gates. The lower part, 1.5 to 2.0 m high, would be lowered to the bed as a first stage of control so that overshot could be established. The upper part of the gate would be normally brought down for full closure only. The divider piers for the outer vents would be extended to reduce interaction with the turbulence of the undershot gates.

With these conditions it was expected that the gate operation could be developed to give the required control of the downstream water level throughout the monsoon season, while the impact on the drift of fish larvae was limited to some extent.

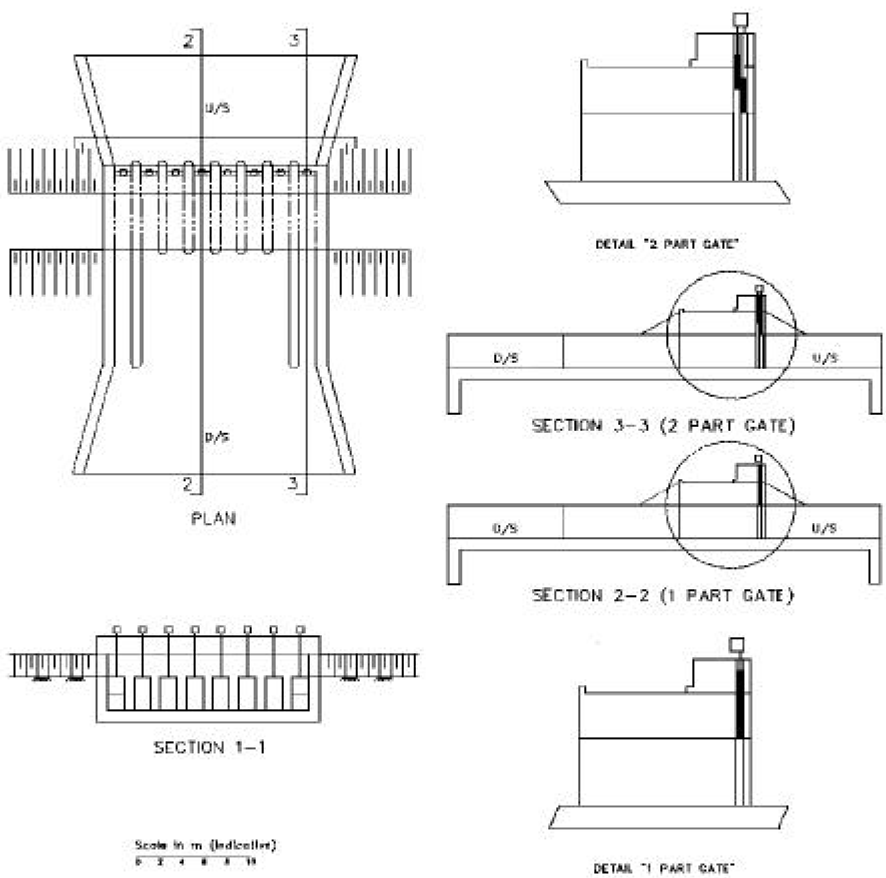


Figure 83: Preliminary design of the main regulator in the Lohajang River

In the early ‘90s the main regulator was constructed (see Figure 84) with some changes from the original design:
The six middle vents of 1.5 m by 3.0 m were replaced by three middle vents of 3.0 by 3.0 m. As a consequence, the gates for these vents became “two part” gates, as otherwise they could not be operated manually because of their weights.
The gates in the two side vents became “one part” gates lowered on two permanent walls.
Energy dissipation measures were the traditional concrete blocks.
The extended pier was added to the structure in 1998.

Figure 84: The main regulator in the Lohajang River

10.5 Impact of the constructed regulator on drifting hatchlings

The main regulator constructed in the Lohajang River can be called "fish friendly" if the location of the drifting hatchlings is considered. It is, however, not known what happens with the fish larvae once they pass through the regulator. CPP studied this aspect of fish migration. In 1995 and 1996 fish larvae were caught before and after the main regulator and mortality rates were compared. From these experiments no conclusions could be drawn as the hatchling density in the water was low and consequently the nets had to be placed in the water for over one hour in order to collect some hatchlings. The mortality caused by the fact that the hatchlings were trapped in the nets for such a period was most likely higher than the mortality caused by the regulator.

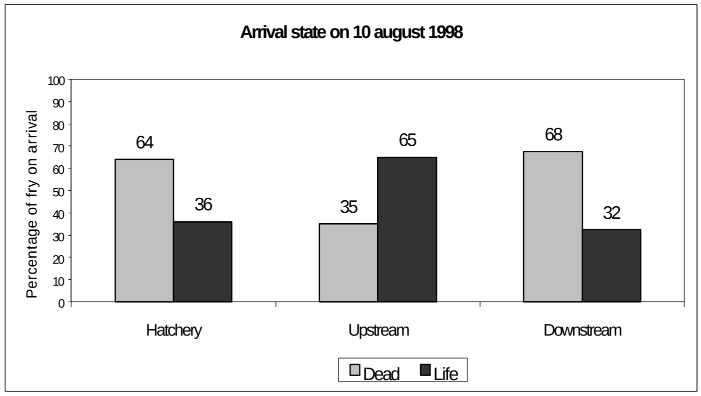
In 1998/99 a new study was begun using another technique to overcome this problem. Fingerlings/hatchlings were released[27] in front of the regulator and were caught just before and just after the regulator, after which mortality rates of the two groups were compared with a non-treated control group.

Results of one experiment carried out in 1998 are given as an example. During this experiment, the head difference was 0.95 meters (upstream 11.95, downstream 11,0); only the fish passes were open, and the average weight of the larvae was 0.30 grams. Catla, Rui and Mrigal were used. 20 000 were released immediately after arrival at the site. A sufficient number of fry could be caught (upstream 854, downstream 700). Dead fish were not removed from the released group. Transport to the laboratory took one hour. After 72 hours, 32% of the downstream larvae, 23% of

[27] About 20,000 per experiment.

the upstream larvae, and 8% of the control group (hatchery) were dead. The mortality rates upon arrival are presented in Figure 85.

Figure 85: Mortality rates of released fry caught upstream and downstream of the main regulator in comparison to a control group from an experiment carried out with large fingerlings in 1998.



However, the results presented here were obtained from a clear experiment; not all the experiments confirmed these results, and no firm conclusion could be drawn.
In 1999 the experiments were repeated with carp hatchlings of 0.1-0.2 gram. Unfortunately the monsoon of 1999 was very dry and only a limited number of experiments could be carried out at **the main gates only**. Due to the extremely low water levels, the special "fish gates" could not be tested. The results of the 1999 experiments are presented and summarised in (Table 39).

Location	Mortality (%)	N
Control group	$6.6^{A} \pm 1.4$	12
Upstream regulator	$17.4^{B} \pm 1.9$	12
Downstream regulator	$42.5^{C} \pm 16.0$	12
Mortality over the regulator	25.1 ± 5.0	12

Table 39: Mortality rates (± standard error) of released carp hatchlings caught in front of the regulator and after passing the main gates of the regulator in comparison to a non-treated control group (different superscripts indicate significance of the difference *$P<0.05$*).

The results indicate that on the average, 25% of all hatchlings passing the main gates of the regulator are dying because of this passage. During the experiments the regulator was operated in three different modes: **Overshot**, **Undershot** or **Free Flow.** The mortality rates of the regulator on the hatchlings for the different modes of operation are presented in Table 40

Mode of operation	Mortality rate (%)	N
Free Flow	$26.8^{A} \pm 6.6$	2
Overshot	$11.8^{B} \pm 3.6$	6
Undershot	$44.0^{A} \pm 5.6$	4

Table 40: Mortality rates of carp hatchlings (± standard error) for different modes of operation of the main gates of the regulator.

About 44% of the hatchlings died within 24 hours after passing the main gates of the regulator if used in an undershot mode, which is the standard mode of operation in Bangladesh. When the main gates of the regulator were used in an overshot mode the mortality reduced significantly to about 11%. It was expected that *"Free Flow"* conditions would even be better than *"Overshot".* This was not the case, but this is because only two experiments could be carried out under Free Flow conditions.
From the results it can be concluded that the **main gates** of the Lohajang regulator are **"not fish friendly",** especially if used in the standard undershot mode of operation. Overshot operation would improve the situation and this type of operation should be used at the main regulator in the Lohajang. This is most likely the case for similar regulators all over Bangladesh.

10.6 Hydrological modelling of more "fish friendly" settings of the gates in the Main Regulator[28]

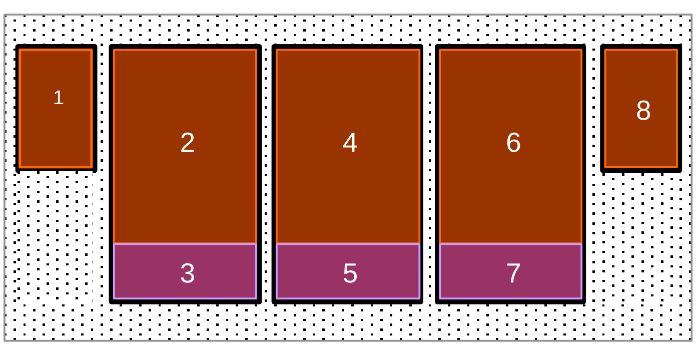
It is generally believed in Bangladesh that regulators should be designed for and operated in an undershot mode. This was also the case in CPP and in its initial phase of a number of runs were made with the numerical hydrological model Mike 11, which showed the effect of gate operation on water regulation for the proposed regulator in the Lohajang River (CPP,1992). It was concluded that the requirements for water regulation and the requirements of fish passage were not mutually compatible, as smooth regulation could only be achieved with undershot gate operations. Therefore a compromise was devised for the regulator, which resulted in the construction of the regulator with three undershot main gates and two fish gates (see Figure 86)

Over the years the hydrological model was substantially improved and in 1998 a new set of runs was made to see whether the regulator could be operated in a "fish friendly" way with overshot only.

10.6.1 Gate settings for fish friendly operation of the main regulator

The completely "fish friendly" gate setting is composed of a different combination of settings of upper gates and lower gates (either fully open or fully closed). No undershot-type flow situation is assumed. Fish Passes are always kept open. Each vent of the three middle gates are operated in a way that only the lower gate is fully closed or both the upper and lower gates are fully open. A total of eight combinations of gate settings were found as fully fish-friendly settings. For clean understanding, upper and lower gates can be numbered as shown in Figure 86.

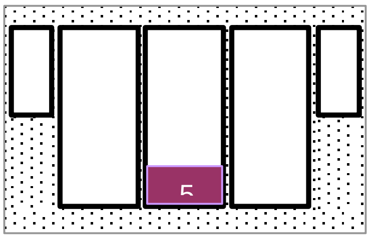
Figure 86: Gate numbers of the Lohajang regulator.



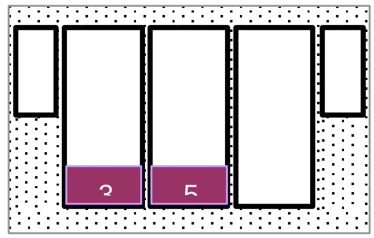
[28] By the Surface Water Modelling Centre (SWMC), Dhaka, Bangladesh

The combinations of gate settings are shown in Figure 87. This set of gate settings provides a full “fish friendly” environment of flows through the main regulator, because it always maintains an overflow type of flow condition.

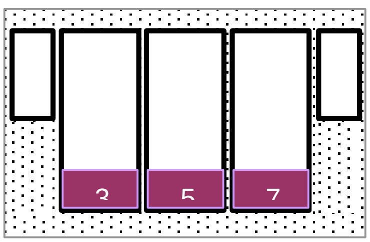
Figure 87: Combinations of Different Gate Settings for “fish friendly” operation of the Lohajang regulator.



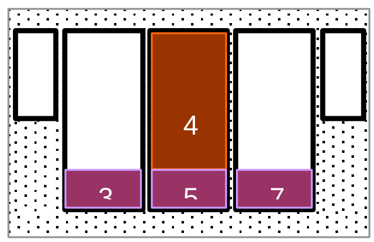
Combination no 1



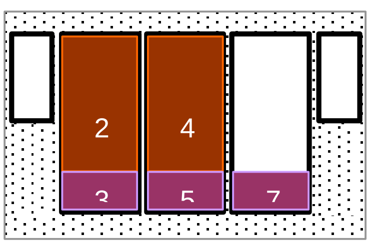
Combination no 2



Combination 3



Combination no 4



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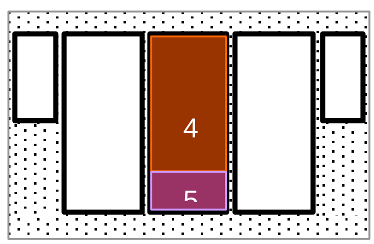

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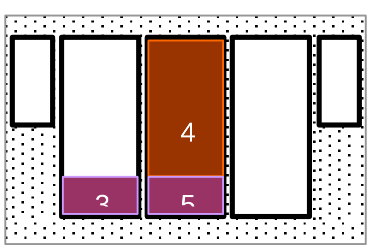

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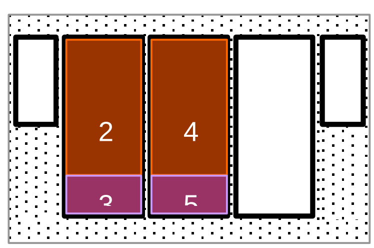


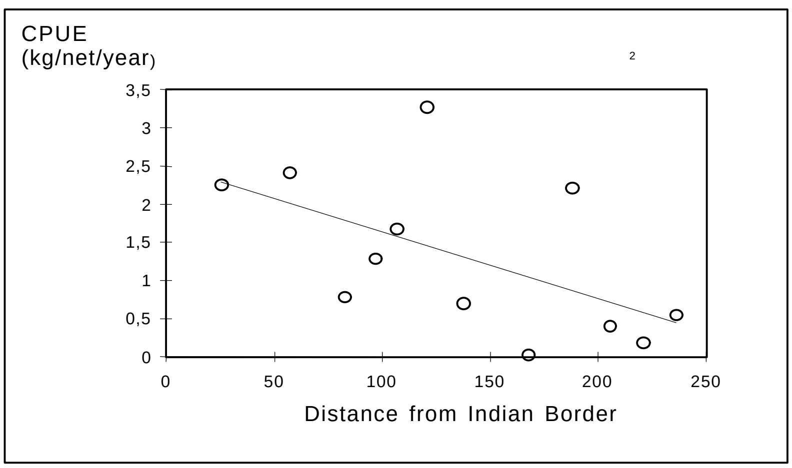
Combination no 8

The Surface Water Modelling Centre simulated water levels immediately upstream and downstream of the Main Inlet Regulator for all gate settings. From the simulation it was concluded that the main regulator can be operated with no adverse impact on water regulation **in a completely “fish friendly” mode** with overshot only.

10.7 Larval Fish densities in the major rivers

CPP studied the drift of hatchlings in the Lohajang and Dhaleswari rivers in the early phase of the project. One of the conclusions was that there was a significant difference in the density of hatchlings between the two rivers (CPP, 1994), and as a mitigation measure, a loop cut between the Lohajang River and the Dhaleswari River was proposed. However, at present, it is realised that the proposed loop cut would most likely not have had the expected results, as some basic principles of hatchling migration, mortalities and densities were overlooked. Tsai and Ali (1986) first studied hatchling densities in the major river systems of Bangladesh and found significant density differences as they looked at the catches of the savar[29] nets at the different locations in the Jamuna and Pabna rivers. They found that the catch of the hatchling nets (CPUE) in the Jamuna River gradually decreases if located further from the Indian border (
Figure 88)

Figure 88: Annual catches per net (CPUE) of hatchling fisheries in the Jamuna River in relation with its distance to the Indian border (Tsai and Ali, 1986).



If the CPUE is a reflection of the density of larvae, which is one of the assumptions of holistic fisheries models, it would mean that the hatchling density in the river gradually decreases during the downward drift of the hatchlings.
In 1997 EGIS (1997) in co-operation with the Fisheries Research Institute studied this phenomenon again, and they confirmed that the average hatchling density is significantly higher in the primary and secondary rivers if compared with the tertiary distributaries (Table 41).

[29] Special nets for fishing on carp larvae

River Class	Average Total Hatchling density (No. m^{-3})	n
Primary	1.80 ± 0.44^{a}	46
Secondary	1.94 ± 0.43^{a}	47
Tertiary	0.45 ± 0.43^{b}	47

Table 41: The average total hatchling density (±sem) and average flow rate (±sem) as measured in primary, secondary and tertiary rivers. Parameters with a different superscript are significantly different (*P£0.05*).

Tsai and Ali (1986) applied most likely for the first time analytical models on fisheries in Bangladesh and for sure for the first time in the World on drifting hatchlings. ← Gertjan – perhaps it's the syntax but this sentence seems a little off base – I noticed it in the manual but didn't say anything though I should have. Are you sure this is the first time in the world there has been an analytical model applied to drifting hatchlings? That's a very big assumption to make. As it is constructed, that is what your sentence says. I'm not sure what you're driving at, so I'm going to leave it for you to rework it. Their paper has not got the attention it should have gotten considering its simplicity and insights it provides on drifting hatchlings. Their concept provides the basis of how drifting of hatchlings in Bangladesh should be studied and analysed. They looked at the reduction of hatchling densities over time in the different rivers of Bangladesh, and time was related to a location in the river system in relation to the Indian border that is located upstream. Their concept can be visualized nowadays in GIS, which makes the practical implications of their findings more clear; therefore, in the next paragraphs their concept and its application are discussed in further detail.

The basic analytical model used is the exponential decay model;

$$Nt = No * e^{-Z*(to-t)}$$

No = Initial number of larvae
Nt = Number of larvae at time t or location t
Z = Mortality rate
T0-T = Time period or distance between t0 and t1

They used this to calculate the mortality rate (Z). For this a pair of estimates, *n1, n2* of the number of larvae at two points in time *t1-t2* is required (Gulland, 1983). Then during the time interval the number will fall by a proportion:

$$\frac{n2}{n1} = e^{-Z(t2-t1)}$$

and therefore Z can be estimated from the relation:

$$Z = -\frac{1}{t2 - t1} Ln\left(\frac{n2}{n1}\right)$$

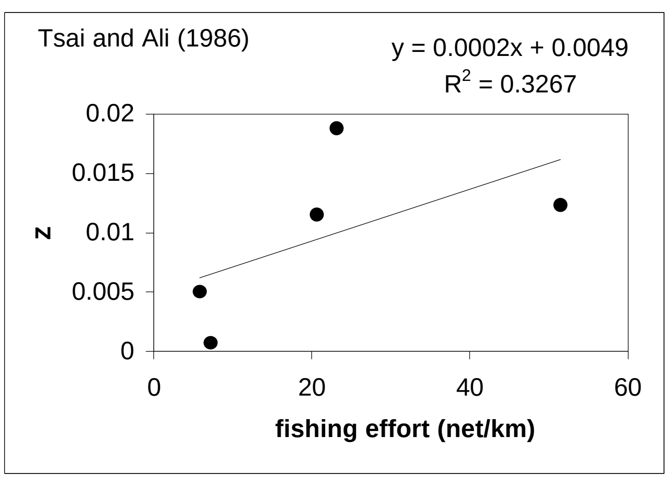
They calculated the mortality rates for five sections of the Padma-Brahmaputra river systems and the results are presented in Table 42.

River section	Fishing effo (nets/km)	Total mortalit (Z)	Natural mortality (M)	Fishing morta (F)	Exploitation rate (F/Z)
Jamuna-Brahmaputra Rivers (west bank)	51.45	0.0123	0.0049	0.0074	0.60
Jamuna-Brahmaputra Rivers (east bank)	20.72	0.0115	0.0049	0.0066	0.5739
Dhaleswari-Kaliganga Rivers	23.18	0.0188	0.0049	0.0139	0.7394
Padma River	5.86	0.0050	0.0049	0.0001	0.0200
Gorai –Madhumati Rivers	7.22	0.0007	-	-	-

Table 42: Mortality rates and fishing effort for hatchling and savar nets in the major river systems of Bangladesh

When the total mortality rate is plotted against the fishing effort, a positive linear relationship is obtained (Figure 89). When the fishing intensity decreases to zero, the rate of reduction is equal to the natural mortality rate of the larvae. In this case the natural mortality equals 0.0049, meaning the larval abundance in the Padma-Brahmaputra river system decreased at a rate of 0.49% per km. The fishing mortality can be calculated by subtracting M from Z (F=Z-M).

Figure 89: The relation between fishing effort and the total mortality rate of drifting fish larvae in the Padma-Brahmaputra river system (source Tsai & Ali, 1986)



The highest number of savar nets are located at the west bank of the Jamuna River, which results in a fishing mortality of 0.74% per km. The highest fishing mortality, i.e. 1.39% per km, was found in the Dhaleswari-Kaliganga river system at a relatively low fishing effort of 23 net/km. This implies that the larvae are rather easy to catch in this river system if compared to the Jamuna River. The fishing pressure in the Padma and the Gorai River was low and resulted in low mortality rates. The spatial distribution of the fishing effort and the mortality rate as analysed in GIS is presented in Figure 90 and

Figure 91and the relation between the two becomes immediately clear.

Figure 90: Distribution of the fishing mortality of drifting hatchlings in the major river systems of Bangladesh.

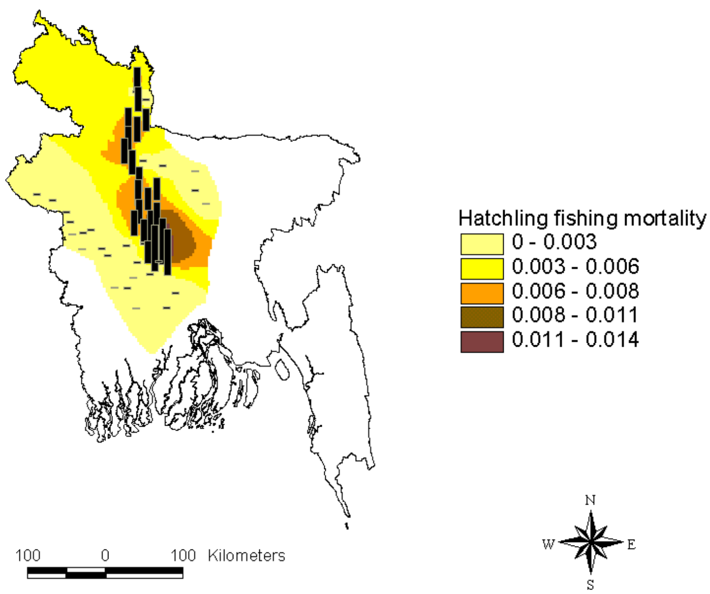
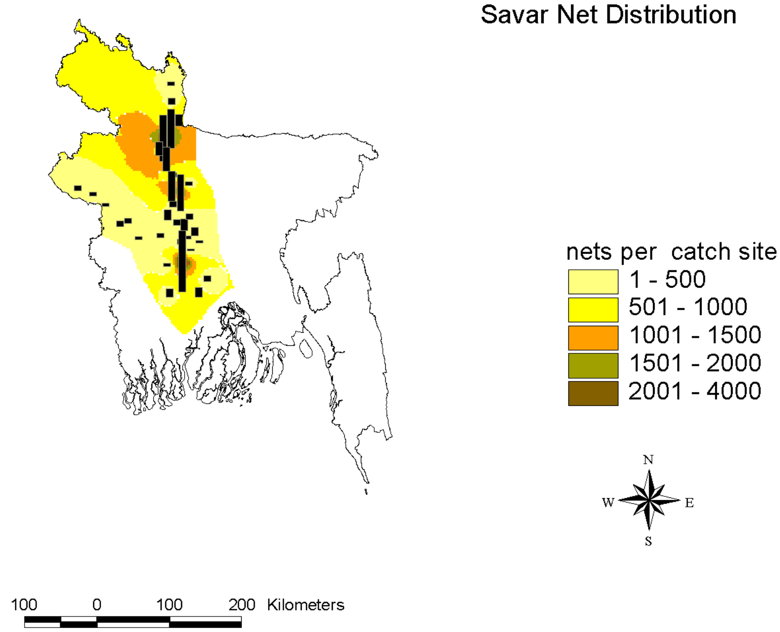
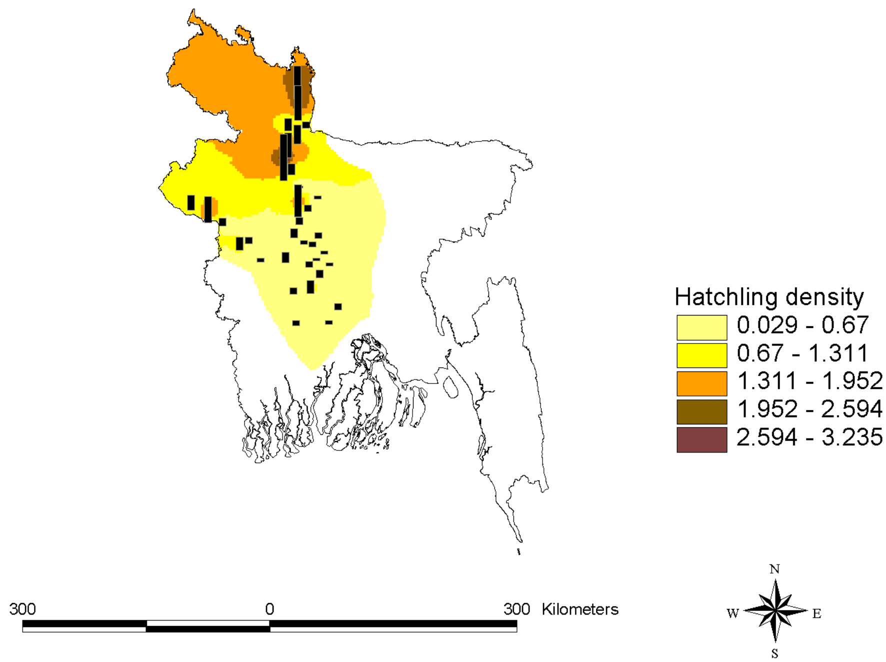


Figure 91: Distribution of the savar nets in the major river systems of Bangladesh.



Similarly, the density distribution of the larvae can be analysed in GIS, whereby the CPUE is used as indicator for abundance (see Figure 92, and it becomes immediately clear that the larval densities gradually decrease when drifting downwards and that the densities in the Jamuna system are much higher if compared with the Padma river system.

Figure 92: Distribution of larval fish density in the major river systems of Bangladesh.



The major conclusion is that differences in hatchling densities, for example between the Dhaleswari and the Lohajang River, is a natural phenomenon caused by mortality, which will not be improved by creating a loop cut.

The analysis has been carried out with the data collected by Tsai and Ali in 1984/85. The next steps would be:

To look at changes in the mortality rates and hatchling densities at the different locations over the last 15 years as the data are available at DoF.
To link larval densities, mortality rate with the hydrological network and the different types of regulators in it.

Within the framework of the Fourth Fisheries Project, the construction of a number of fish passes and the modification of a number of regulators is envisaged. It is strongly recommended to carry out beforehand this analysis, as it could provide information on the different bottlenecks needed for the successful planning and design and implementation of this intervention. In the next chapter the difference of fish passes and regulators are discussed in more detail.

10.8 Fish gates or fish passes

As mentioned in the previous chapter it is envisaged under the Fourth Fisheries Project to construct a number of fish passes based on the experiences of the first fish pass constructed by FAP 6 in the mid ‘90s.
The question arises whether this intervention will mitigate the problem of **“declining catches of migratory fish species in Bangladesh”.** In this chapter, different sides of the problem are highlighted to provide "Building blocks" for the discussions on this.

The major conclusions of the fisheries monitoring programme of CPP were:
The major driving force behind floodplain fisheries is the fishing effort.

A further increase in the number of fishermen in Bangladesh, which can be expected considering the population growth, will threaten inland fisheries production of Bangladesh. Without intervention, it can be expected that the remaining "miscellaneous species" will meet the same fate as the Indian carp.
Within the CPP, project fisheries concentrated on the miscellaneous species. This was not a choice; rather, it was forced upon us by the reality. Indian carp were of no importance in the catch, which consisted mainly of "miscellaneous species" with an average length of 6-15 cm.

In general, it can be stated that in over-exploited floodplains, with a high fishing pressure, the large, slow-growing species and the species that start to reproduce after 2-3 years are replaced by quick-growing and fast-reproducing species (Hoggarth et al., 1999), and this is most likely what happened over the last several decades in Bangladesh.

The construction of embankment and conversion of floodplains into "dry" agricultural land has certainly had an impact on the migratory stocks but should be regarded in combination with over-exploitation of the stocks.
In numerous fisheries studies executed under the Flood Action Plan, blockage of migratory routes are mentioned as a major problem for migration of riverine species. If migration of riverine species is discussed, the understanding of the different forms of migration/drift is of importance as each type can be hampered in different ways and requires different interventions to improve the present situation.
In principle, riverine migratory fish species in Bangladesh have two types of migratory behaviour:

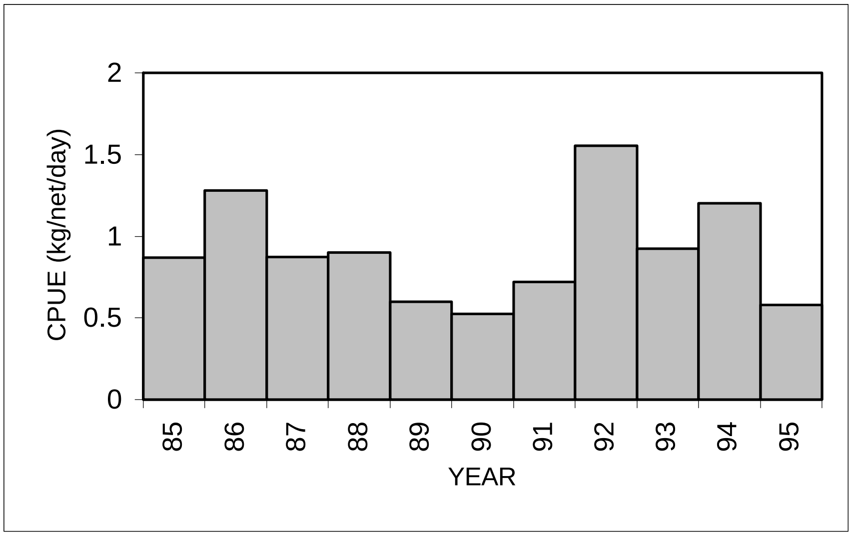
The **outward active migration** of the adults from the deeper water bodies towards the river in the pre-monsoon and further upstream migration towards the spawning grounds located upstream in the rivers. If this migration is blocked then a **"fish pass"** is needed to improve the situation. A fish pass is a structure that facilitates spawning migration against the current towards the river system. This is the reason why flow rates in a fish pass are critical, as the adults must be able to swim against the current.

Once the adult fish have spawned upstream in the river system, millions of eggs and larvae **drift passively** with the current towards the floodplains located downstream in the system. On their way downstream the larvae die in large numbers due to: predation, natural mortality, fishing activities and all the regulators they have to pass before they arrive at the floodplain. The latter can be enormous as the results from CPP indicated that 44% of the larvae passing the regulator die within 24 hours.

Interventions in the form of the construction of fish passes are based on the philosophy that the number of larvae in the system is decreasing due to the blockage of the migration route towards the spawning places. The assumption is that the stocks will recover by improvement of the spawning area and by enlarging of the spawning, and this is obtained by the construction of fish passes The first question is:
Did the number of larvae drifting in the major rivers in Bangladesh decline in the last decade?
Surprisingly, the official statistics of the BFRSS on the catch of larval fish in the major rivers seem to indicate that there have been no changes in the Catch per Unit of

Effort of the savar nets over the period 1985-1995 (Figure 93). The CPUE[30] is an indication of the abundance of the larval density, and it would mean that since 1985, the larval density in the major rivers did not change significantly. What the situation was before 1985, we do not know.

Figure 93: The average CPUE of the savar nets in the major rivers of Bangladesh (source BFRSS, 85-95)



Such a conclusion has a direct impact on the decision to construct fish passes as apparently the basic assumptions of declining number of larvae due to reduced adult spawning stocks is not supported by available data.

It seems that the problem has to be looked upon from another angle. CPP monitored hatchling migration during three years and the results indicated that about 35-40 million larvae[31] were entering the project area annually, resulting in a catch of only 10-20 Mt/year of riverine fish (3-8% of the total catch). Combined with the results of the experiments on the mortality rates of the larvae passing the main regulator it was concluded that:

[30] Assuming that the design or size of the nets has not been changed in the years.

[31] 3-5 days old

- Upstream in the river system of Bangladesh substantial spawning still takes place.
- The newborn larvae drift passively downstream through the major river systems and die in large numbers due to natural causes and larval fishing
- The remaining larvae enter the secondary and tertiary system and finally arrive at the floodplains. It is most likely that during this last phase the majority of the mortality takes place due to the numerous regulators they have to pass.

If this were also the case for the whole of Bangladesh it would mean that a major impact could be expected if a programme would focus on the improvement of the management and where possible on the adaptation of existing regulators in the river system. The latter could be more cost effective as illustrated by the example of CPP.

Annually 40 million larvae are entering the CPP area of which at least 20 million die due to the regulators. In order to bring 20 million larvae back into the natural system, a "fish pass" has to be constructed, which allows 2,200[32] adult fish to migrate each year upstream towards their spawning places.

It is therefore strongly recommended to look at these aspects more in detail before interventions are implemented, and especially to look at the regional differences. For example, a fish pass in the CPP area would be a waste of money because there are no carp left to migrate back to the river system and because the hydrological connection between the main river system and the beels takes place too late in the season. However, this situation could be completely different in areas with large water bodies and permanent connections with the major river system.

[32] Calculated with 5% survival from egg to 3-day-old larvae under natural conditions and a fecundity of 3 000 000 eggs per female.

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